Renee Purdy - Draft L.A. County MS4 Permit, Planning and Land Development Program

From:	Melinda Becker <melinda.becker@pgenv.com>
To:	Amelia Whitson <Whitson.Amelia@epamail.epa.gov>, Eugene Bromley <Bromley...
Date:	9/13/2011 1:26 PM
Subject:	Draft L.A. County MS4 Permit, Planning and Land Development Program
CC:	Jim Parker <jim.parker@pgenv.com>, Wesley Ganter <wes.ganter@pgenv.com>
Attachments:	LA_MS4_Land_Development_91311ed.pdf; Copy of wqo_2009_0009_app_21, with L.A. example.xls; Ventura Land Development excerpt.pdf; CA LID Ordinance summaries_8-24-11[1].pdf

Hello everyone:

Attached is the revised draft memorandum with recommendations for the Planning and Land Development Program (Part 4.E) of the draft Los Angeles County MS4 permit. This version of the memo reflects comments from the smaller Working Group, consisting of John Kemmerer, Ivar Ridgeway, and Melinda Becker. The major changes between this version and the August 25 version are as follows:

- Added design requirements for bio-treatment based on the Natural Resources Defense Council's May 8, 2009, letter to the Santa Ana Regional Water Board.
- Agreed to retain the treatment requirements in subpart 4.E.III.4. These requirements are in addition to requirements to provide off-site mitigation when technical infeasibility prevents the on-site retention of the storm water quality design volume (SWQDv) or biofiltration of 1.5 times the SWQDv. There is a placeholder for defining the pollutant-specific performance levels, which may be interpreted as technology-based effluent limitations. Performance levels may be described by referencing the draft SWRCB Phase II MS4 permit or the American Society of Civil Engineers (ASCE) BMP performance levels.
- Provided an alternative to Horner's equation for calculating infiltration rates by making conservative assumptions that the soil is wet and the infiltration rates are always at the low end of the reported range.
- Recommended that we not require, or rely upon the Permittees, to develop a Technical Guidance Manual.
- Recommended that we develop a spreadsheet calculator that credits or incentivizes reductions in impervious area, the preservation of trees and riparian buffers, and LID design. A copy of a similar spreadsheet from the California Construction General Permit is attached to this e-mail for your information.

Also attached for your information is a copy of part 4.E of the Ventura MS4 permit and a comparative summary of LID Ordinances.

Best regards,

Melinda Becker
PG Environmental, LLC

818/414-1440
melinda.becker@pgenv.com

Visit our website at www.pgenv.com

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TECHNICAL MEMORANDUM

PG Environmental, LLC
Permitting & Compliance Specialists

TO: U.S. EPA Region 9
State Water Resources Control Board
Los Angeles Regional Water Quality Control Board

FROM: PG Environmental, LLC

DATE: September 13, 2011

SUBJECT: L.A. MS4, Planning and Land Development Program

I. Introduction

This memorandum summarizes recommendations for the Planning and Land Development Program (Part 4.E) of the draft Los Angeles County Municipal Separate Storm Sewer System (MS4) permit (L.A. MS4 permit). These recommendations reflect discussions with staff from the Los Angeles Regional Water Quality Control Board (Regional Water Board), the State Water Resources Control Board (SWRCB), and the U.S. Environmental Protection Agency, Region 9 (EPA), collectively referred to hereinafter as the "Working Group." The larger Working Group discussed these issues during conference calls July 11 and August 25. The smaller Working Group discussed them separately August 8 and September 1. The notes from the two meetings were distributed to the Working Group members. This version of the memo reflects comments from the smaller Working Group, consisting of John Kemmerer (EPA), Ivar Ridgeway (Regional Water Board), and Melinda Becker (PG Environmental, LLC, referred to hereinafter as PG), during a conference call September 1. The major changes between this version and the August 25 version are as follows:

- Added design requirements for bio-treatment based on the Natural Resources Defense Council's May 8, 2009, letter to the Santa Ana Regional Water Board.
- Agreed to retain the treatment requirements in subpart 4.E.III.4. These requirements are in addition to requirements to provide off-site mitigation when technical infeasibility prevents the on-site retention of the storm water quality design volume (SWQDv) or biofiltration of 1.5 times the SWQDv. There is a placeholder for defining the pollutant-specific performance levels, which may be interpreted as technology-based effluent limitations. Performance levels may be described by referencing the draft SWRCB Phase II MS4 permit or the American Society of Civil Engineers (ASCE) BMP performance levels.
- Provided an alternative to Horner's equation for calculating infiltration rates by making conservative assumptions that the soil is wet and the infiltration rates are always at the low end of the reported range.
- Recommended that we not require, or rely upon the Permittees to develop, a Technical Guidance Manual.
- Recommended that we develop a spreadsheet calculator that credits or incentivizes reductions in impervious area, the preservation of trees and riparian buffers, and LID design. A copy of a

similar spreadsheet from the California Construction General Permit is provided under separate cover as an example.

PG is using the Ventura County MS4 permit (Order No. R4-2010-0108) as a template for the draft L.A. County MS4 permit. The recommended language changes to subpart 4.E. of the Ventura County permit, Planning and Land Development Program, are provided in this memo. Significant changes or additions to the recommended language in the August 25 memorandum are highlighted. A copy of the relevant parts of the Ventura County MS4 permit is provided as a separate attachment for ease of reference; the table of contents for this subpart is reproduced below for the reader's orientation.

II. Recommendations and Suggested Permit Language

The recommended changes in the requirements for the Land Development Program, as presented in the Ventura County MS4 permit, are described in this section.

Recommended Changes to Subpart 4.E.I.—Purpose:

All references to effective impervious area (EIA) are to be deleted. Instead, the permit will implement design criteria based on a volume capture approach. The permit should promote designs that minimize soil compaction during construction, as well as the construction of new impervious areas (IAs). The language is to remain consistent with the Ventura County MS4 permit except as follows:

(c) Minimize the percentage of ~~effective~~ impervious surfaces on land developments <u>by minimizing soil compaction during construction, designing projects to minimize the impervious area footprint, and</u>

employing Low-Impact Development (LID) design principles to mimic predevelopment water balance through infiltration, evapotranspiration and reuse.

(e) *Properly select, design and maintain ~~Treatment Control BMPs~~ LID and Hydromodification Control BMPs to address pollutants that likely will be generated, reduce changes to pre-development hydrology, ensure long-term function, and avoid the breeding of vectors.*

Recommended Changes to Subpart 4.E.II.—Applicability

Language is to remain consistent with the Ventura County MS4 permit.

Recommended Changes to Subpart 4.E III.—New Development/Redevelopment Performance Criteria

1. Delete all references to EIA and ineffective impervious surfaces.
2. New language: Subpart 4. E. III.1.(a):

Except as provided in subpart 4.E.III.1.(b), 4.E.III.2, or 4.E.III.3, the Permittees shall require the project to infiltrate and/or evapotranspire stormwater runoff and/or harvest rainwater for reuse. The total volume of storm water runoff retained on-site must equal or exceed the Storm Water Quality Design Volume (SWQDv) defined as the runoff from:

- *The 0.75-inch 24-hour rain event or*
- *The 85th percentile, 24-hour rain event, as determined from the Los Angeles County 85th percentile precipitation isohyetal map, whichever is greater.*

When calculating the capacity of the infiltration system, the Permittees shall account for the 24-hour infiltration loss considering the impact of increasing soil moisture content using Horton's Equation or other means approved by the Executive Officer of the Los Angeles Regional Water Quality Control Board. Horton's Equation is as follows:

(Eq. 1) $$Ft = fmin + (fmax - fmin)\, e^{-kt}$$

where:
Ft = infiltration rate at time t (in/hr),
fmin = minimum or saturated infiltration rate (in/hr),
fmax = maximum or initial infiltration rate (in/hr),
k = infiltration rate decay factor (/hr), and
t = time (hr) measured from time runoff first discharged into infiltration area.

Or

When calculating the capacity of the infiltration system, the designer shall assume that the soil is wet and the minimum infiltration rate applies. The infiltration rates presented by Hydrologic Soil Group in Table X will apply, absent more site-specific information:

Table X

Hydrologic Soil Group	*Description*	*Assumed Infiltration Rate (inches/hour)*
A	*Sand, loamy sand, or sandy loam*	*0.30*
B	*Silt loam or loam*	*0.15*
C	*Sandy clay loam*	*0.05*
D	*Clay loam, silty clay loam, sandy clay, silty clay, or clay*	*0.00*

If rainwater harvested for use in irrigation is to be credited toward the total volume of stormwater runoff retained on-site, the Permittees must require that the project proponent conduct a conservative (assuming reasonable worst-case scenarios) assessment of water demand during the wet season. This volume will be referred to as the "reliable" estimate of irrigation demand. The portion of water to be credited as retained on-site for reuse in irrigation may not exceed the reliable estimated irrigation demand during the wet season.

Harvested rainwater must be stored in a manner that precludes the breeding of mosquitoes or other vectors or with a draw down not to exceed 72 hours.

When evaluating the potential for on-site retention, the Permittees must consider the maximum potential for evapotranspiration from green roofs and harvest and reuse. ~~*The permittees shall develop minimum criteria for enhanced storm water reuse for non-potable and/or potable water supplies specific to the following land use categories:*~~

- ~~*Residential Development (4 Units and less)*~~
- ~~*Residential Development (5 Units or more)*~~
- ~~*Commercial*~~
- ~~*Industrial*~~
- ~~*Other*~~

The requirements shall address at a minimum the use of harvested rainwater for non-potable uses including toilet flushing, laundry, and cooling water makeup water. If the municipal or county plumbing code does not specifically address requirements for harvested rainwater, the Permittees shall develop a model ordinance and submit it to the city council or County Supervisors for consideration within X months of the effective date of this permit. The model ordinances shall be based on the International Association of Plumbing and Mechanical Officials' (IAPMO's) Green Plumbing and Mechanical Code Supplement to the

2012 National Standard Plumbing Code, or similar guidance to ensure the safe and effective use of harvested rainwater, separate from the existing provisions, if any, for reclaimed wastewater.

Recommended Changes to Subpart 4.E.III.1.(b)—Biofiltration

Except as provided in subpart 4.E.III.2 or 4.E.III.3, if the Permittee determines that the project cannot reliably retain 100 percent of the SWQDv on-site, even with the maximum application of green roofs and rainwater harvest and reuse, the project will be required to biofiltrate 1.5 times the volume of storm water runoff that cannot reliably be retained on-site, in accordance with the following equation.

(Eq. 2) $Bv= 1.5 * [Dv* (Dv-Rv/DV)]$

where :
Bv = *biofiltration volume,*
Dv = *SWQDv, and*
Rv= *volume reliably retained on-site.*

Bio-filtration systems discharging to a receiving water that is included on the Clean Water Act section 303(d) list of water-quality-limited water bodies due to nitrogen shall be designed and maintained to achieve enhanced nitrogen removal capability.

Bio-filtration BMPs shall be designed to accommodate the design flow at a surface loading rate no greater than 5 inches per hour and shall have a total volume, including pore spaces and prefilter detention volume, no less than the runoff volume generated by the design storm depth times 0.75.

Recommended Changes to Subpart 4.E.III.2.—Alternative Compliance for Technical Infeasibility

Subparts 4.E.III.2.(a) and (b) regarding smart growth and infill and technical infeasibility are to remain consistent with the text in the Ventura County MS4 permit, except that subpart 4.E.III.2.(b)(1) is to be changed as follows to make it consistent with City of Santa Monica Urban Runoff Reduction Requirements.

(1) Locations where seasonal high groundwater is within ~~5~~ 10 feet of the surface.

Subparts 4.E.III.2.(c)(1), (2), and (3) are to be replaced by the following text.

When a Permittee finds that the project applicant has demonstrated technical infeasibility, after confirming that the project design minimizes the impervious area to the extent allowed by local zoning regulations and considering recommended protective riparian buffers and protection of *environmentally sensitive areas, and the use of all available LID controls including green roofs and rainfall harvest and use, and biofiltration ~~geotechnical site constraints~~, the Permittee shall require the applicant to provide off-site mitigation.*

The required off-site mitigation volume will be equal to:

(Eq .3) $Mv = 1.5 * [Dv * (Dv - Ov/DV)]$

where
Mv = mitigation volume,
Dv = SWQDv, and
Ov = on-site volume = Rv (volume retained on-site) + Bv (on-site biofiltration volume).

The project applicant must perform off-site mitigation or provide sufficient funding for public or private off-site mitigation to achieve equivalent mitigation storm water volume through infiltration, reuse, evapotranspiration, and/or biofiltration.

The Permittees must develop a prioritized list of off-site mitigation projects, and when feasible, the mitigation must be directed to the highest priority mitigation project within the same drainage area as, or the nearest downstream drainage from, the proposed development or re-development. ~~*mitigation must be directed to the highest priority mitigation project within the affected drainage system (defined as draining the same hydrologic area) as identified in the Watershed Plan.*~~

Subpart 4.E.III.2.(c)(4) is to remain consistent with the Ventura County MS4 permit.
Subpart 4.E.III.2.(c)(5) is to be deleted.
Subpart 4.E.III.2.(d) is to remain essentially the same as that in the Ventura County MS4 permit except that the reference to the "5 percent EIA requirement" is to be replaced with "by retaining the SWQDv."

Recommended Changes to Subpart 4.E.III.3.—Hydromodification (Flow/Volume/Duration) Control Criteria

The Working Group expressed consensus that the L.A. MS4 permit should include a "placeholder" requirement to address hydromodification pending more detailed or site-specific requirements to be developed by the Permittees based on the pending SWRCB-funded studies. The placeholder should be stringent to be protective of the most sensitive or vulnerable water bodies and to incentivize the Permittees to conduct further analysis. A second goal is to identify a simple but protective approach for projects disturbing less than 50 acres. The following are recommended Interim Hydromodification Control Criteria.

4.E.III.3.(a)(3) Interim Hydromodification Control Criteria

RB-AR32601

(A) The Interim Hydromodification Control Criteria to protect natural drainage systems (to be defined) until Permittees complete Hydromodification Control Plans (HCPs), described in subpart (4) below, are as follows:

(i) ***<u>Projects disturbing land area less than 50 acres within natural drainage systems</u>*** *will be presumed to meet pre-development hydrology if one of the following demonstrations is made:*

(I) The project is designed to retain on-site, through infiltration, evapotranspiration, and/or harvest and reuse, the stormwater volume from the runoff of the 95th percentile storm, or

(II) The runoff flow rate, volume, velocity, and duration for the post-development condition do not exceed the pre-development ~~(i.e., naturally occurring)~~ condition for the 2-year, 24-hour rainfall event. This condition may be substantiated by simple screening models, including those described in Hydromodification Effects on Flow Peaks and Durations in Southern California Urbanizing Watersheds *(Hawley et al., 2011) or other models acceptable to the Permittee, or*

(III) The Erosion Potential (Ep) in the receiving water channel will approximate 1, as determined by a Hydromodification Analysis Study and the equation presented in Attachment X.

(ii) ***Projects disturbing land area greater than 50 acres within natural drainage systems (to be defined)*** *will be presumed to meet pre-development hydrology based on the successful demonstration of one of the following conditions:*

(I) The site infiltrates on-site at least the runoff from a 2-year, 24-hour storm event, or

(II) The runoff flow rate, volume, velocity, and duration for the post-development condition does not exceed the pre-development ~~(i.e., naturally occurring)~~ condition for the 2-year, 24-hour ~~or the 10-year, 24-hour~~ rainfall events. These conditions must be substantiated by hydrologic modeling acceptable to the Permittee, or

(III) The Erosion Potential (Ep) in the receiving water channel will approximate 1, as determined by a Hydromodification Analysis Study and the equation presented in Attachment X.

Recommended Changes to Subpart 4.E.III.4.—Water Quality Mitigation Criteria

~~This section is largely obsolete because the permit language as drafted no longer allows for treatment of the runoff from the EIA. Suggest replacing the existing text with the following:~~

The smaller Working Group decided that this section should retain provisions for treatment and recommended the following language change:

<u>(a) Each Permittee shall require all New Development and Redevelopment projects</u> ~~identified in subpart 4.E.II~~ <u>that have demonstrated that it is technically infeasible to retain 100 percent of the SWQDv on-site, per the criteria defined in subpart 4.E.III.2.(a) and (b), to provide treatment of the excess storm water</u>

runoff from the site. This requirement is in addition to the Alternative Compliance Measures described in subpart 4.E.III.2(c). The Permittee shall require these projects to implement post-construction storm water treatment BMPs and control measures to reduce pollutant loading as necessary (1) to meet the technology-based performance levels listed in Table X or (2) to ensure that the discharge does not cause or contribute to an exceedance of water quality standards in the receiving water, whichever is more stringent.

Table X—Technology-Based Treatment [Note: This table to be completed after agreement on language and approach]

Pollutant	**Effluent Concentration**	**References**
		SWRCB draft Phase II MS4 Permit. American Society of Civil Engineers, Storm Water BMPs

In addition to the requirements for controlling pollutant discharges as described in subpart 4.E.III.1 and the treatment requirements described above, the Permittees will ensure that the New Development and Redevelopment project will not cause the Permittee to exceed applicable wasteload allocations (WLAs) or fail to comply with Total Maximum Daily Load (TMDL) implementation plan requirements as described in part 5 of this permit.

Recommended Changes to Subpart 4.E.IV.—Implementation

In the Ventura County MS4 permit, the specifics of the implementation measures are to be developed in the *Ventura County Technical Guidance Manual*. PG recommends that the L.A. MS4 permit provide more prescriptive minimum standards to prevent soil compaction during construction and to provide enhanced protection of riparian buffers, habitat for endangered or threatened species, and preservation of native vegetation.

Recommended Changes to Subpart 4.E.IV.3.—Alternative Post-Construction Storm Water Mitigation

The recommended change deletes the reference to EIA and holds the RPAMP to meeting the on-site retention requirement. As written, this provision would not allow biofiltration or mitigation outside the Master Plan area.

(b)(3) ~~Reduce the percentage of Effective Impervious Area (EIA) to a target of 5 percent or less of the Redevelopment Project Area,~~ Captures or intercepts the SWQDv as defined in subpart 4.E.III.1(a).

Recommended Changes to Subpart 4.E.IV.4.—Developer Technical Guidance and Information:

The smaller Working Group agreed that Permittees should not be required to develop a Technical Guidance Manual. The Permittees are free to develop such manuals for internal guidance or guidance to their community. However, the manuals will not be subject to review or approval by the Regional Water Board Executive Officer, nor will they serve as a defense for failure to meet the terms of the MS4 permit. Therefore, it might be necessary to provide more detailed requirements in the MS4 permit. The following are examples of model requirements that could be included in subpart 4.E.IV.4.

- *Locate structures on less pervious soils where possible so as to preserve areas with permeable soils (Hydrologic Soil Group Classes A and B, as defined by the National Cooperative Soil Survey), to the extent possible, for use in storm water infiltration and groundwater recharge. Minimize the need to grade the site by concentrating development in areas with minimal non-engineered slopes and existing infrastructure, and mitigate any construction disturbance.*
- *The total disturbed area shall be no greater than 110 percent of the final project footprint plus the area of the construction storm water detention basins, if any, and as required to meet applicable Fire Department regulations for brush clearance.*
- *Construction vehicles shall be confined at all times to the area specifically permitted to be disturbed by construction as depicted in the approved construction documents. Physical barriers shall be used to designate and protect the boundary between disturbed and undisturbed areas.*
- *Materials staging shall be confined to the area permitted to be disturbed by construction or may be temporarily stored off-site at an approved location at the Contractor's option.*
- *Construction vehicles shall not traverse areas within the drip lines of those trees and other landscaping to be preserved. Approved visible physical barriers, such as continuous fencing, shall be provided to completely surround all trees and other landscaping to be preserved. Barriers shall be placed not less than 5 feet outside the drip lines of trees.*
- *Preserve or restore continuous riparian buffers widths along all natural drainages to a minimum width of 100 feet from each bank top, for a total of 200 feet plus the width of the stream, unless the Watershed Plan demonstrates that a smaller riparian buffer width is protective of water quality, hydrology, and aquatic life beneficial uses within a specific drainage.*
- *Identify and avoid development of areas containing habitat with threatened or endangered plant and animal species.*[1]

In addition, the Regional Water Board may consider including a spreadsheet for calculating the SWQDv and storm water runoff from the design storm, giving credit (and incentives) for maintaining trees, maintaining riparian buffers, and using various LID elements, including green roofs, pervious pavement, and rainfall harvesting. An example copy of the spreadsheet from the California Construction General Permit, Appendix 2.1, is provided as a separate attachment. It applies to post-construction development outside an MS4 jurisdiction. It could be modified, however, for use in the L.A. MS4, and it might be especially useful for smaller projects.

[1] Endangered Species Act, 16 U.S.C. §§ 1531–1544: http://water.epa.gov/lawsregs/guidance/wetlands/eo11990.cfm.

Appendix A

Excerpt from the *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act.*

United State Environmental Protection Agency, Office of Water (4503T), EPA 841-B-09-001. Washington, D.C. December 2009.

Pp. 12–16

Establishing Section 438 Performance Design Objectives
Described below are options site designers can use to comply with Section 438. There may be situations where Option 1 (retaining the 95th percentile rainfall event) is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams). In these cases, Option 2 (site-specific hydrologic analysis) could be used to determine the types of stormwater practices necessary to preserve predevelopment runoff conditions. Option 2 could also be used if predevelopment runoff conditions can be maintained by retaining less than the 95th percentile rainfall event. Because a performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site, Option 2 was provided in recognition that there are established methodologies that can be utilized to estimate the volume of infiltration and evapotranspiration based on site-specific hydrology and thus establish the predevelopment hydrology performance design objectives.

Option 1: Retain the 95th Percentile Rainfall Event

One approach to establishing the performance design objectives is to design, construct, and maintain stormwater management practices that manage rainfall onsite, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible (METF). This objective should be accomplished by the use of practices that infiltrate, evapotranspire and/or harvest and use rainwater. The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all storm events over a given period of record. For example, to determine what the 95th percentile storm event is in a specific location, all 24 hour storms that have recorded values over a 30 year period would be tabulated and a 95th percentile storm would be determined from this record, i.e., 5% of the storms would be greater than the number determined to be the 95th percentile storm. Thus the 95th percentile storm would be represented by a number such as 1.5 inches, and this would be the design storm (example 95th percentile storm events for selected cities are presented in Table 1). The designer would then select a system of practices, to the METF, that infiltrate, evapotranspire or harvest and use this volume multiplied by the total area of the facility/project footprint. Methods and data used to estimate the 95th percentile event are discussed in Part II of this document.

For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites. This 95th percentile approach was identified and recommended because this storm size represents the volume that appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain this pre-development hydrology for duration, rate and volume of stormwater flows. In general, only large storms generate significant runoff. In addition, this approach was identified because it employs natural treatment and flow attenuation methods that are presumed to have existed on the site before construction of infrastructure (e.g., building, roads, parking lots, driveways,) and is intended to infiltrate or evapotranspirate the full volume of the 95th percentile storm. Because this approach necessitates the use of practices that generally preclude extended detention, it will also typically address the issue of maintaining predevelopment temperatures. However, in cases where there are discharges to cool water streams or other sensitive receiving waters, additional strategies may be needed to ensure that stormwater discharges do not result in greater thermal impacts than would occur in pre-development conditions (Schueler and Helfrich, 1988).

Where technically feasible, the goal of Option 1 is that one hundred percent (100%) of the volume of water from storms less than or equal to the 95th percentile event over the footprint of the project should not be discharged to surface waters. In some cases, runoff can be harvested and used and ultimately may be discharged to surface waters or a sanitary treatment system; such direct or indirect discharges must be authorized or allowed by the regulatory authority. For example, if runoff is captured for nonpotable uses such as toilet flushing or other uses that are not irrigation related, these waters potentially could be discharged into the sanitary sewer system. Preferred mechanisms for retaining discharges from storms greater than the 95th percentile event are through overflow or diversion for the volume that exceeds the 95th percentile amount. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume. For structures such as roofs and paved surfaces that can increase the temperature of stormwater runoff, materials that minimize temperature increases (e.g., concrete vs. asphalt; vegetated roofs) should be considered and used as appropriate.

Retaining 100 percent of all rainfall events equal to or less than the 95th percentile rainfall event was identified as Option 1 because small, frequently-occurring storms account for a large proportion of the annual precipitation volume, and the runoff from those storm events also significantly alters the discharge frequency, rate and temperature of the runoff.

The runoff produced by these small storms and the initial portion of larger storms has a strong negative cumulative impact on receiving water hydrology and water quality. In areas that have been developed, runoff is generated from almost all storms, both small and large, due to the impervious surfaces associated with development and the loss of soils and vegetation. In contrast, natural or undeveloped areas discharge little or no runoff from small storms because the rain is absorbed by the landscape and vegetation. Studies have shown that increases in runoff event frequency, volume and rate can be diminished or eliminated through the use of GI/LID designs and practices, which infiltrate, evapotranspire and capture and use stormwater.

Option 1 was identified because it is a simplified approach to meet the intent of Section 438 in contrast to Option 2 which requires the designer to conduct a hydrologic analysis of the site based on site-specific conditions.

Option 2: Site-Specific Hydrologic Analysis

Another approach to establishing the performance design objective is to design, construct, and maintain stormwater management practices that preserve the pre-development runoff conditions following construction. Option 2 allows the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. If the designer elects to use Option 2, the designer would then identify the pre-development condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions.

The post-construction rate, volume, duration and temperature of runoff should not exceed the pre-development rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible. These goals should be accomplished through the use of infiltration, evapotranspiration, and/or rainwater harvesting and use. Defensible and consistent hydrological assessment tools should be used and documented. Additional discussions of appropriate methodologies to use in assessing site hydrology have been included in the technical sections of this document. See, for example, the discussion of spreadsheet versions or curve numbers based on the Natural Resource Conservation Service Technical Release 55 (TR-55) Method in Appendix A of this document.

RB-AR32607

(c) **Investigation of Complaints Regarding Facilities – Transmitted by the Regional Water Board Staff:** Each Permittee shall initiate, within one business day,[1] investigation of complaints (other than non-storm water discharges) to the MS4 from facilities within its jurisdiction. The initial investigation shall include, at a minimum, a limited inspection of the facility to confirm the complaint to determine if the facility is effectively complying with the municipal storm water urban runoff ordinances and, if necessary, to oversee corrective action.

(d) **Assistance of Regional Water Board Enforcement Actions:** As directed by the Regional Water Board Executive Officer, Permittees shall assist Regional Water Board enforcement actions by: helping in identification of current owners, operators, and lessees of facilities; providing staff, when available, for joint inspections with Regional Water Board inspectors; appearing as witnesses in Regional Water Board enforcement hearings; and providing copies of inspection reports and other progressive enforcement documentation.

(e) **Participation in a Task Force:** The Permittees shall participate with the Regional Water Board, and other public agencies on an enforcement task force such as the Storm Water Task Force, to communicate concerns regarding special cases of storm water violations by industrial and commercial facilities and to develop a coordinated approach to enforcement action.

E. Planning and Land Development Program

I. Purpose

1. The Permittees shall implement a Planning and Land Development Program pursuant to part 4.E. for all New Development and Redevelopment projects subject to this Order to:
   (a) Lessen the water quality impacts of development by using smart growth practices such as compact development, directing development towards existing communities via infill or redevelopment, safeguarding of environmentally sensitive areas, mixing of land uses (e.g., homes, offices, and shops), transit accessibility, and better pedestrian and bicycle amenities.
   (b) Minimize the adverse impacts from storm water runoff on the biological integrity of Natural Drainage Systems and the beneficial uses of waterbodies in accordance with requirements under CEQA (Cal. Pub. Resources Code § 21100).
   (c) Minimize the percentage of effective impervious surfaces on land developments to mimic predevelopment water balance through infiltration, evapotranspiration and reuse.

[1] Permittees may comply with the Permit by taking initial steps (such as logging, prioritizing, and tasking) to "initiate" the investigation within that one business day. However, the Regional Water Board would expect that the initial investigation, including a site visit, to occur within four business days.

RB-AR32608

(d) Minimize pollutant loadings from impervious surfaces such as roof-tops, parking lots, and roadways through the use of properly designed, technically appropriate BMPs (including Source Control BMPs such as good housekeeping practices), Low Impact Development Strategies, and Treatment Control BMPs.
(e) Properly select, design and maintain Treatment Control BMPs and Hydromodification Control BMPs to address pollutants that are likely to be generated, assure long-term function, and to avoid the breeding of vectors.[1]
(f) Prioritize the selection of BMPs suites to remove storm water pollutants, reduce storm water runoff volume, and beneficially reuse storm water to support an integrated approach to protecting water quality and managing water resources in the following order of preference:
  (1) Infiltration BMPs
  (2) BMPs that store and reuse storm water runoff.
  (3) BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses
  (4) BMPs which percolate runoff through engineered soil and allow it to discharge downstream slowly
  (5) Approved modular/ proprietary treatment control BMPs that are based on LID concepts and that meet pollution removal goals

II. Applicability

1. New Development Projects.
(a) Development projects subject to Permittee conditioning and approval for the design and implementation of post-construction controls to mitigate storm water pollution, prior to completion of the project(s), are:
  (1) All development projects equal to 1 acre or greater of disturbed area and adding more than 10,000 square feet of impervious surface area
  (2) Industrial park 10,000 square feet or more of surface area
  (3) Commercial strip mall 10,000 square feet or more of impervious surface area
  (4) Retail gasoline outlet 5,000 square feet or more of surface area
  (5) Restaurant (SIC 5812) 5,000 square feet or more of surface area
  (6) Parking lot 5,000 square feet or more of impervious surface area, <u>or</u> with 25 or more parking spaces
  (7) Streets, roads, highways, and freeway construction of 10,000 square feet or more of impervious surface area shall incorporate USEPA guidance regarding Managing Wet Weather with Green Infrastructure: Green Streets to the maximum extent practicable.
  (8) Automotive service facilities (SIC 5013, 5014, 5511, 5541, 7532-7534 and 7536-7539) [5,000 square feet or more of surface area]

[1] Treatment BMPs when designed to drain within 72 hours of the end of rainfall minimize the potential for the breeding of vectors.

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(9) Redevelopment projects in subject categories that meet Redevelopment thresholds (identified in subpart E.II.2 below)

(10) Projects located in or directly adjacent to, or discharging directly to an Environmentally Sensitive Area (ESA), where the development will:
  (A) Discharge storm water runoff that is likely to impact a sensitive biological species or habitat; and
  (B) Create 2,500 square feet or more of impervious surface area

(11) Single-family hillside homes. To the extent that a Permittee may lawfully impose conditions, mitigation measures or other requirements on the development or construction of a single-family home in a hillside area as defined in the applicable Permittee's Code and Ordinances, each Permittee shall require that during the construction of a single-family hillside home, the following measures to be implemented:
  (A) Conserve natural areas
  (B) Protect slopes and channels
  (C) Provide storm drain system stenciling and signage
  (D) Divert roof runoff to vegetated areas before discharge unless the diversion would result in slope instability
  (E) Direct surface flow to vegetated areas before discharge unless the diversion would result in slope instability

2. Redevelopment Projects

(a) Redevelopment projects subject to Permittee conditioning and approval for the design and implementation of post-construction controls to mitigate storm water pollution, prior to completion of the project(s), are:
  (1) Land-disturbing activity that results in the creation or addition or replacement of 5,000 square feet or more of impervious surface area on an already developed site on development categories identified in subpart 4.E.III.1.
  (2) Where Redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, the entire project must be mitigated.
  (3) Where Redevelopment results in an alteration to less than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to post development storm water quality control requirements, only the alteration must be mitigated, and not the entire development.

(b) Redevelopment does not include routine maintenance activities that are conducted to maintain original line and grade, hydraulic capacity, original purpose of facility or emergency redevelopment activity required to protect public health and safety. Impervious surface replacement, such as the reconstruction of parking lots and roadways which does not disturb additional area and maintains the original grade and alignment, is considered a routine maintenance activity. Redevelopment does not include the repaving of existing roads to maintain original line and grade.

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(c) Existing single-family dwelling and accessory structures are exempt from the Redevelopment requirements unless such projects create, add, or replace 10,000 square feet of impervious surface area.

3. Effective Date –The New Development and Redevelopment requirements contained in Section E of the Order shall begin (90 calendar days) after Regional Water Board Executive Officer approval of the changes to the Technical Guidance Manual needed to comply with this permit. After that date all discretionary permit projects or project phases that have not been deemed complete for processing, or discretionary permit projects without vesting tentative maps that have not requested and received an extension of previously granted approvals must comply with the requirements in Section E. Projects that have been deemed complete prior to the update of the technical design manual are not subject to this section. For Permittee's projects the effective date shall be the date the governing body or their designee approves initiation of the project design.

III. New Development/ Redevelopment Performance Criteria

1. Integrated Water Quality/ Flow Reduction/Resources Management Criteria
   (a) Except as provided in subpart 4.E.III.1.(c) below, Permittees shall require all New Development and Redevelopment projects identified in subpart 4.E.II to control pollutants, pollutant loads, and runoff volume emanating from impervious surfaces through infiltration, storage for reuse, evapotranspiration, or bioretention/ biofiltration by reducing the percentage of Effective Impervious Area (EIA) to 5 percent or less of the total project area.
   (b) Impervious surfaces may be rendered "ineffective", and thus not count toward the 5 percent EIA limitation, if the stormwater runoff from those surfaces is fully retained on-site for the design storm event specified in provision (c), below. To satisfy the EIA limitation and low-impact development requirements, the permittees must require stormwater runoff to be infiltrated, reused, or evapotranspired on-site through a stormwater management technique allowed under the terms of this permit and implementing documents. If on-site retention is determined to be technically infeasible pursuant to 4.E.III.2(b), an on-site biofiltration system that achieves equivalent stormwater volume and pollutant load reduction as would have been achieved by on-site retention shall satisfy the EIA limitation. An on-site biofiltration system that releases above the design volume shall achieve 1.5 times the amount of stormwater volume and pollutant load reduction as would have been achieved by on-site retention and, thereby, shall satisfy the EIA limitation.
   (c) The permittees shall require all features constructed or otherwise utilized to render impervious surfaces "ineffective", as described in provision (b), above, to be properly sized to infiltrate, store for reuse, or evapotranspire, without any runoff at least the volume of water, or in the case of biofiltration with release above the design volume, 1.5 times the volume of water, that results from:

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(1) The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998);
(2) The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in the Ventura County Technical Guidance Manual for Storm Water Quality Control Measures (July 2002 and its revisions); or
(3) The volume of runoff produced from a 0.75 inch storm event.

(d) To address any impervious surfaces that may not be rendered "ineffective", surface discharge of stormwater runoff if any, that results from New Development and Redevelopment projects identified in subpart 4.E.II which have complied with subparts 4.E.III.1.(a)-(c), above, shall be mitigated in accordance with subpart 4.E.III.4.

2. Alternative Compliance for Technical Infeasibility

(a) To encourage smart growth and infill development of existing urban centers where on-site compliance with post-construction requirements may be technically infeasible, the permittees may allow projects that are unable to meet the Integrated Water Quality/Flow Reduction/Resources Management Criteria in subpart 4.E.III.1, above, to comply with this permit through the alternative compliance measures described in subpart 4.E.III.2.(c), below.

(b) To utilize alternative compliance measures, the project applicant must demonstrate that compliance with the applicable post-construction requirements would be technically infeasible by submitting a site-specific hydrologic and/or design analysis conducted and endorsed by a registered professional engineer, geologist, architect, and/or landscape architect. Technical infeasibility may result from conditions including the following:
(1) Locations where seasonal high groundwater is within 5 feet of the surface
(2) Locations within 100 feet of a groundwater well used for drinking water
(3) Brownfield development sites or other locations where pollutant mobilization is a documented concern
(4) Locations with potential geotechnical hazards
(5) Smart growth and infill or redevelopment locations where the density and/ or nature of the project would create significant difficulty for compliance with the on-site volume retention requirement
(6) Other site or implementation constraints identified in the LID Technical Guidance document required by subpart 4.E.IV.4.

(c) Alternative Compliance Measures. When a permittee finds that a project applicant has demonstrated technical infeasibility, the permittee shall identify alternative compliance measures that the project will need to comply with as a substitute for the otherwise applicable post-construction requirements listed in subparts 4.E.III.1.(a)-(c) of this permit. The Ventura County Technical Guidance Manual shall be revised to identify the alternative compliance measures and shall include the following requirement:

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(1) Minimum on-site requirement. The project must take all feasible measures to reduce the percentage of Effective Impervious Area to no more than 30 percent of the total project area and treat all remaining runoff pursuant to the design and sizing requirements of subparts 4.E.III.1.(b)-(d).

(2) Offsite mitigation volume. The difference in volume between the amount of stormwater infiltrated, reused, and/ or evapotranspired and/or biofiltered by the project on-site and the otherwise applicable requirements of subparts 4.E.III.1.(a)-(c) (the "offsite mitigation volume'), above, must be mitigated by the project applicant either by performing offsite mitigation that is approved by the permittee or by providing sufficient funding for public or private offsite mitigation to achieve equivalent stormwater volume and pollutant load reduction through infiltration, reuse, evapotranspiration and/ or biofiltration.
   - For projects with demonstrable technical infeasibility that cannot reduce the Effective Impervious Area to 5% or less of the total project, but are able to reduce the Effective Impervious Area to no more than 30 percent of the total project, mitigation or payment in lieu must be equivalent to the amount of stormwater not managed on site.
   - For projects with demonstrable technical infeasibility that cannot reduce the Effective Impervious Area to 30% of the total project or less, mitigation or payment in lieu must be for 1.5 times the amount of stormwater not managed on site

(3) Location of off site mitigation. Offsite mitigation projects must be located in the same sub-watershed (defined as draining to the same hydrologic area in the Basin Plan) as the new development or redevelopment project. A list of eligible public and private offsite mitigation projects available for funding shall be identified by the Permittees and provided to the project applicant. Off site mitigation projects include green streets projects, parking lot retrofits, other site specific LID BMPs, and regional BMPs. Project applicants seeking to utilize these alternative compliance provisions may propose other offsite mitigation projects, which the Permittees may approve if they meet the requirements of this subpart.

(4) Timing and Reporting Requirements for Offsite Mitigation Projects. The Permittee(s) shall develop a schedule for the completion of offsite mitigation projects, including milestone dates to identify fund, design, and construct the projects. Offsite mitigation projects shall be completed as soon as possible, and at the latest, within 4 years of the certificate of occupancy for the first project that contributed funds toward the construction of the offsite mitigation project, unless a longer period is otherwise authorized by the Executive Officer. For public offsite mitigation projects, the permittees must provide in their annual reports a summary of total offsite mitigation funds raised to date and a description (including location, general design concept, volume of water expected to be retained, and total estimated budget) of all pending public offsite mitigation projects. Funding sufficient to address the offsite mitigation volume must be

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transferred to the permittee (for public offsite mitigation projects) or to an escrow account (for private offsite mitigation projects) within one year of the initiation of construction.

(5) The project applicant must demonstrate that the EIA achieved on-site is as close to 5 percent EIA as technically feasible, given the site's constraints.

(d) Watershed equivalence. Regardless of the methods through which permittees allow project applicants to implement alternative compliance measures, the sub-watershed -wide (defined as draining to the same hydrologic area in the Basin Plan) result of all development must be at least the same level of water quality protection as would have been achieved if all projects utilizing these alternative compliance provisions had complied with subparts 4.E.III.1.(a)-(d) of the permit. The permittees shall provide in their annual report to the Regional Board a list of mitigation project descriptions and pollutant and flow reduction analyses (compiled from design specifications submitted by project applicants and approved by the permittee(s)) comparing the expected aggregate results of alternative compliance projects to the results that would otherwise have been achieved by meeting the 5 percent EIA requirement on-site.

3. Hydromodification (Flow/ Volume/ Duration) Control Criteria

(a) Each Permittee shall require all New Development and Redevelopment projects identified in subpart 4.E.II to implement hydrologic control measures, to prevent accelerated downstream erosion and to protect stream habitat in natural drainage systems. The purpose of the hydrologic controls is to minimize changes in post-development hydrologic storm water runoff discharge rates, velocities, and duration. This shall be achieved by maintaining the project's pre-project storm water runoff flow rates and durations.

(1) Description

(A) Hydromodification control in natural drainage systems shall be achieved by maintaining the Erosion Potential (E_p) in streams at a value of 1, unless an alternative value can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat (see Attachment "E" - Determination of Erosion Potential)

(B) Hydromodification control may include one, or a combination of on-site, regional subregional hydromodification control BMPs, LID strategies, or stream restoration measures, with preference given to LID strategies and hydromodification control BMPs. Any in-stream restoration measure shall not adversely affect the beneficial uses of the natural drainage systems

(C) Natural drainage systems, which include unlined or unimproved (not engineered) creeks, streams, rivers and their tributaries, are located in the following watersheds:

(i) Ventura River

(ii) Santa Clara River

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(iii) Calleguas Creek
(iv) Malibu Creek
(v) Miscellaneous Ventura Coastal

(D) The Southern California Storm Water Monitoring Coalition (SMC) is developing a regional methodology to eliminate or mitigate the adverse impacts of hydromodification as a result of urbanization, including hydromodification assessment and management tools.

(i) The SMC has identified the following objectives for the Hydromodification Control Study (HCS):

(I) Establishment of a stream classification for Southern California streams

(II) Development of a deterministic or predictive relationship between changes in watershed impervious cover and stream-bed/ stream bank enlargement

(III) Development of a numeric model to predict stream-bed/ stream bank enlargement and evaluate the effectiveness of mitigation strategies

(E) The Permittees shall participate in the SMC HCS to develop:

(i) A regional stream classification system
(ii) A numerical model to predict the hydrological changes resulting from new development
(iii) A numerical model to identify effective mitigation strategies

(F) Until the completion of the SMC HCS, Permittees shall implement the Interim Hydromodification Control Criteria, described in subpart 4.E.III.3(a)(3)(A) below, to control the potential adverse impacts of changes in hydrology that may result from new development and redevelopment projects identified in subpart 4.E.II

(G) Existing single-family structures are exempt from the Hydromodification control requirements unless such projects disturb one acre or more of land or create, add, or replace 10,000 square feet or more of impervious surface area

(2) Exemptions to Hydromodification Controls. Permittees may exempt the following New Development and Redevelopment projects from implementation of Hydromodification controls where assessments of downstream channel conditions and proposed discharge hydrology indicate that adverse Hydromodification effects to present and future beneficial uses of Natural Drainage Systems are unlikely:

(A) All projects that disturb less than one acre.

(B) Projects that are replacement, maintenance or repair of a Permittee's existing flood control facility, storm drain, or transportation network.

(C) Redevelopment Projects in the Urban Core that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-project conditions.

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(D) Projects that have any increased discharge go directly or via a storm drain to a sump, lake, area under tidal influence, into a waterway that has a 100-year peak flow (Q100) of 25,000 cfs or more, or other receiving water that is not susceptible to Hydromodification impacts;

(E) Projects that discharge directly or via a storm drain into concrete or improved (not natural) channels (e.g., rip rap, sackcrete, etc.), which, in turn, discharge into receiving water that is not susceptible to Hydromodification impacts (as in D above).

(3) Interim Hydromodification Control Criteria

(A) The Interim Hydromodification Control Criteria to protect natural drainage systems until Permittees complete Hydromodification Control Plans (HCPs), described in subpart 4.E.III.3(a)(4) below, are as follows:

(i) **Projects disturbing land area of less than fifty acres** will be subject to LID and/or source or treatment BMPs as addressed in this permit. The combined effects of LID and the treatment BMPs are considered adequate for Hydromodification control for projects that disturb less than 50 acres.

(ii) **Projects disturbing land areas of fifty acres or greater** Projects in this category shall develop and implement a Hydromodification Analysis Study (HAS) that demonstrates that post development conditions are expected to approximate the pre-project erosive effect of sediment transporting flows in receiving waters. The HAS must lead to the incorporation into the project design features intended to approximate, to the extent feasible, an Erosion Potential value of 1 or any alternative value that can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat in natural drainage systems, or

(I) Alternatively, project proponents in this category may elect to develop, in partnership with Permittees, an equivalent implementation method based on flow duration control in the form of nomographs relating planned impervious area and local soil type (infiltration rates) to determine hydromodification control BMP volume and land area requirements for the proposed project. The nomographs shall be derived from continuous simulation modeling using Ventura County specific rain gauge records and soil types, and calibrated using data from a local undeveloped watershed with similar conditions; or

(II) Alternatively, the Co-Permittees may revise the Ventura County Technical Guidance Manual for Stormwater

Quality Control Measures to address projects that disturb more than 50 acres.

(4) Final Criteria

(A) The Permittees shall develop and implement watershed specific HCPs no later than (180 days) after the completion of the SMC HCS.

(i) The HCP shall identify:

(I) Stream classifications

(II) Flow rate and duration control methods

(III) Sub-watershed mitigation strategies

(IV) Stream restoration measures, which will maintain the stream and tributary Erosion Potential at 1 unless an alternative value can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat in natural drainage system tributaries

(B) The HCP shall contain the following elements:

(i) Hydromodification Management Standards

(ii) Natural Drainage Areas and Hydromodification Management Control Areas

(iii) New Development and Redevelopment Projects subject to the HCP

(iv) Description of authorized Hydromodification Management Control BMPs

(v) Hydromodification Management Control BMP Design Criteria.

(vi) For flow duration control methods, the range of flows to control for, and goodness of fit criteria

(vii) Allowable low critical flow, Q_c, which initiates sediment transport

(viii) Description of the approved Hydromodification Model.

(ix) Any alternate Hydromodification Management Model and Design

(x) Stream Restoration Measures Design Criteria

(xi) Monitoring and Effectiveness Assessment

(xii) Record Keeping

(C) The HCP shall be deemed in effect upon Executive Officer approval.

4. Water Quality Mitigation Criteria

(a) Each Permittee shall require all New Development and Redevelopment projects identified in subpart 4.E.II to implement post-construction storm water treatment BMPs and control measures to mitigate storm water pollution as follows:

(1) Projects disturbing land areas less than 50 acres

(A) Volumetric Treatment Control BMP

(i) The 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area using a 48 to

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72-hour draw down time, from the formula recommended in *Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998)*; or

(ii) The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in the Ventura County Technical Guidance Manual for Storm Water Quality Control Measures (July 2002 and its revisions); or

(iii) The volume of runoff produced from a 0.75 inch storm event, prior to its discharge to a storm water conveyance system;[1] and/ or

(B) Flow Based Treatment Control BMP

(i) The flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity; or

(ii) The flow of runoff produced from a rain event equal to at least 2 times the 85th percentile hourly rainfall intensity as determined from local rainfall records; or

(iii) Eight percent of the 50-year storm design flow rate as determined from the method recommended in the Ventura County Technical Guidance Manual for Storm Water Quality Control Measures (July 2002 and its revisions)

(2) Projects disturbing land area of 50 acres or greater

(A) Eighty percent of the average runoff volume using an appropriate public domain continuous flow model (such as Storm Water Management Model (SWMM) or Hydrologic Engineering Center – Hydrologic Simulation Program – Fortran (HEC-HSPF), using the local rainfall record and relevant BMP Performance data.

IV. Implementation

1. Maintenance Agreement and Transfer

(a) Prior to issuing approval for final occupancy each Permittee shall require that all new development and redevelopment projects subject to post-construction BMP requirements provide an operation and maintenance plan and verification of ongoing maintenance provisions for LID practices, Treatment Control BMPs, and Hydromodification Control BMPs including but not limited to: final map conditions, legal agreements, covenants, conditions or restrictions, CEQA mitigation requirements, conditional use permits, and/ or other legally binding maintenance agreements.

(1) Verification at a minimum shall include the developer's signed statement accepting responsibility for maintenance until the responsibility is legally transferred; and either

[1] This option is available only for construction projects that disturb land area less than 5 acres.

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(A) A signed statement from the public entity assuming responsibility for BMP maintenance; or

(B) Written conditions in the sales or lease agreement, which require the property owner or tenant to assume responsibility for BMP maintenance and conduct a maintenance inspection at least once a year; or

(C) Written text in project covenants, conditions, and restrictions (CCRs) for residential properties assigning BMP maintenance responsibilities to the Home Owners Association (HOA); or

(D) Any other legally enforceable agreement or mechanism that assigns responsibility for the maintenance of BMPs.

(b) Each Permittee shall require all development projects subject to post-construction BMP requirements to provide a plan for the operation and maintenance of all structural and treatment controls. The Operation and Maintenance plan shall follow the Technical Guidance Manual Appendix D "Maintenance Plan Guidance" (or subsequent guidance manual) for each BMP component. The plan shall be submitted for examination of relevance to keeping the BMPs in proper working order. Where BMPs are transferred to Permittee for ownership and maintenance, the plan shall also include all relevant costs for upkeep of BMPs in the transfer. Operation and Maintenance plans for private BMPs shall be kept on-site for periodic review by Permittee inspectors.

2. Tracking, Inspection, and Enforcement of Post-Construction BMPs

(a) Each Permittee shall implement a tracking system and an inspection and enforcement program for new development and redevelopment post-construction storm water BMPs as set forth in part 4.E. no later than (one year after Order adoption date).

(1) Implement a GIS or other electronic system for tracking projects that have been conditioned for post-construction BMPs. The electronic system, at a minimum, should contain the following information:

(A) Municipal Project ID
(B) State WDID No
(C) Project Acreage
(D) BMP Type and Description
(E) BMP Location (coordinates)
(F) Date of Acceptance
(G) Date of Maintenance Agreement
(H) Maintenance Records
(I) Inspection Date and Summary
(J) Corrective Action
(K) Date Certificate of Occupancy Issued
(L) Replacement or Repair Date

(b) Inspect all development sites upon completion of construction and prior to the issuance of occupancy certificates to ensure proper installation of LID measures, structural BMPs, treatment control BMPs and Hydromodification control BMPs. The inspection may be combined with other inspections provided it is conducted by trained personnel.

(c) Verify proper maintenance and operation of post-construction BMPs previously approved for new development and redevelopment and operated by the Permittees. The post construction BMP maintenance inspection program shall incorporate the following elements:
   (1) Post-construction BMP Maintenance Inspection checklist.
   (2) Inspection at least once every 2 years, beginning (Order adoption date), of post-construction BMPs to assess operation conditions with particular attention to:
   (3) Criteria and procedures for post construction Treatment Control and Hydromodification Control BMP repair, replacement, or re-vegetation.

(d) For post construction BMPs operated and maintained by parties other than the Permittees, the Permittees shall require annual reports by the other parties demonstrating proper maintenance and operations.

(e) Undertake enforcement as appropriate based on the results of the inspection.

3. Alternative Post Construction Storm Water Mitigation Programs

(a) A Permittee or a coalition of Permittees may apply to the Regional Water Board for approval of a Redevelopment Project Area Master Plan (RPAMP) for redevelopment projects within the Redevelopment Project Areas, in consideration of exceptional site constraints that inhibit site-by-site or project-by-project implementation of post-construction requirements.

(b) Upon review and a determination by the Regional Water Board Executive Officer that the proposal is technically valid and appropriate, the Regional Water Board may consider for approval such a program if its implementation will:
   (1) Result in equivalent or superior reduction of storm water pollutant loads in comparison to individual projects regulated by this permit.
   (2) Satisfy, on a Redevelopment Project Area-wide basis, the hydromodification criteria of this section.
   (3) Reduce the percentage of Effective Impervious Area (EIA) to a target of 5 percent or less of the Redevelopment Project Area, using properly sized storm water treatment/ collection features, as described in this Section.
   (4) Be fiscally sustainable and have secure funding; and
   (5) Be completed in four years of the adoption date of this permit.

(c) The RPAMP should prioritize the implementation of LID storm water mitigation measures, as described in this section.

(d) A Permittee or a coalition of Permittees may apply to the Regional Water Board for approval of a Redevelopment Project Area Master Plan (RPAMP) that takes into consideration the balancing of water quality protection with the needs for adequate housing, population growth, public transportation and management, land recycling, and urban revitalization.

(e) For the RPAMP to be considered, a technical panel of the Local Government Commission or an equivalent state or regional planning agency must have

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reviewed and approved the proposed RPAMP, prior to its submittal to the Regional Water Board. The Regional Water Board Executive Officer may then consider the RPAMP for approval, or elect to submit it to the Regional Water Board for consideration.

(f) The RPAMP, on approval, may substitute in part or wholly for post-construction requirements.

(g) Redevelopment Project Areas include the following:
  (1) City Center areas
  (2) Historic District areas
  (3) Brownfield areas
  (4) Infill Development areas
  (5) Urban Transit Villages
  (6) Any other redevelopment area so designated by the Regional Water Board

(h) Nothing in these provisions shall be construed as to delay the implementation of post-construction control requirements, as approved in this Order.

4. Developer Technical Guidance and Information

(a) The Permittees shall update the Ventura County Technical Guidance Manual for Storm Water Quality Control Measures to include, at a minimum, the following:
  (1) Hydromodification Control criteria described in this Order, including numerical criteria.
  (2) Expected BMP pollutant removal performance including effluent quality (ASCE/ U.S. EPA International BMP Database, CASQA New Development BMP Handbook, technical reports, local data on BMP performance, and the scientific literature appropriate for southern California geography and climate).
  (3) Selection of appropriate BMPs for storm water pollutants of concern.
  (4) Data on Observed Local Effectiveness and performance of implemented BMPs.
  (5) BMP Maintenance and Cost Considerations.
  (6) Guiding principles to facilitate integrated water resources planning and management in the selection of BMPs, including water conservation, groundwater recharge, public recreation, multipurpose parks, open space preservation, and redevelopment retrofits.
  (7) LID principles and specifications, including the objectives and specifications for integration of LID strategies in the areas of:
    (A) Site Assessment.
    (B) Site Planning and Layout.
    (C) Vegetative Protection, Revegetation, and Maintenance.
    (D) Techniques to Minimize Land Disturbance.
    (E) Techniques to Implement LID Measures at Various Scales
    (F) Integrated Water Resources Management Practices.
    (G) LID Design and Flow Modeling Guidance.
    (H) Hydrologic Analysis.
    (I) LID Credits.

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(b) Permittees shall update the Technical Guidance Manual within (120 days after Order adoption date).
(c) The Permittees shall facilitate implementation of LID by providing key industry, regulatory, and other stakeholders with information regarding LID objectives and specifications contained in the LID Technical Guidance Section through a training program. The LID training program will include the following:
(1) LID targeted sessions and materials for builders, design professionals, regulators, resource agencies, and stakeholders
(2) A combination of awareness on national efforts and local experience gained through LID pilot projects and demonstration projects
(3) Materials and data from LID pilot projects and demonstration projects including case studies
(4) Guidance on how to integrate LID requirements into the local regulatory program(s) and requirements
(5) Availability of the LID Technical Guidance regarding integration of LID measures at various project scales
(6) Guidance on the relationship among LID strategies, Source Control BMPs, Treatment Control BMPs, and Hydromodification Control requirements
(d) The Permittees shall submit revisions to the Ventura County Technical Guidance Manual to the Regional Water Board for Executive Officer approval.

5. Project Coordination
(a) Each Permittee shall facilitate a process for effective approval of post-construction storm water control measures. The process shall include:
(1) Detailed BMP review including BMP sizing calculations, BMP pollutant removal performance, and municipal approval; and
(2) An established structure for communication and delineated authority between and among municipal departments that have jurisdiction over project review, plan approval, and project construction through memoranda of understanding (MOU) or an equivalent agreement.

V. State Statute Conformity

1. California Environmental Quality Act (CEQA) Document Update
(a) Each Permittee shall incorporate into its CEQA process no later than (365 days after Order adoption date) those additional procedures necessary for considering potential storm water quality impacts and providing for appropriate mitigation when preparing and reviewing CEQA documents.
(1) The procedures shall require consideration of the following:
(A) Potential impact of project construction on storm water runoff.
(B) Potential impact of project post-construction activity on storm water runoff.
(C) Potential for discharge of storm water from areas from material storage, vehicle or equipment fueling, vehicle or equipment

Checklist for Minimizing Vector Production in Stormwater Management Structures

Management of mosquitoes and other vectors in stormwater management structures, such as flood control basins and Best Management Practices, is critical for protecting public health. With careful planning, such structures can be designed, built, operated, and maintained in a manner that minimizes opportunities for the proliferation of vectors. This publication provides checklists of action items intended to lessen the short and long-term potential for vector production in stormwater management structures while reducing dependence on pesticides to the maximum extent possible. With the wide variety of structures and build locations, it is anticipated that not all action items will apply to every project. Answers to frequently asked questions follow the checklist.

For simplicity, stormwater management structures have been divided into three categories, each with specific considerations. Certain structures may require reference to more than one checklist.

Dry Systems. Any structure designed to drain completely following capture and/or treatment of runoff. Examples include flood control basins, extended detention basins, infiltration basins and trenches, Austin sand filters, swales and strips, drain inlet inserts, linear-radial gross solids removal devices. Permanent-water features sometimes included as part of dry system design, such as micropools, should be considered separately using the checklist for “wetlands”.

Wet Systems. Any structure designed with features such as sumps, vaults, and/or basins that hold water permanently, or longer than 4 days. Examples include open catch basins, concrete retention basins, Delaware sand filters, and a variety of belowground proprietary devices.

Wetlands. Any structure constructed as a naturalistic system with permanent surface waters, regardless of the formal given name (e.g., stormwater pond, retention basin, wet basin, constructed wetlands, treatment wetlands, etc.). This section also applies to permanent-water features sometimes included as part of dry system design such as micropools.

Additional information is available from the California Department of Public Health
http://www.cdph.ca.gov/HealthInfo/discond/Pages/MosquitoBorneDiseases.aspx
and from the University of California, Division of Agriculture and Natural Resources (UCANR)
http://www.ipm.ucdavis.edu/PDF/MOSQ/mosquitostormwater.pdf

To facilitate public health mosquito control, it is strongly recommended that project locations be provided to the local vector control agency. To locate your local mosquito and vector control agency, go to http://westnile.ca.gov and search by zip code.

DRY SYSTEMS

Recommended strategy: Complete discharge of all captured water in 4 days or less.

- ☐ Is the structure designed to discharge all captured water in 4 days or less?
- ☐ Has every effort been made to trace and eliminate persistent non-stormwater flows (e.g. irrigation runoff) that may enter the system and jeopardize non-chemical vector control efforts?
- ☐ Has groundwater depth been carefully evaluated to ensure that the structure will not be permanently or seasonally flooded (i.e. is the base of the basin higher than the local groundwater table)?
- ☐ Does the design provide an adequate slope between the inlets and outlets, with special attention given to ensure corners are above grade?
- ☐ Has soil been compacted adequately during grading to minimize subsidence, which can result in pools of standing water?
- ☐ Does the design slope take into consideration the inevitable accumulation of sediment and debris between maintenance periods that can result in standing water, especially in and around the inlet?
- ☐ Does the design minimize the use of features that increase the potential for standing water, such as loose riprap and concrete curbs?
- ☐ Does the structure include a concrete or earthen low-flow channel to concentrate (i.e. minimize available surface area) and direct non-stormwater flows to the outlet?
- ☐ Is the distribution piping sloped adequately and smooth (not corrugated) on the inside to prevent standing water?
- ☐ Are the inlet structures and energy dissipaters designed and sloped sufficiently to prevent scour depressions?
- ☐ Are the outlets designed with debris screens or other features that reduce the potential for clogging?
- ☐ Is the structure designed with safe and sufficient access for inspection, maintenance, and/or vector control activities when needed?
- ☐ Does the operation and maintenance plan include a minimum of quarterly inspections to ensure that vegetation overgrowth, sediment accumulation, or other factors have not created areas of standing water?
- ☐ Does the operation and maintenance plan include a minimum annual maintenance to remove vegetation overgrowth, remove sediment and debris accumulation, and otherwise return the structure to “as-designed” conditions?
- ☐ Is signage provided and clearly visible with minimum information indicating the type of structure (e.g. extended detention basin), ownership, and contact information?

WET SYSTEMS

Recommended strategy: Deny mosquito access to standing water by using covers, screens, and/or other barriers.

- ☐ Have sumps, vaults, or basins that hold water permanently, or longer than 4 days, been completely or partially sealed against adult mosquito entry?
- ☐ If used, are covers tight fitting, with gaps or holes of no greater than 1/16" (2 mm)?
- ☐ If used, are aluminum or nylon screens for sealing small openings secured with gaps or holes of no greater than 1/16" (2 mm)?
- ☐ If cast iron manhole covers are used, are pick holes sealed or is a mosquito-proof insert provided below?
- ☐ Where feasible, are the inlet and/or outlet conveyance pipes submerged to prevent adult mosquito entry into the main water storage area?
- ☐ Where feasible, are conveyance pipes fitted with flapper valves, collapsible fabric tubes, or other barriers to prevent adult mosquito entry into the main water storage area?
- ☐ Is the structure designed with safe and sufficient access to permanent water areas for inspection, maintenance, and/or vector control activities when needed?
- ☐ Does the operation and maintenance plan include a minimum of quarterly inspections to ensure that barriers to mosquito entry are intact and in place as designed?
- ☐ Where possible, is signage provided with minimum information indicating type of structure (e.g. CDS™), ownership, and contact information?

WETLANDS

Recommended strategy: Create and maintain habitat least-suitable for mosquito breeding.

- ☐ Is the system designed with features that minimize the areas suitable for mosquito production?
- ☐ Does the design discourage emergent vegetation in shallow water zones where vegetation is not needed or desired, for example by using concrete liners in sediment forebays?
- ☐ Are slopes designed as steep and uniform as possible to discourage invasive, emergent vegetation?
- ☐ Does the system include deep water zones, in excess of 4 ft, to reduce available area for emergent vegetation and provide refuge for natural mosquito predators such as mosquitofish and certain invertebrates?
- ☐ Where permitted, have mosquitofish been introduced to help control mosquitoes?
- ☐ Does the system include provisions for rapid dewatering if needed for emergency control of mosquitoes?
- ☐ Is the structure designed with safe and sufficient access for inspection, maintenance, and/or vector control activities when needed?
- ☐ Are access roads built close to the shoreline and around the perimeter of the wetland to the extent feasible?
- ☐ Are access points incorporated at regular intervals along the perimeter to allow for vector monitoring and control when necessary.
- ☐ Does the operation and maintenance plan include a minimum of quarterly inspections to ensure that vegetation overgrowth, sediment accumulation, or other factors have not created areas suitable for mosquito production?
- ☐ Does the operation and maintenance plan include a minimum annual maintenance to remove vegetation overgrowth, remove sediment and debris accumulation, and otherwise return the structure to “as-designed” conditions?
- ☐ Is signage provided and clearly visible with minimum information indicating type of structure (e.g. stormwater treatment pond), ownership, and contact information?

Frequently Asked Questions

DRY SYSTEMS

1. Why is it important to drain all captured water in 4 days or less?
Most mosquito species important to public health require at least 6 days to develop from egg to adult. Designing dry systems to drain completely in 4 days ensures that no mosquitoes will be produced with a built-in margin of safety of several days.

2. Our stormwater treatment BMPs were designed to dewater in 4 days, but persistent non-stormwater flows result in areas of standing water that routinely produce mosquitoes. How do we address this problem?
Dry-weather urban runoff is a major contributor to mosquito production in urban areas everywhere. If the source(s) cannot be traced and eliminated, the best alternate solution is to minimize the surface area available to mosquitoes by cutting a low-flow channel through the BMP to direct the water to the outlet as efficiently as possible.

3. Will very shallow areas of standing water that remain in our detention basins after a storm event provide a potential source of mosquito production?
Certain species of mosquitoes important to public health are very adaptable. Water as shallow as 1/16", and sometimes less, can be sufficient to allow mosquito larvae to develop.

WET SYSTEMS

1. Our stormwater treatment BMPs are installed belowground and covered. Why should we be concerned about mosquitoes?
Unfortunately, certain species of mosquitoes capable of transmitting disease are well-adapted for finding and breeding in belowground habitats. These mosquitoes can access belowground sources through openings as small as 1/16" (2mm) and they can fly great distances through pipes.

2. We wish to install a belowground proprietary BMP in a new housing development. If we seal the access covers against mosquitoes, how far away should we design the inlet grates to keep mosquitoes from accessing the permanent-water sump?
The absolute flight limits of mosquitoes that can breed belowground are unknown; however, recent studies found that females could fly at least 80 feet through 4" diameter pipe to reach a source of standing water and were unaffected by changes in pipe course. It is unlikely that mosquitoes can be excluded from underground sources using conveyance pipe length alone.

3. We are considering the addition of weep holes to our belowground sumps to allow them to dewater between storms so they do not produce mosquitoes. Will this work?
Weep holes are typically not a reliable choice for preventing mosquito production due to their high probability of failure due to clogging.

4. I was told that mosquitoes can not breed in water with a visible oil sheen on the water surface. Is this true or false?
With some exceptions, this is false. In most cases, the oil sheen visible on the water surface is not uniform, but is broken. Certain species of mosquitoes capable of transmitting disease can exploit these habitats by using the oil-free areas for egg laying and larval development. In addition, surface oils are broken down over time, disappearing altogether if not regularly replenished by oily runoff.

5. We are considering a provision to dewater our belowground sumps after every storm event to prevent mosquito production. Will this be effective?
It has the potential to be effective, but there are several complicating factors to consider: 1) dry-weather urban runoff frequently replenishes belowground sumps making pumping efforts futile, and 2) pumps often leave a small amount of residual water in the bottom of the sumps, and water as shallow as 1/16" or less can be sufficient to allow mosquito larvae to develop.

6. Our stormwater sumps contain very deep water. Will this prevent mosquito production?
Unlike deep water zones in ponds and wetlands where mosquitoes generally do not develop due to predators, wind, and wave action, mosquitoes are unaffected by water depth and/or surface area in belowground systems.

7. *Will flowing water prevent mosquito production?*
Flowing water will discourage females from laying eggs and can kill larvae. For example, a vortex separator receiving year-round flow from an urban stream should not produce mosquitoes due to constant movement of the entire water surface area. However, water flow through systems with square sumps (or sumps of other geometrical shapes) may not completely eliminate mosquito production due to the stagnant zones created in the corners where water movement is minimal.

8. *Will surface agitators prevent mosquito production?*
Agitators, sprinklers, or other means of disturbing the water surface will discourage females from laying eggs and can kill larvae, however, in order to be effective the *entire* surface must be disturbed.

9. *It seems that controlling mosquitoes in belowground stormwater systems without resorting to chemical treatment is rarely successful. How do we deal with this problem?* Field research has documented the difficulty in controlling mosquitoes in belowground stormwater systems without chemicals (i.e. exclusion of mosquitoes was successful in a few systems studied, but the vast majority of attempts resulted in only marginal reductions). However, for reasons that are not entirely understood, not all belowground systems produce mosquitoes equally; some are sporadic and some are year-round producers. It is strongly recommended that the local vector control agency be consulted to determine site-specific monitoring and control needs.

WETLANDS

1. Why are mosquitoes still being detected in well designed and maintained wetlands?
Mosquitoes are difficult to eliminate completely from wetlands due to the complexity of the created environment. The goal should be to minimize mosquito production by making the habitat less desirable for them.

2. Will the deep areas of stormwater ponds where no emergent vegetation can grow produce mosquitoes?
Deep, open areas of water are typically unsuitable for mosquito production due to surface disturbance caused by wind and exposure to predators. However, if the deep zones become colonized by floating vegetation such as water hyacinth or by clumps of floating filamentous algae, mosquitoes may breed in the shelters created among these plants.

3. Why is it important to keep emergent vegetation such as cattails and bulrush from getting overly dense?
Dense emergent vegetation, especially along perimeter margins, will prevent predators such as mosquitofish from accessing these areas, creating ideal habitats for mosquitoes.

4. Why is it important to eliminate floating vegetation such as water hyacinth and maintain water quality to discourage clumps of floating filamentous algae?
Not only are certain floating plants such as water hyacinth considered exotic invasive species harmful to North American ecosystems, but these plants provide excellent habitats for mosquitoes sheltered from predators.

5. How do I determine if mosquitofish are permissible for use in my area?
As a general rule, if the stormwater wetland is self contained, and does not empty into a natural waterway, mosquitofish can be used to control mosquitoes. If in doubt, it is best to consult with the local office of the Department of Fish and Game before stocking fish.

6. How often should mosquitofish be restocked to reduce mosquito numbers?
In general, mosquitofish are very hardy and will rapidly increase in numbers to form a stable population. Large game fish such as bluegill and bass may negatively impact or eradicate mosquitofish populations, as can large numbers of fishing birds; however, low temperatures are the leading cause of population failures. In cold climates, mosquitofish may need to be restocked each spring following the last frost.

7. Do we need to be concerned with mosquito production during "cold snaps" or winter periods?
Most mosquitoes important to public health can develop successfully in water ranging from approximately 45 to 100 °F, with the ability to survive short periods outside this spectrum. Short cold snaps may not be lethal to larvae if the habitat provides a buffer area, however, extended periods of cold below 45 °F will halt mosquito production.

8. Will encouraging nesting and roosting habitat for certain birds and bats around our stormwater wetland reduce the population of adult mosquitoes appreciatively?
Although certain birds (e.g. swallows, martins) and bats have been reported to consume large numbers of adult mosquitoes, these animals do not preferentially feed on mosquitoes and there is no evidence to show that they substantially reduce mosquito populations.

Vector-Borne Disease Section
California Department of Public Health
(916) 552-9730
September 2010

RB-AR32630

Photo Courtesy
Sacramento-Yolo
MVCD

Best Management Practices for Mosquito Control in California

Recommendations of the
California Department of Public Health
and the
Mosquito and Vector Control Association of California

MVC
ASSOCIATION of CALIFORNIA

July 2012

CDPH
California Department of
PublicHealth

RB-AR32631

BEST MANAGEMENT PRACTICES
FOR MOSQUITO CONTROL IN CALIFORNIA

An electronic version of this manual and the companion document “Best Management Practices for Mosquito Control on California State Properties” are available from the California West Nile virus website at http://www.westnile.ca.gov/resources.php. Please see Table 1, page 22, for a list of California mosquito control agencies or visit http://mvcac.org.

For more information, please contact:
Vector-Borne Disease Section
California Department of Public Health
vbds@cdph.ca.gov
(916) 552-9730
http://www.cdph.ca.gov
http://www.westnile.ca.gov

Purpose of this Manual

This manual provides landowners with Best Management Practices (BMPs) for mosquito control. The term BMP is used to describe actions landowners can take to reduce mosquito production from permanent water sources, reduce or eliminate mosquito production from temporary water sources, and reduce the potential for disease transmission to humans on their property.

General Recommendations

- **Implement universal BMPs**
  - Use personal protective measures
  - Eliminate unnecessary standing water

- **Identify and implement applicable mosquito control BMPs**
  - Reduce stagnation by providing water flow and manage vegetation in ponds or other water bodies.
  - Collaborate with local vector control agencies to develop and implement appropriate Integrated Pest Management (IPM) strategies that are most suitable for specific land-use type(s).

Use personal protective measures when potentially exposed to adult mosquitoes.

Eliminate unnecessary standing water, reduce stagnation by providing water flow, and manage vegetation in ponds or other water bodies.

Collaborate with local vector control agencies to coordinate activities on your property within a larger Integrated Pest Management mosquito control program.

Table of Contents

Executive Summary

The California Department of Public Health (CDPH) in collaboration with the Mosquito and Vector Control Association of California (MVCAC) developed this Best Management Practices (BMPs) plan to promote mosquito control on California properties, and enhance early detection of West Nile virus (WNV).

This plan describes mosquito control BMPs to be implemented by property owners and managers. These recommended practices, when properly implemented, can reduce mosquito populations through a variety of means including: 1) reducing or eliminating breeding sites, 2) increasing the efficacy of biological control, and 3) decrease the amount of pesticides applied while increasing the efficacy of chemical control measures. It is critical that property owners and managers communicate regularly with local vector control agencies regarding control practices on lands that are located within or near a local agency's jurisdiction. Local vector control agencies may have more specific policies regarding the implementation of BMPs and other control operations, which may include use of enforcement powers authorized by the California Health and Safety Code.

There are many different BMPs included in this document and they are intended to provide overall guidance to reduce mosquito production on properties throughout California, though not all mosquito sources and land uses will be addressed in this document. If it is deemed necessary, site-specific BMP plans may be developed in collaboration with CDPH and the respective local mosquito and vector control agency.

Effective mosquito-borne disease surveillance and mosquito control to protect public health are dependent upon factors that may fluctuate temporally and regionally. Such factors include mosquito and pathogen biology, environmental factors, land-use patterns, resource availability; strategies that incorporate BMPs are the most effective means by which mosquito control can be conducted and individualized to specific situations. Best management practices included in this plan emphasize the fundamentals of integrated pest management (IPM) which include:

1. Knowledge of mosquito species composition and corresponding mosquito behavior and habitat, for both immature and adult stages.

2. Detecting and monitoring WNV activity by testing mosquitoes, birds, sentinel chickens, horses, and humans. Identifying the mosquito species present, locations, densities, and disease potential.

3. Managing mosquito populations by source reduction, habitat modification, and biological control (e.g., introduced predators and parasites). Pesticides are used to target immature and, when indicated, adult stages of the mosquito. Mosquito control products are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment.

4. Educating the general public about reducing mosquito production and minimizing their risk of exposure to WNV.

RECOMMENDATIONS FOR PROPERTY OWNERS AND MANAGERS

- Use this plan to identify and implement appropriate Best Management Practices to control mosquitoes.
- Eliminate unnecessary standing water, reduce stagnation by providing water flow, and manage vegetation in ponds or other water bodies.
- Collaborate with local vector control agencies to develop and implement appropriate integrated pest management strategies that are most suitable for specific land-use type(s).
- Ensure individuals use personal protective measures when potentially exposed to adult mosquitoes.

Introduction

Controlling mosquitoes is critical to maintaining both a high quality of life and protecting people from mosquito-transmitted (vectored) diseases such as West Nile virus (WNV). In many parts of California, residents have voted to form local mosquito control programs or agencies. As a result, approximately half the land area and 85% of the population of California are within the boundaries of a mosquito control program. Landowners and land managers have a responsibility to minimize mosquito production on their lands and play a key role in reducing mosquito populations throughout the State, regardless whether their property is inside or outside the jurisdiction of a mosquito control program. Information about mosquito surveillance, mosquito-borne diseases, and mosquito control is available in Appendices A and B.

Best Management Practices (BMPs) are defined as actions landowners can take to reduce or eliminate mosquito production from water sources on their property in an environmentally and fiscally responsible manner, and to reduce the potential for transmission of disease from mosquitoes to humans.

Each property is unique, and the BMPs listed in this manual will apply to some properties, but not others. Landowners should implement universally applicable BMPs and after evaluating their own property, also employ the mosquito control BMPs that are applicable to their situation.

Landowner Responsibility

According to the California Health and Safety Code, landowners in California are legally responsible to abate (eliminate the source of) a public nuisance arising from their property, including mosquitoes [H&S Code Sections 2001 - 4(d); 2002; 2060 (b)]. In areas that are within the jurisdictional boundaries of a mosquito control program, landowners should work with staff to address mosquito problems, particularly in areas where irrigation is used for agricultural purposes. Landowners that are not within the jurisdictional boundary of an established mosquito control program should seek advice from the nearest mosquito control agency or health department. Landowners may also contact the California Department of Public Health (CDPH) or consult the CDPH West Nile virus website for additional information about mosquitoes and mosquito control. http://www.westnile.ca.gov/resources.php.

Mosquito control programs have substantial authority to access private property, inspect known or suspected sources of mosquitoes, abate the source of a mosquito problem, and charge the landowner for work performed and/or charge fees if a landowner is unwilling or unable to address a mosquito problem arising from their property [H&S Code sections 2060-2067, 100170, and 100175]. Applicable sections of the California Health and Safety Code are summarized in Appendix C.

Mosquito Biology

The more than 50 species of mosquitoes in California share one common life history trait: the mosquito life cycle requires standing water. Management of standing water is the key to most of the mosquito control BMPs presented in this manual and is one of the oldest and most cost effective forms of mosquito control.

Mosquito species are broadly separated into two groups according to where they lay eggs, floodwater mosquitoes and standing water mosquitoes. Adult female floodwater mosquitoes lay eggs on mud or previously submerged vegetation. The eggs may remain dormant for days, months, or even years until they are flooded, at which time larvae hatch. Standing water mosquitoes lay eggs on the water surface. The eggs float on the surface for a few hours to a few days until the larvae hatch into the water.

Floodwater mosquito larval development (breeding) sites include irrigated pastures, rice fields, seasonally flooded duck clubs and other managed wetlands, tidal wetlands, riparian corridors, and snowmelt pools. These intermittent or seasonally flooded habitats can be among the most productive sources of mosquitoes because they are often free of natural predators.

Standing water mosquito breeding sites include artificial containers, treeholes, catch basins, open ditches, retention/detention ponds, natural or constructed ponds and wetlands, stormwater management devices, and along the edges of flowing streams. Sources are found everywhere from highly urban areas to natural wetlands and often produce multiple generations of mosquitoes each season. In southern California, urban sources can produce some species of mosquitoes year round.

Landowners or land managers can identify the presence of immature mosquitoes in water on their property. Mosquito larvae breathe air from above the water surface and most hang at an angle from or lay parallel with the surface of the water while consuming small bits of organic matter. When disturbed, larvae swim down into the water column in a serpentine motion. Mosquitoes may live as larvae from a couple of days to more than a month depending on the species, water temperature, and the amount of food available.

Mosquitoes then go through a non-feeding stage called a pupa. During this stage the mosquito changes into the winged adult form. The easily identified comma-shaped pupae hang from the water surface and move down through the water column in a rolling or tumbling motion when disturbed. This life stage typically lasts about a day, with the mosquito emerging from the back of the pupal case (above the water) as a flying adult. (See Figure 1: Mosquito Life Cycle).

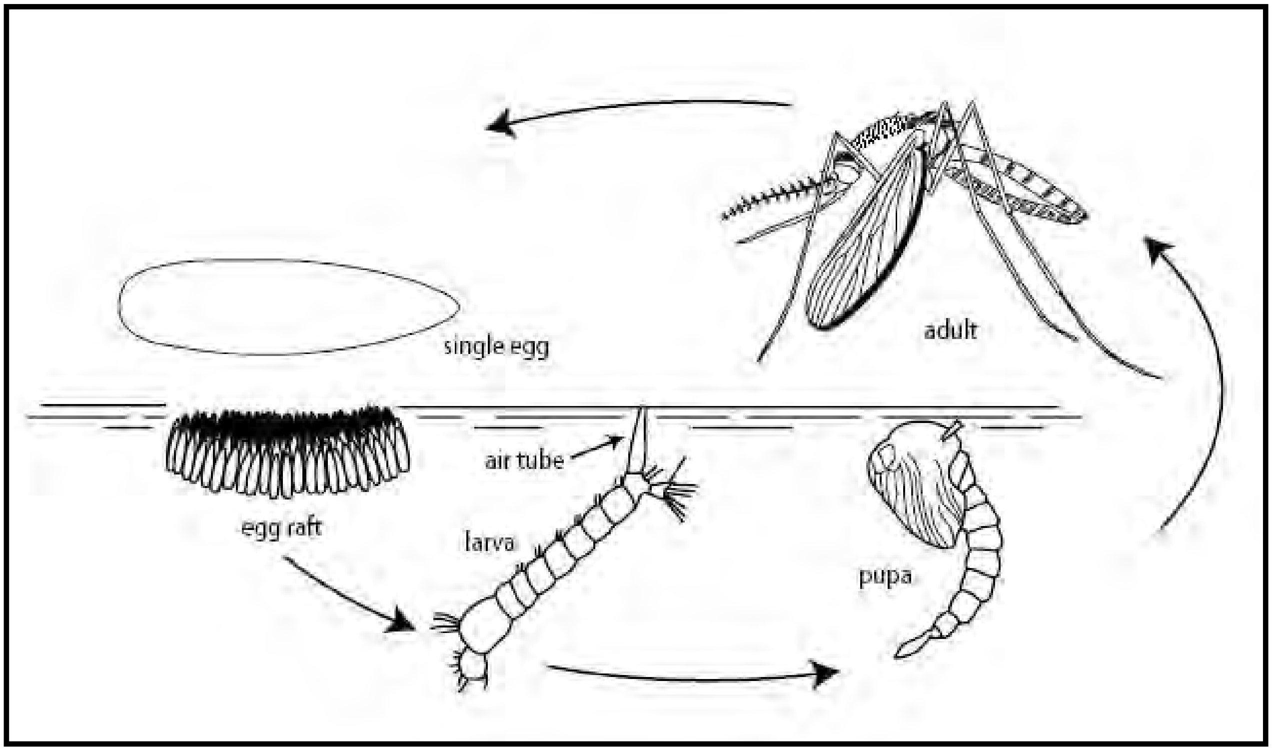

Figure 1. The life cycle of all mosquito species consists of four stages: egg, larva, pupa, and adult.

All adult mosquitoes feed on plant nectar; however blood is essential for female mosquitoes to produce eggs. To take a blood meal, the female's mouth parts pierce the skin, inject saliva, and suck blood out. It is through the injection of saliva that a mosquito causes the typical itchy bump and can infect a person or domestic animal with a disease causing organism. Depending on an individual's immune response, even a single bite can be a significant nuisance.

For more information on mosquito biology and key mosquito species found in California, please see Appendix D.

For additional information on the larval habitats of California mosquitoes, please see Appendix E.

Best Management Practices (BMPs)

Mosquito Control Best Management Practices At-A-Glance

- Eliminate artificial mosquito sources.
- Ensure man-made temporary sources of surface water drain within four days 96 hours) to prevent development of adult mosquitoes.
- Control plant growth in ponds, ditches, and shallow wetlands.
- Design facilities and water conveyance and/or holding structures to minimize the potential for producing mosquitoes.
- Use appropriate bio-rational products to control mosquito larvae.
- Use personal protective measures to prevent mosquito bites.

Each property is unique. Landowners should implement universally applicable mosquito control BMPs, and after evaluating their own property, also employ the mosquito control BMPs that are applicable to their property and circumstances. Using appropriate BMPs is an efficient and effective way to help prevent a mosquito problem.

Universally Applicable Mosquito Control BMPs

Eliminate Artificial Mosquito Breeding Sites and Harborage

- Examine outdoor areas and drain temporary and unnecessary water that may stand longer than 96 hours.
- Dispose of unwanted or unused artificial containers.
- Properly dispose of old tires.
- If possible, drill drainage holes, cover, or invert any container or object that holds standing water that must remain outdoors. Be sure to check for containers or trash in places that may be hard to see, such as under bushes or buildings.
- Clean clogged rain gutters and storm drains. Keep outdoor drains flowing freely and clear of leaves, vegetation, and other debris.
- Aerate ornamental ponds to avoid letting water stagnate.
- Change water in birdbaths, fountains, and animal troughs at least once per week.
- Ensure rain and/or irrigation water does not stand in plant containers, trash cans, boats, or other containers on commercial or residential properties.
- Regularly chlorinate swimming pools and keep pumps and filters operating. Unused or unwanted pools should be kept empty and dry, or buried.
- Maintain irrigation systems to avoid excess water use and runoff into storm drains.
- Minimize sites mosquitoes can use for refuge (harborage) by thinning branches, trimming and pruning ornamental shrubs and bushes, and keeping grass mowed short.

Use Personal Protective Measures

- Apply an EPA-registered mosquito repellent when outdoors; especially around dusk and dawn when mosquitoes are most active (see Appendix F for additional information on insect repellents).
- Wearing loose-fitting protective clothing including long sleeves and pant legs.
- Install and properly maintain fine mesh screens on windows and doors to prevent mosquito entry into homes.

Provide Mosquito Management Related Information to Property Managers

- Off-site landowners should provide property managers with basic information about mosquitoes and appropriate measures to minimize mosquito habitats.

Contact Local Mosquito Control Program

- Contact the local mosquito control program to evaluate your property for mosquito breeding sites and work cooperatively to prevent a mosquito problem on your property. A contact list for mosquito control programs is provided in Table 1.

Where local mosquito control programs do not exist, landowners may contact CDPH for assistance or consult the California West Nile virus website for additional information about mosquito control: http://www.westnile.ca.gov/resources.php

Mosquito Control BMPs for Residential and Landscaped Properties

Many residential and commercial properties have potential mosquito sources around buildings and grounds associated with excess or poorly managed irrigation, poor drainage, and miscellaneous landscape features. Mosquitoes can develop in the standing water associated with over-irrigation, irrigation breaks and/or runoff, clogged gutters, stormwater management structures, ornamental ponds, swimming pools, trash cans and flower pots, low areas or holes in turf where water collects and stands and low areas underneath pier and beam homes or buildings.

Mosquito sources can be minimized by taking precautions such as regular inspection and proper maintenance of irrigation systems and other water features, and elimination of unwanted standing water.

- Avoid over-irrigating to prevent excess pooling and runoff.
- Routinely inspect, maintain, and repair irrigation system components.

- All underground drain pipes should be laid to grade to avoid low areas that may hold water for longer than 96 hours.
- Back-fill tire ruts or other low areas that hold water for more than 96 hours.
- Improve drainage channels and grading to minimize potential for standing water.
- Keep drainage ditches free of excessive vegetation and debris to provide rapid drainage.
- Check and repair leaky outdoor faucets.
- Report any evidence of standing water to responsible maintenance personnel.
- Use waterfalls, fountains, aerators and/or mosquitofish in ponds and ornamental water features. Land owners must consult with the local mosquito control agencies or California Fish and Game regarding proper use of mosquitofish.
- Prevent mosquito breeding in rain barrels by properly screening all openings, preventing mosquito access to the stored water.
- For ponds and ornamental water features where mosquitofish cannot be used, landowners should use one of several readily available larval mosquito control products to treat water when they see immature mosquitoes.

Landowners should also review the stormwater runoff section of this manual because building rooftops, parking lots, etc. may have associated stormwater management features that produce mosquitoes.

Mosquito Control BMPs for Rural Properties

Mosquito breeding on rural properties is highly variable due to differences in location, terrain, and land use. This list is intended to provide general guidance, not site-specific requirements. BMPs that are most applicable and relevant to a specific mosquito source may be selected from the list and incorporated into the overall property management plan. Ideally, activities should be coordinated with those of a local mosquito control program.

Flood irrigation is a common practice in rural areas throughout California and always poses the potential for creating mosquito breeding sites. Mosquitoes commonly develop within irrigation infrastructure including in ditches clogged with vegetation, irrigation tail water areas and return sumps, blocked ditches or culverts, vegetated ditches; and leaking irrigation pipes, head gates, pumps, stand pipes, etc. The fields, orchards, and pastures being irrigated may also produce mosquitoes, particularly where natural undulation or poor grading create low lying areas where water collects and stands.

Recommendations for rural properties are based on “Mosquito Control Best Management Practices” produced by the Sacramento-Yolo Mosquito and Vector Control District, and from Lawler and Lanzaro (2005).

Mosquito Control BMPs for Ditches and Drains

- Construct or improve large ditches to a slope of at least 2:1 (vertical: horizontal) and a minimum 4 foot wide bottom. Consider a 3:1 slope or greater to discourage burrowing animal damage, potential seepage problems, and prevent unwanted vegetation growth.
- Keep ditches clean and well-maintained. Periodically remove accumulated sediment and vegetation. Maintain ditch grade and prevent areas of standing water.
- Design irrigation systems to use water efficiently and drain completely to avoid standing water.
- Prevent wet areas associated with seepage by repairing leaks in dams, ditches, and drains.

Mosquito Control BMPs for Irrigated Pastures and Cropland

- Grade to eliminate standing water from pastures and fields. Use Natural Resource Conservation Service (NRCS) guidelines: Laser leveling and periodic maintenance may be needed to allow proper drainage, efficient water flow, and reduce low-lying areas where standing water may accumulate.
- Reuse wastewater through return flow systems to effectively minimize mosquito production and conserve water. Eliminate and reuse excess water that may typically stagnate and collect at lower levels of irrigated fields.
- Irrigate only as frequently as is needed to maintain proper soil moisture. Check soil moisture regularly.
- Drain water as quickly as possible following irrigation. Check slopes may be used to direct water movement and drainage. Drainage ditches may be used to remove water from the lower end of the field.
- Install surface drains to remove excess water that collects at lower levels of irrigated fields.
- Inspect fields for drainage and broken checks to see whether re-leveling or reconstruction of levees is needed. Broken checks create cross-leakage that may provide habitat for mosquitoes.
- If possible, use closed conduits instead of open canals for water conveyance.
- Do not over fertilize. Over-fertilization can leach into irrigation run-off making mosquito production more likely in ditches or further downstream.
- When possible, use sprinklers or drip systems rather than flood irrigation.
- Keep animals off the pasture while the soil is soft. Mosquito habitat is created in irrigated pastures when water collects in hoof prints.

Mosquito Control BMPs for Rice Fields

Flooded rice fields can always support the development of mosquitoes. As the rice stand develops and grows denser, the production of mosquitoes tends to increase while the ability for chemical control agents to penetrate the canopy decreases. The BMPs presented in this section attempt to balance the needs of the grower with the need to control mosquitoes.

In California there is a long-standing cooperative effort among the Rice Commission, individual growers, and mosquito control agencies to manage mosquitoes on rice lands. Close cooperation between growers and vector control is particularly important with organic rice producers. With severe limits on chemical control options and greater expense for organic-compatible larvicides, organic rice growers should implement as many mosquito control BMPs as possible.

- Wherever feasible, maintain stable water levels during mosquito season by ensuring constant flow of water into ponds or rice fields to reduce water fluctuation due to evaporation, transpiration, outflow, and seepage.
- Inspect and repair levees to minimize seepage.
- Drain and fill in borrow pits and seepage areas external to the fields.
- Wherever feasible, maintain at least 4" – 6" (10-15 cm) of water in the rice field after rice seedlings have begun to stand upright. Any drainage should be coordinated with local vector control (where possible). Restocking of mosquitofish or use of alternative mosquito control measures should be instituted as soon as possible when fields are re-flooded.
- Whenever feasible, remove vegetation on the outer-most portions of field levees and checks, specifically where they interface with standing water.
- Control algae and weed growth as effectively as possible.
- Communicate frequently with your local mosquito control program regarding your crop management activities.
- Wherever feasible, maintain borrow pits (12" – 18" deep) (30-45 cm) on both sides of each check throughout rice fields to provide refuge for mosquitofish during low water periods.
- If a pyrethroid pesticide is to be applied to the fields stocked with mosquitofish, contact your local mosquito control program for advice on minimizing fish mortality.
- If a pesticide is applied, fields should be inspected for mosquitofish afterward and if needed, fish should be restocked as soon as feasible.

Mosquito Control BMPs for Dairies and Animal Holding Operations

Frequently infrastructure associated with dairies, feedlots, or other animal holding facilities can produce mosquitoes. Watering troughs and irrigated fields associated with the operation can create mosquito problems. Animal washing areas may also create mosquito problems, particularly drains and ditches, sumps, ponds, and wastewater lagoons.

The following activities can reduce mosquito production and simplify control activities around dairies and animal holding operations:

- All holding ponds should be surrounded by lanes of adequate width to allow safe passage of mosquito control equipment. This includes keeping the lanes clear of any materials or equipment (e.g. trees, calf pens, hay stacks, silage, tires, equipment, etc.).
- If fencing is used around the holding ponds, it should be placed on the outside of the lanes with gates provided for vehicle access.
- Large ponds should be divided into a series of smaller ponds that can be drained for removal of solid waste material.
- Ponds and lagoons should be narrow enough to allow solid waste removal after drying.
- All interior banks of the holding ponds should have a grade of at least 2:1.
- If possible, an effective solids separation system should be utilized such as a mechanical separator or two or more solids separator ponds. If ponds are used, they should not exceed 60' (18m) in surface width.
- Drainage lines should never by-pass the separator ponds, except those that provide for normal corral run-off and do not contain solids.
- When possible, floating debris should be removed from ponds prior to crust formation.
- If a thick crust exists (grass growing on crust), it should be left intact until the pond can be drained and the solid material removed.
- Vegetation should be controlled regularly to prevent emergent vegetation and barriers to access. This includes access lanes, interior pond embankments, and any weed growth that might become established within the pond surface.
- Dairy wastewater discharge for irrigation purposes should be managed so it does not stand for more than 4 days.
- Tire sidewalls or other objects that will not hold water should be used to hold down tarps (e.g. on silage piles). Whole tires or other water-holding objects should be replaced.

Mosquito Control BMPs for Wetlands

Wetlands are an important source of mosquito production on public and privately owned lands. Under the California Wildlife Protection Act, the term "wetlands" is defined as any lands which may be covered periodically or permanently with shallow water, which

include freshwater and saltwater marshes, open or closed brackish water marshes, swamps, mudflats, fens, and vernal pools (Fish & Game Code Section 2785). Many wetlands are protected by federal and state laws.

By definition, "natural" wetlands are not intensely managed and options for implementing mosquito control BMPs in these areas are very limited. Even in managed wetlands, not all BMPs listed below may be suitable for use in all wetlands. It is the responsibility of the landowner to become informed on timing and extent of acceptable activities in a given wetland habitat. Intermittently or seasonally flooded wetlands can produce formidable numbers of mosquitoes, whereas well-managed semi-permanent and permanent wetlands usually produce fewer mosquitoes because of their limited acreage, stable water levels, and abundance of natural predators of mosquito larvae.

Information within this section has been partially adapted from Kwasny et al. (2004). Based on the site activities and potential for mosquito production, the existing BMPs may need to be modified or supplemented to address public health risk, goals and management strategy issues, and requirements of California Department of Fish and Game (DFG), the local mosquito and vector control program, and CDPH.

Due to the delicate and sometimes protected wetlands ecosystems, landowners, biologists, managers, and staff from mosquito control programs should collaborate to control mosquitoes. Source reduction and source maintenance can be combined with the judicious use of specific larvicides to minimize mosquito production from these wetlands.

General Mosquito Control BMPs for Wetlands

- Manage vegetation routinely; activities such as annual thinning of rushes and cattails and removing excess vegetative debris enables natural predators to hunt mosquito larvae more effectively in permanent wetlands. Vegetation in shallow, temporary wetlands can be mowed when dry.
- Time flooding of seasonal wetlands to reduce overlap with peak mosquito activity.
- Flood wetlands from permanent-water sources containing mosquito predators (e.g., mosquito-eating fish or invertebrate predators) to passively introduce mosquito predators. Permanent wetlands and brood ponds can be stocked with mosquitofish or native predatory species.
- Maintain permanent or semi-permanent water within the wetland to maintain populations of larval mosquito predators. Discourage the use of broad spectrum pesticides.
- Use fertilizers conservatively and manage irrigation drainage to prevent or minimize fertilizer and/or manure flowing into wetlands. Buffers between agriculture fields and wetlands should be established.
- Comply with all Federal and State Environmental Laws and the California Health and Safety Code to prevent environmental harm while reducing or eliminating mosquito production.

Mosquito Control BMPs for Design and Maintenance of Wetlands

- Provide reasonable access on existing roads and levees to allow for monitoring, abatement, and implementation of BMPs. Make shorelines of natural, agricultural, and constructed water bodies accessible for periodic maintenance, mosquito monitoring and abatement procedures, and removal of emergent vegetation.
- Construct, improve, or maintain ditches with 2:1 slopes and a minimum 4 foot (1.2 m) width at the bottom. Consider a 3:1 slope or greater to discourage burrowing animal damage, potential seepage problems, and prevent unwanted vegetation growth.
- Construct, improve, or maintain levees to quality standards that ensure stability and prevent unwanted seepage. Ideally build levees with >3:1 slopes and > 80% compaction; consider 5:1 slope or greater in areas prone to overland flooding and levee erosion.
- Provide adequate water control structures for complete draw-down and rapid flooding.
- When possible, include independent inlets and outlets in the design of each wetland unit.
- Construct or enhance swales so they are sloped from inlet to outlet and allow maximum draw-down.
- Excavate deep channels or basins to maintain permanent water areas (>2.5 feet deep) within a portion of seasonal managed wetlands. This provides year-round habitat for mosquito predators that can inoculate seasonal wetlands when they are irrigated or flooded.

Wetland Infrastructure Maintenance Mosquito Control BMPs

- Inspect levees at least annually and repair as needed.
- Periodically inspect, repair, and clean water control structures.
    - Remove all debris, including silt and vegetation, which can impede drainage and water flow.
    - Ensure water control structures are watertight to prevent unnecessary water flow or seepage.
- Regularly remove trash, silt and vegetation from water delivery ditches to allow efficient water delivery and drainage.
    - Remove problem vegetation that inhibits water flow using herbicides or periodic dredging.
    - If possible, use closed conduits instead of open canals for water conveyance.
- Periodically test and repair pumps used for wetland flooding to maximize pump output.

Water Management Mosquito Control BMPs for Seasonal Wetlands

- Timing of flooding
  - Delay or "phase" fall flooding of wetlands as long as possible in consultation with local vector control agencies. Fall flooding is known to produce large numbers of mosquitoes and/or those in close proximity to urban areas to minimize late season mosquito production.
  - Strategically locate wetlands identified for early flooding. Wetlands that are flooded in early fall should not be close to urban areas or historically produce great numbers of mosquitoes.
  - When possible, water in managed wetlands should be drawn-down in late March or early April.
  - Use a flood-drain-flood regime to control floodwater mosquitoes; flood to trigger hatching of dormant mosquito eggs, drain water and larvae into an area where they can be easily treated, drowned in moving water, or consumed by predators, and immediately re-flood wetland. This water management regime should be used only when it does not conflict with water quality regulations.
- Speed of flooding
  - Flood wetlands as quickly as possible to reduce the potential for large numbers of mosquitoes. Coordinate flooding with neighbors and/or the water district to maximize flood-up rate.
- Water source
  - Flood wetlands with water from permanent water sources containing mosquito predators (i.e., mosquito-eating fish or invertebrate predators) to passively introduce mosquito predators. Permanent wetlands and brood ponds used as flooding sources can be stocked with mosquito-eating fish or maintained to encourage natural predator populations.
  - Maintain a separate permanent water reservoir that conveys water to seasonal wetlands that provides year-round habitat for mosquito predators that can inoculate seasonal wetlands when they are irrigated or flooded.
- Frequency and duration of irrigation
  - When possible, reduce the number and duration of irrigations to minimize standing water. The need to irrigate should be evaluated based on spring habitat conditions and plant growth. If extended duration irrigation

(generally 14-21 days) is considered for weed control (e.g., cocklebur),
    - additional measures to offset the potential for increased mosquito production may be needed.
    - Irrigate managed wetlands before soil completely dries after spring draw-down to discourage floodwater mosquitoes from laying eggs in the dry, cracked substrate.
    - Drain irrigation water into ditches or other water sources with mosquito predators instead of nearby dry fields.
    - Maintain high ground water levels by keeping channels or deep swales permanently flooded for subsurface irrigation to reduce the amount of irrigation water needed during the mosquito season.
- Communicate with your local mosquito control agency (if there is one)
    - Advise your local mosquito control agency when you intend to flood so that they can make timely applications of larvicide if necessary.
- Emergency preparedness
    - Whenever feasible, have an emergency plan that provides for immediate drainage into acceptable areas if a mosquito-borne disease related public health emergency occurs.

Vegetation Management Mosquito Control BMPs

- Control floating vegetation conducive to mosquito production (i.e., water hyacinth, water primrose, parrot feather, duckweed, and filamentous algae mats).
- Perform routine maintenance to reduce problematic emergent plant densities to facilitate the ability of mosquito-eating fish to move through vegetated areas and allow good penetration of chemical control agents.
- Manage vegetation based on local land management objectives and associated habitat uses to minimize mosquito production. Methods of vegetation control for managed wetlands include mowing, burning, disking, and grazing.
- Manage the spread and density of invasive, non-native emergent wetland vegetation to increase native plant diversity, increase the mobility of larval mosquito predators, and allow for more efficient penetration of chemical control agents.

Additional Water Management BMPs for Permanent Wetlands

- Maintain stable water levels in wetlands that are flooded during summer and early spring to prevent intermittent flooding of shoreline areas favorable to mosquito production. Water level fluctuation can be minimized by continuing a constant flow of water into the wetland.
- Circulate water to avoid stagnation (e.g., provide a constant influx of water equal to the net loss or discharge of water).
- Maintain water depths as deep as possible (18” – 24” [45-60 cm] or more) during the initial flood-up to minimize shallow habitats preferred by mosquito larvae. Shallow water levels can be maintained outside of the mosquito breeding season.

Additional Mosquito Control BMPs for Saltwater Marsh

- Improving water flow through the wetland system minimizes stagnant water and facilitates movement of fish and other natural predators. For example, mosquitoes in coastal tidal wetlands can be managed by constructing and maintaining ditches that drain off the water when the tide falls.

Mosquito Control BMPs for Stormwater Management and Associated Infrastructure

Federal and state environmental regulations require mitigation of the harmful effects of runoff water from storms, irrigation or other sources prior to entering natural waterways from point and non-point sources. Mitigation may include water capture, slowing flow velocity, reducing volume, and removal of pollutants. The term “stormwater” is used as a generic term for runoff water, regardless of source.

Stormwater infrastructure typically includes conveyance systems (e.g. drain inlets, catch basins, pipes, and channels), storage and infiltration systems (e.g. flood control basins, percolation basins), and more recently, structural treatment devices designed and installed specifically to remove suspended and dissolved pollutants from runoff (e.g., vegetated swales, dry detention basins, ponds and constructed wetlands, media filtration devices, and trash capturing devices). The size and variability of stormwater infrastructure, inconsistent quantity and timing of water flows, and propensity to carry and accumulate sediment, trash, and debris, makes these systems highly conducive to holding areas of standing water ideal for production of mosquitoes. Identification of the potential mosquito sources (often belowground) found within stormwater infrastructure is often more difficult than the solutions needed to minimize mosquitoes. Some of the information within this section has been adapted from Metzger (2004).

General Stormwater Management Mosquito Control BMPs

- Manage sprinkler and irrigation systems to minimize runoff entering stormwater infrastructure.
- Avoid intentionally running water into stormwater systems by not washing sidewalks and driveways, washing cars on streets or driveways, etc.
- Inspect facilities weekly during warm weather for the presence of standing water or immature mosquitoes.
- Remove emergent vegetation and debris from gutters and channels that accumulate water.
- Consider mosquito production during the design, construction, and maintenance of stormwater infrastructure.
- Design and maintain systems to fully discharge captured water in 96 hours or less.
- Include access for maintenance in system design.

- Design systems with permanent water sources such as wetlands, ponds, sumps, and basins to minimize mosquito habitat and plan for routine larval mosquito inspection and control activities with the assistance of a local mosquito control program.

Stormwater Conveyance

- Provide proper grades along conveyance structures to ensure that water flows freely.
- Inspect on a routine basis to ensure the grade remains as designed and to remove accumulations of sediment, trash, and debris.
- Keep inlets free of accumulations of sediment, trash, and debris to prevent standing water from backing up on roadways and gutters.
- Design outfalls to prevent scour depressions that can hold standing water.

Stormwater Storage and Infiltration Systems (Aboveground)

- Design structures so that they do not hold standing water for more than 96 hours to prevent mosquito development. Features to prevent or reduce the possibility of clogged discharge orifices (e.g., debris screens) should be incorporated into the design. The use of weep holes is not recommended due to rapid clogging.
- Provide a uniform grade between the inlets and outlets to ensure that all water is discharged in 96 hours or less. Routine inspection and maintenance are crucial to ensuring the grade remains as designed.
- Avoid the use of electric pumps. They are subject to failure and often require permanent-water sumps. Structures that do not require pumping should be favored over those that have this requirement.
- Avoid the use of loose rock rip-rap that may hold standing water.
- Design distribution pumping and containment basins with adequate slopes to drain fully. The design slope should take into consideration buildup of sediment between maintenance periods.

Stormwater Structures with Permanent-Water Sumps or Basins (Belowground)

- Where possible, seal access holes (e.g., pickholes in manhole covers) to belowground structures designed to retain water in sumps or basins to minimize

entry of adult mosquitoes. If using covers or screens, maximum allowable gaps of 1/16 inch (2 mm) will exclude entry of adult mosquitoes. Inspect barriers frequently and replace when needed.

- If the sump or basin is completely sealed against mosquitoes, with the exception of the inlet and outlet, the inlet and outlet should be completely submerged to reduce the available surface area of water for mosquitoes to lay eggs (female mosquitoes can fly through pipes).
- Where possible, design belowground sumps with the equipment necessary to allow for easy dewatering of the unit.
- Contact the local mosquito control program for advice with problem systems.

Stormwater Treatment Ponds and Constructed Treatment Wetlands

- Whenever possible, stock stormwater ponds and constructed wetlands with mosquito-eating fish available from local mosquito control programs.
- Design and maintain accessible shorelines to allow for periodic maintenance and/or control of emergent and shoreline vegetation, and routine monitoring and control of mosquitoes. Emergent plant density should be routinely managed so mosquito predators can move throughout the vegetated areas and are not excluded from pond edges.
- Whenever possible, design and maintain deep zones in excess of four feet (1.2 m) to limit the spread of invasive emergent vegetation such as cattails. The edges below the water surface should be as steep as practicable and uniform to discourage dense plant growth that may provide immature mosquitoes with refuge from predators and increased nutrient availability.
- Use concrete or liners in shallow areas to discourage plant growth where vegetation is not necessary.
- Whenever possible, provide a means for easy dewatering if needed.
- Manage the spread and density of floating and submerged vegetation that encourages mosquito production (i.e., water hyacinth, water primrose, parrot's feather, duckweed, and filamentous algal mats).
- If possible, compartmentalize managed treatment wetlands so the maximum width of ponds does not exceed two times the effective distance (40 feet [12 m]) of land-based application technologies for mosquito control agents.

General Access Requirements for Stormwater Treatment Structures

- All structures should be easily and safely accessible, without the need for special requirements (e.g., Occupational Safety and Health Administration - OSHA - requirements for "confined space"). This will allow for monitoring and, if necessary, abatement of mosquitoes.
- If utilizing covers, the design should include spring-loaded or lightweight access hatches that can be easily opened.
- Provide all-weather road access (with provisions for turning a full-size work vehicle) along at least one side of large aboveground structures that are less

than seven meters wide, or both sides if shore-to-shore distance is greater than seven meters. *Note:* Mosquito larvicides are applied with hand held equipment at small sites and with backpack or truck mounted high-pressure sprayers at large sites. The effective swath width of most backpack or truck-mounted larvicide sprayers is approximately 20-25 feet (6-7meters) on a windless day.

- Build access roads as close to the shoreline as possible to allow for maintenance and vector control crews to periodically maintain, control and remove emergent vegetation and conduct routine mosquito monitoring and abatement. Remove vegetation and/or other obstacles between the access road and the structure that might obstruct the path of larvicides to the water.
- Control vegetation (by removal, thinning, or mowing) periodically to prevent barriers to access.

Mosquito Control BMPs for Right of Ways and Easements

Right of ways and easements for a variety of infrastructure exist throughout California. Roadways, power lines, pipelines, canals, bike paths, utility access, railroads, etc. have lands associated with them that may produce mosquitoes. It is the responsibility of the company or individual associated with the infrastructure to prevent a public nuisance arising from the property, including a mosquito problem. The lands are as varied as the terrain in California, but the mosquito breeding sites found on these properties will be similar to those found in other sections of this manual.

Inspection of Property and Identification of Mosquito Sources

- Inspect property for standing water or evidence of standing water that may become mosquito sources.

Review and Implement Mosquito Control BMPs as Appropriate

Some rights of way and easements are very long and may have multiple types of mosquito breeding sites that fall within every category listed below, others will have none. After inspecting the property, implement mosquito control BMPs found in the sections below.

- If the property is in an urban area and is managed as commercial property, please refer to the following section:
  - *Residential and landscaped properties*, see page 5.

- If the property is associated with an irrigation canal or similar rural water conveyance, please refer to the following sections:
  - *Rural properties*, see page 6.
  - *Wetlands*, see page 9.

- If the property is associated with a variety of habitats like a railroad or pipeline

right of way, please refer to the following sections:
- o *Rural* properties, see page 6.
- o *Wetlands*, see page 9.

- If the property is associated with a roadway or other structure that would require management of runoff water, please refer to the following section:
  - o *Stormwater management* (associated BMPs), see page 14.

In many instances, right of ways and easements will simply fall to the local mosquito and vector control program or go completely unmanaged because they are very large and it is not possible to determine the responsible party.

Mosquito Control BMPs for Wastewater Treatment Facilities

Wastewater treatment facilities are designed to collect, treat, and release nutrient rich highly organic water. These facilities implement practices appropriate to removing contaminants from wastewater, but which may be in direct conflict with BMPs intended to prevent development of mosquito larvae. Further, managers are under intense pressure to meet water quality standards in effluent water and are frequently concerned that mosquito control BMPs will jeopardize compliance with effluent standards.

Wastewater facilities often include features that can produce mosquitoes. Examples include 1) a series of treatment or evaporation ponds, 2) the use of tules or other emergent vegetation to remove contaminants, 3) aerated and non-aerated ponds with emergent vegetation around the edges or throughout, 4) cracks and openings in crusted waste matter on the surface of treatment ponds, and 5) abandoned or unused pond basins that frequently hold shallow water. Certain activities may also create or enhance mosquito habitat including 1) allowing evaporation of wastewater from treatment ponds for maintenance or as a standard treatment method, 2) release of wastewater into marshes or floodplains for evaporation or infiltration, and 3) distribution of sludge onto irrigated agricultural lands.

For mosquito control around buildings and grounds, consult the *residential and landscape* section of this document. Similarly, many BMPs included in the *wetlands and dairy* sections of this document are pertinent to wastewater management facilities, particularly those sections related to construction and management of treatment ponds and wetlands and the use and distribution of wastewater or sludge onto agricultural lands. For mosquito control related to wastewater collection, conveyance, and distribution consult the *stormwater management* section of this manual.

- Monitor all treatment ponds for mosquito larvae – particularly in areas of emergent vegetation.
- Remove emergent vegetation from edges of aerated ponds.
- Immediately incorporate sludge into soil through plowing or disking.
- Insure all water distributed onto evaporation ponds dries completely in less than 96 hours.

- Check abandoned ponds or tanks weekly to ensure they are completely dry.
- Use mechanical agitation to prevent the formation of any crust on treatment ponds or tanks.
- Work closely with a local vector control program. If there is no local vector control agency, consult the closest vector control program, the local public health officer, or CDPH to prevent or abate a mosquito problem from the facility.

Mosquito Control BMPs for Wildlands – Undeveloped Areas

California encompasses about 100 million acres (40 million hectares) of land. Approximately 75 million acres (30 million hectares) are classified as wildlands, which include all undeveloped and non-cultivated property in the state. In many cases the properties are remote and mosquito control is neither feasible nor warranted. However, if you own a property that is near a town or are aware of a mosquito problem at the property, you may wish to contact the closest vector control program or CDPH to determine what if anything can be done to alleviate the problem.

Mosquito Control BMPs that May be Applicable to Wildlands

- Conduct routine mosquito surveillance by looking for immature mosquitoes in the water. Apply EPA-registered products (typically containing Bti, Bs, or methoprene) to control mosquito larvae.
- Evaluate reports of mosquito annoyance from visitors or the public, and if possible work with a local mosquito control program to be notified if there is an adult mosquito problem on or near your property.
- After a rainfall, pay particular attention to temporary water sources and ponds that rise. Treat sources with mosquito control products if needed.
- Stock ornamental ponds and other water features with mosquitofish available from local mosquito control programs. However, their use is restricted in natural bodies of water or in water features that drain into natural bodies of water. Land managers must consult with the local mosquito control agencies regarding proper use of mosquitofish or other available biological control agents.
  Work closely with a local mosquito control program to accurately identify, map, and monitor areas that may produce mosquitoes; and tailor control measures for each site, contingent on the species of mosquitoes that are present.
- Implement personal protective measures
  - Provide visitors and guests with information regarding the risk of mosquito-borne disease transmission and personal protective measures.
  - Install and maintain tight-fitting window and door screens on buildings.
  - If possible, minimize outdoor activities at dawn and dusk when mosquitoes are the most active.
  - Wear protective clothing such as long-sleeved shirts and long pants when going into mosquito-infested areas.
  - Use mosquito repellent when necessary, carefully following the directions on the label.

Evaluation of the Efficacy of BMPs

Landowners can easily evaluate the efficacy of the mosquito control BMPs they have implemented. You can do a simple evaluation as follows:

- Immature mosquitoes: Look for immature mosquitoes in standing water on your property – if the number is decreasing noticeably or immature mosquitoes can not be found, the BMPs you have implemented are working.
- Adult mosquitoes: Simply be aware of the level of mosquito annoyance you experience and ask guests or employees about their experience with regard to mosquitoes. People become accustomed to a certain level of mosquito activity and commonly notice increases or decreases in that level. If the annoyance level is increasing, you have more work to do; if the number is decreasing or mosquitoes are not noticeable – good job! The BMPs you have implemented are working.

The best way to evaluate the effectiveness of BMPs is through a comprehensive surveillance program of larval dipping and adult mosquito trapping, including species identification. Some important strengths of local mosquito control programs are their ability to evaluate treatment options, estimate treatment costs, recommend and implement those BMPs most appropriate for a property. Local mosquito abatement programs also are familiar with indigenous mosquito species and therefore know the type of habitat those mosquitoes come from, often monitor adult populations, and can identify if there is a mosquito problem in a particular area. Landowners can make substantial progress in solving mosquito problems on their own, but if possible, they should work closely with a local mosquito control program to implement and evaluate mosquito control BMPs.

CDPH disclaims any warranty or warranty for fitness of use for a particular purpose, expressed or implied, with respect to this data.CDPH disclaims any responsibility for the accuracy or completeness of this data. The mapped data does not constitute a legal survey.

Table 1: Mosquito Control Agencies in California

COUNTY	AGENCY	WEBSITE or ADDRESS	TELEPHONE
ALAMEDA	ALAMEDA CO MAD	http://www.mosquitoes.org	(510) 783-7744
ALAMEDA	ALAMEDA CO VCSD	http://www.acvcsd.org	(510) 567-6800
AMADOR	AMADOR CO ENV HEALTH DEPT	http://www.co.amador.ca.us/index.aspx?page=385	(209) 223-6487
BUTTE	BUTTE CO MVCD	http://www.bcmvcd.com/	(530) 533-6038
BUTTE	DURHAM MAD	PO Box 386, Durham, CA 95938	(530) 345-2875
BUTTE	OROVILLE MAD	PO Box 940, Oroville, CA 95965	(530) 534-8383
CALAVERAS	SADDLE CREEK CSD	http://www.saddlecreekcsd.org	(209) 785-0100
COLUSA	COLUSA MAD	PO Box 208, Colusa, CA 95932	(530) 458-4966
CONTRA COSTA	CONTRA COSTA MVCD	http://www.contracostamosquito.com/	(925) 771-6100
EL DORADO	CO OF EL DORADO CO ENV. MGT. DEPT.	http://www.edcgov.us/VectorControl/	(530) 573-3450
FRESNO	COALINGA-HURON MAD	P. O. Box 278, Coalinga, CA 93210	(559) 935-1907
FRESNO	FRESNO MVCD	http://www.fresnomosquito.org	(559) 268-6565
FRESNO	FRESNO WESTSIDE MAD	PO Box 125, Firebaugh, CA 93622	(559) 659-2437
FRESNO / KINGS	CONSOLIDATED MAD	http://www.mosquitobuzz.net	(559) 896-1085
GLENN	GLENN CO MVCD	165 County Rd. G, Willows, CA 95988	(530) 934-4025
IMPERIAL	IMPERIAL CO VCP	http://www.icphd.org/sub.php?menu_id=307	(760) 336-8530
INYO	INYO COUNTY DEPT OF AG OWENS VALLEY MAP	http://www.inyomonoagriculture.com/ovmap.html	(760) 873-7853
KERN	DELANO MAD	PO Box 220, Delano, CA 93216	(661) 725-3114
KERN	KERN MVCD	4705 Allen Road, Bakersfield, CA 93314	(661) 589-2744
KERN	SOUTH FORK MAD	P. O. Box 750, Kernville, CA 93238	(760) 376-4268

COUNTY	AGENCY	WEBSITE or ADDRESS	TELEPHONE
KERN	WEST SIDE MVCD	PO Box 205, Taft, CA 93268	(661) 763-3510
KINGS	KINGS MAD	PO Box 907, Hanford, CA 93232	(559) 584-3326
LAKE	LAKE CO VCD	http://www.lcvcd.org	(707) 263-4770
LOS ANGELES	ANTELOPE VALLEY MVCD	http://www.avmosquito.org	(661) 942-2917
LOS ANGELES	COMPTON CREEK MAD	1224 S. Santa Fe Avenue, Compton, CA 90221	(310) 933-5321
LOS ANGELES	GREATER LOS ANGELES CO VCD	http://glacvcd.org	(562) 758-6501
LOS ANGELES	LONG BEACH CITY DHHS	http://www.longbeach.gov/health/eh/vector/	(562) 570-4170
LOS ANGELES	LOS ANGELES CO DHS, VMP	http://www.lapublichealth.org/eh/SSE/Vector_Management/vecman.htm	(626) 430-5450
LOS ANGELES	LOS ANGELES CO WEST VCD	http://www.lawestvector.org	(310) 915-7370
LOS ANGELES	PASADENA CITY HD	http://www.cityofpasadena.net/publichealth/environmental_health_sevices/	(626) 744-6062
LOS ANGELES	SAN GABRIEL VALLEY MVCD	http://www.sgvmosquito.org	(626) 814-9466
MADERA	MADERA CO MVCD	http://maderamosq.org/	(559) 674-6729
MARIN / SONOMA	MARIN / SONOMA MVCD	http://www.msmosquito.com/	(707) 285-2204
MERCED	MERCED CO MAD	http://mcmosquito.org/	(209) 722-1527
MODOC	CA PINES CSD	HCR Box 43002, Alturas, CA 96101	(530) 233-2766
MODOC	CITY OF ALTURAS	http://www.cityofalturas.org	(530) 223-2377
MONO	JUNE LAKE PUD	P. O. Box 99, June Lake, CA 93529	(760) 648-7778
MONO	MAMMOTH LAKES MAD	PO Box 1943, Mammoth Lakes, CA 93546	(760) 924-8240
MONTEREY	NORTHERN SALINAS VALLEY MAD	http://www.montereycountymosquito.com/Site/Welcome.html	(831) 422-6438
NAPA	NAPA CO MAD	http://www.napamosquito.org	(707) 553-9610
NEVADA	NEVADA COUNTY COMMUNITY DEVELOPMENT AGENCY	http://www.mynevadacounty.com/nc/cda/eh/Pages/West-Nile-virus-Information.aspx	(530) 265-1500
ORANGE	ORANGE CO VCD	http://www.ocvcd.org	(714) 740-4150

COUNTY	AGENCY	WEBSITE or ADDRESS	TELEPHONE
PLACER	PLACER MVCD	http://www.placermosquito.org	(916) 380-5444
RIVERSIDE	BLYTHE CITY PWD	http://www.cityofblythe.ca.gov/index.aspx?NID=108	(760) 922-6611
RIVERSIDE	COACHELLA VALLEY MVCD	http://www.cvmvcd.org	(760) 342-8287
RIVERSIDE	NORTHWEST MVCD	http://www.northwestmosquitovector.org/Northwest_MVCD/Home.html	(951) 340-9792
RIVERSIDE	RIVERSIDE CITY PWD	http://www.riversideca.gov/pworks/vector-control.asp	(909) 351-6127
RIVERSIDE	RIVERSIDE CO DEH, VCP	http://www.rivcoeh.org/opencms/rivcoeh/ProgServices/Food_Program/Vector.html	(909) 358-5172
SACRAMENTO / YOLO	SACRAMENTO-YOLO MVCD	http://www.fightthebite.net	(916) 685-1022
SAN BERNARDINO	SAN BERNARDINO CO VCP	http://www.sbcounty.gov/ehlus/Depts/VectorControl/mosquito_and_vector_control_home.aspx	(909) 387-4688
SAN BERNARDINO	WEST VALLEY MVCD	http://www.wvmosquito.org	(909) 635-0307
SAN DIEGO	SAN DIEGO CO DEH, VSC	http://www.sdcounty.ca.gov/deh/pests/vector_disease.html	(858) 694-2888
SAN FRANCISCO	SAN FRANCISCO DPH	http://www.sfdph.org/dph/EH/Vector/default.asp	(415) 252-3988
SAN JOAQUIN	SAN JOAQUIN CO MVCD	http://sjmosquito.org	(209) 982-4675
SAN MATEO	SAN MATEO CO MVCD	http://www.smcmad.org	(650) 344-8592
SAN MATEO	SOUTH BAYSIDE SYSTEM AUTHORITY	http://www.sbsa.org/	(650) 594-8411
SANTA BARBARA	SANTA BARBARA COASTAL VCD	http://www.sbcvcd.org	(805) 969-5050
SANTA CLARA	SANTA CLARA CO VCD	http://www.sccgov.org/portal/site/vector	(408) 918-4770
SANTA CRUZ	SANTA CRUZ CO MVCD	http://www.agdept.com/mvc.html	(831) 454-2590
SHASTA	BURNEY BASIN MAD	PO Box 1049, Burney, CA 96013	(530) 335-2133
SHASTA	PINE GROVE MAD	PO Box 328, MacArthur, CA 96056	(530) 336-5740
SHASTA	SHASTA MVCD	http://www.shastamosquito.org/	(530) 365-3768
SOLANO	SOLANO CO MAD	http://www.solanomosquito.com	(707) 437-1116

COUNTY	AGENCY	WEBSITE or ADDRESS	TELEPHONE
STANISLAUS	EAST SIDE MAD	http://www.eastsidemosquito.com	(209) 522-4098
STANISLAUS	TURLOCK MAD	http://mosquitoturlock.com	(209) 634-8331
STATEWIDE	CALIFORNIA DEPARTMENT OF PUBLIC HEALTH VECTOR-BORNE DISEASE SECTION	http://www.westnile.ca.gov/	(916) 552-9730
SUTTER / YUBA	SUTTER-YUBA MVCD	http://www.sutter-yubamvcd.org/	(530) 674-5456
TEHEMA	TEHAMA CO MVCD	PO Box 1005, Red Bluff, CA 96080	(530) 527-1676
TULARE	DELTA VCD	http://www.deltavcd.com	(559) 732-8606
TULARE	TULARE MAD	6575 Dale Fry Road, Tulare, CA 93274	(559) 686-6628
VENTURA	MOORPARK CITY VCD	http://ci.moorpark.ca.us/cgi-bin/htmlos.exe/03565.1.14766059450000012944	(805) 517-6248
VENTURA	VENTURA CO EHD	http://www.ventura.org/rma/envhealth/technical-services/vector/index.html	(805) 654-2818

Appendix A

Mosquito Control and Arbovirus Surveillance

Mosquito Control Practices

Mosquito control agencies and private landowners in California work cooperatively to implement an integrated pest management (IPM) approach to mosquito control. Source reduction (eliminating the places where mosquito larvae hatch and develop) is the most effective way of preventing adult mosquitoes; however, it may be possible to eliminate mosquito production from a source through other modifications of habitat and/or water management. Biological control agents, including native or introduced predators, are often utilized in combination with water management practices. Pesticides are an important part of an IPM program and mosquito specific larval control pesticides are often used to supplement other source reduction activities. When source reduction and larval control have not adequately reduced the mosquito population, the application of pesticides to control adult mosquitoes may be necessary. Personnel working for vector control agencies who apply pesticides in California are certified by California Department of Public Health (CDPH) after demonstrating the knowledge necessary to control mosquitoes safely and effectively using IPM techniques.

Larval Control

Larval control is the foundation of most mosquito control programs in California. Whereas adult mosquitoes are widespread in the environment, larvae must have water to develop; control efforts therefore can be focused on aquatic habitats. Minimizing the number of adults that emerge is crucial to reducing the incidence and risk of disease. The three key components of larval control are environmental management, biological control, and chemical control.

Environmental Management

Manipulating or eliminating potential mosquito breeding sources can provide dramatic reductions in mosquito populations. There are three levels of environmental management.

1. Source elimination: This approach completely eliminates potential habitats for mosquitoes. This strategy is generally limited to artificial habitats created by urbanization. Examples of source elimination include emptying or turning over containers holding water, filling in holes containing water with sand or gravel, cleaning drainage ditches of debris, and covering or inverting structures and vessels that could hold water.

2. Source reduction: This strategy aims to alter and sometimes eliminate available habitat for larvae which substantially reduces mosquito breeding and the need for

repeatedly applying pesticides. Unlike source elimination, standing water may exist but the total amount of water, or the time the water is left standing, is greatly reduced. Source reduction may require some maintenance (see below) to prevent further mosquito breeding. Examples of source reduction include limiting the growth of emergent vegetation in wetlands and ponds, constructing drainage ditches to remove water from areas prone to flooding, and clearing stormwater channels of silt and debris. Routine larval monitoring can indicate whether these efforts are effective or need further action.

3. Source maintenance: When eliminating or significantly altering mosquito breeding sources is prohibited and/or inappropriate, reducing the number of sheltered, predator-free habitats while having minimal impact on the surrounding environment can make an area unsuitable for mosquitoes. Source maintenance can include water management, vegetation management, wetland infrastructure maintenance, and wetland restoration. Strategic, focused plans must be developed for each site.

Biological Control

Biological control uses predators, parasites, or pathogens to reduce populations of mosquito larvae and is often combined with environmental management to enhance results. The mosquitofish (*Gambusia affinis)* has been used to control mosquitoes in California since 1921 and is the most widely used biological control agent in the world. These small fish are effective against mosquito larvae because they grow and reproduce rapidly, feed at the water surface where mosquito larvae are found, and tolerate a wide range of temperature and water quality.

Other fish are occasionally used with mixed success. Fish are most effective in permanent ponds and wetlands, but are also used in rice fields and stormwater canals with permanent water. Many local mosquito control agencies propagate mosquito-eating fish.

Although many other animals have been tested for mosquito control, and in natural wetlands predation is an important factor in reducing mosquito production, biological control by the intentional addition of mosquito predators other than mosquitofish is largely experimental rather than operational.

Chemical Control

Pesticides that control mosquito larvae are called larvicides. Four types of larvicides (bio-rational, surface films, growth regulators, and chemical products) encompassing seven active ingredients are registered for use in California. Larvicides are applied by hand, from hand-held or vehicle-mounted engine-driven blowers, or by aircraft, depending on the product, the formulation, and the target habitat. Applicators of any of these products must be certified by the CDPH or an appropriate regulatory authority.

1. Bio-rational products

Bio-rational products exploit insecticidal toxins found in certain naturally occurring bacteria. These bacteria are cultured in mass and packaged in various formulations. The bacteria must be ingested by mosquito larvae so the toxin is released. Therefore bio-rational products are only effective against larvae since pupae do not feed. The bacteria used to control mosquito larvae have no significant effects on non-target organisms when applied for mosquito control in accordance with product labels.

Two products that are used against mosquito larvae singly or in combination are *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (Bs). Manufactured Bti contains dead bacteria and remains effective in the water for 24 to 48 hours; some slow release formulations provide longer control. In contrast, Bs products contain spores that in favorable conditions remain effective for more than 30 days. Both products are safe enough to be used in water that is consumed by humans.

Another bio-rational product available for mosquito control is derived from the soil bacterium *Saccharopolyspora spinosa,* which produces natural metabolites called spinosyns during fermentation. These metabolites are lethal to mosquito larvae when ingested or by contact. The most active metabolites are formulated into a product called “spinosad”. The product affects the central nervous system of the mosquito causing uncontrolled nervous impulses, ultimately killing the larvae.

2. Surface agents

Mosquito larvae and pupae breathe through tubes called “siphons” that extend above the water surface. Surface agents such as highly refined mineral oils or monomolecular films (alcohol derivatives) can spread across the surface of the water to prevent mosquitoes from breathing. Depending on the product, the film may remain on the water’s surface from a few hours to a few days. Surface films are the only available products that are effective against very late stage larvae and pupae.

3. Insect growth regulators

Insect growth regulators (IGRs) disrupt the physiological development of larvae thus preventing adults from emerging. The two products currently used for controlling mosquito larvae are methoprene and diflubenzuron.

The effective life of these products varies with the formulation. Methoprene can be applied in granular, liquid, pellet, or briquette formulation. Methoprene has minimal non-target effects and no use restrictions. Diflubenzuron is rarely used in California because it may affect growth of non-target aquatic invertebrates. IGRs for mosquito control can be used in sources of water that are consumed by humans.

4. Chemical larvicides

Chemical pesticides are rarely used to control mosquito larvae. Organophosphate larvicides are used infrequently because of their potential non-target effects and label restrictions. The organophosphate pesticides temephos and malathion are registered for use as larvicides in California. However, malathion is currently used exclusively for adult mosquito control in the state. Temephos can be safely and effectively used to treat temporary water or highly polluted water where there are few non-target organisms and/or livestock are not allowed access. The efficacy of temephos may be up to 30 days depending on the formulation.

Adult Control

IPM mosquito control programs initiate adult mosquito control when action levels or thresholds are reached or exceeded. Thresholds are based on local sampling of the adult mosquito population and/or when the risk of mosquito-borne disease increases above levels established by a local agency, often following guidelines established in the California Mosquito-borne Virus Surveillance and Response Plan. Thresholds are an integral component of mosquito control because they provide a range of predetermined actions based on quantified data. Thresholds also establish expectations and boundaries for responses that ensure appropriate mosquito control activities are implemented at the appropriate time. The threshold for adult mosquito control depends on several factors including:

- How local citizens tolerate nuisance mosquitoes by evaluating public service requests.
- Overall mosquito abundance.
- Presence of mosquito-borne disease in the region.
- Abundance of mosquito species that are vectors of disease.
- Local acceptance of adult mosquito control activities.
- Climate data.

Adult mosquitoes can only be controlled with adulticides. Many mosquito control programs in California include adulticiding as an integral component of their IPM program. Adulticiding falls into two categories – barrier applications and ultra-low volume (ULV) applications. Barrier applications target resting mosquitoes by applying pesticides to vegetation and structures. Barrier applications typically cover relatively small areas and are applied to alleviate specific problems rather than an area wide adult mosquito problem.

ULV applications are used to control adult mosquitoes over large areas. An “ultra-low volume” (typically less than 2 oz / acre [140 ml / ha] total volume) of tiny oil or water droplets carrying an insecticide are emitted from specialized equipment mounted to trucks or aircraft. The droplets kill adult mosquitoes on contact. ULV applications are made after sunset or before sunrise to coincide with the time that mosquitoes are most active, when non-target insects are least active, and when temperature inversions are most likely to occur. These applications are employed when mosquito populations must be reduced immediately to halt disease transmission. Multiple applications in a particular area may be utilized when the objective is to kill a high enough proportion of older adult mosquitoes to break a disease transmission cycle.

Adverse effects from ULV applications are rare; however, people with health problems should be aware when and where the applications are being conducted. This information can be obtained by contacting the local vector control agency. Chemicals currently registered for ULV applications against mosquitoes in California (as of June, 2010) include organophosphates (e.g., malathion and naled), pyrethrins, (e.g., pyrethrum) and pyrethroids (e.g., resmethrin, sumithrin, permethrin, and etofenprox). With the exception of the active ingredient etofenprox, formulations of both pyrethrins and pyrethroids include the synergist piperonyl butoxide (PBO), which increases their activity against mosquitoes.

1. Organophosphates

   Malathion and naled are neurotoxins that act by blocking the enzyme cholinesterase, inhibiting neurologic transmission. Malathion or naled may be used as rotational products with pyrethroid insecticides to help prevent development of pesticide resistance.

2. Pyrethrins

   Pyrethrins and pyrethroids are neurotoxins that act by causing uncontrolled firing of neurons. Pyrethrum is a natural insecticide derived from chrysanthemum flowers. Adult mosquitoes are rapidly paralyzed and killed on contact. Pyrethrins are degraded rapidly by sunlight and chemical processes. Residual pyrethrins from ULV applications typically remain less than one day on plants, soil, and water.

3. Pyrethroids

   Pyrethroids are manufactured pyrethrins. They have very low toxicity to birds and mammals but are toxic to fish if misapplied.

Compounds currently approved for larval and adult mosquito control in California are listed in Appendix B.

Mosquito Surveillance

Mosquito and Mosquito-Borne Disease Monitoring

Monitoring mosquito populations and mosquito-borne disease levels provides the necessary data to make informed management decisions.

The application of any pesticide to control mosquitoes in an IPM program is done after establishing the need to do so through mosquito population monitoring (surveillance).

Larval mosquito surveillance is the process of identifying and checking likely larval developmental sites for immature mosquitoes and treating the water to kill the mosquitoes prior to them emerging as flying, biting adults.

Adult mosquito surveillance is accomplished through a network of traps and through mosquito annoyance reports. Adult mosquito surveillance is a critical component of determining where mosquitoes are coming from, the potential for disease transmission in an area, and the need for adult mosquito control. Districts also use adult surveillance as a feedback or quality control mechanism to determine how effective the overall program is in reducing mosquito populations. Trapping adult mosquitoes and submitting those mosquitoes to test for diseases is often one component of a mosquito-vectored disease surveillance program. Collecting baseline data on mosquito populations and mosquito-borne disease also helps target educational efforts.

Mosquito Surveillance Techniques

1. Larval surveillance

   Larval surveillance is the routine sampling of aquatic habitats for developing mosquitoes. The primary tool is the "dip count" which indicates whether a habitat is producing mosquitoes and estimates larval density. A one-pint cup attached to a long handle is used to collect a standard volume of water ("dip sample"). The "dip count" may be expressed as the number of immature (larvae and pupae) mosquitoes per dip, per unit volume, or per unit surface area of the site.

2. Adult surveillance

   Several types of traps are used for adult surveillance, because mosquitoes are attracted to different traps depending on their species, sex, and physiological condition. The most common traps use light, carbon dioxide, water for egg laying, and a resting area. Trapped adults provide information about local distribution, density, and identity. The size of an adult mosquito population can also be assessed by the number and distribution of service requests from the public. Data are used to help locate new sources of mosquitoes or known sources with a recurrent problem

Annoyance Biting

Many species of mosquitoes are not important as vectors of disease, but can cause serious injury and discomfort to humans and animals. Each time a female mosquito pierces the skin to take blood, she contaminates the wound with her saliva, creating the potential for a mild allergic reaction. The common symptom of mosquito bites is irritated and swollen skin surrounding the bite with persistent itching for several days. Scratching these bites to alleviate the itching can result in secondary bacterial infections. In addition, when mosquito populations explode, the sheer number of mosquitoes attempting to bite can make life miserable.

Mosquitoes as Disease Vectors

Mosquitoes are the most important insect vectors of disease worldwide, causing millions of human deaths every year. Mosquito-borne pathogens are typically transmitted or "vectored" when a mosquito ingests a disease causing organism, the organism reproduces inside the mosquito, and is subsequently injected along with saliva into another animal or human host. The potential or "competence" to vector any particular disease causing organism varies greatly among mosquito species.

California has a long history of mosquito-borne disease. Mosquito control programs were first developed in the early 1900s to combat malaria and other diseases, and to reduce populations of nuisance mosquitoes. Currently, there are 12 mosquito-borne viruses recognized in California; however, only West Nile virus (WNV), western equine encephalomyelitis (WEE), and Saint Louis encephalitis (SLE) are significant threats to public health. Global trade and travel will continue to provide an avenue for introducing or re-introducing other mosquito-borne pathogens and their vectors into California and the United States. The diseases of greatest concern include Japanese encephalitis, dengue, yellow fever, Rift Valley fever, chikungunya, Venezuelan encephalitis, and malaria.

Virus Surveillance

In 2000, CDPH collaborated with the University of California, Davis, the California Department of Food and Agriculture, local mosquito and vector control agencies, and other state and local agencies to develop a comprehensive statewide surveillance program to detect and monitor WNV activity. More than 70 local mosquito and vector control districts and agencies, environmental health agencies, and county public health departments throughout California routinely contribute to the program. Surveillance includes testing for WNV infections in humans, horses, mosquitoes, wild birds, and "sentinel" chicken flocks located throughout California. The program also includes testing dead birds reported by the public for infections with WNV. A special website (http://www.westnile.ca.gov/) and toll-free hotline (877-WNV-BIRD) were created and are maintained by CDPH to support this surveillance program. The information from the program allows CDPH and local agencies to identify conditions conducive to WNV transmission and areas with elevated risk. This information is used by local mosquito control agencies to reduce the threat of WNV transmission to humans.

Mosquito Transmitted Diseases

Landowners throughout California, mosquito and vector control agencies, health departments, and CDPH work together to protect Californians from mosquito-borne diseases. Work to minimize the risk of disease transmission includes 1) comprehensive mosquito surveillance and control efforts on private and public lands, 2) agencies providing technical guidance and information to the medical and veterinary communities, and 3) educating the public about mosquitoes, the diseases they carry, and personal protective measures.

Encephalitis

Several mosquito-borne viruses that occur in California can cause encephalitis. The majority of human infections with these viruses have no symptoms. Those with so-called mild symptoms can still have significant illness and face prolonged recovery, and severe cases can be fatal or cause permanent neurological damage. There are several species of mosquitoes in California that can transmit WNV, SLE, and WEE viruses to people and animals. The most important species belong to the genus *Culex*. Specifically *Cx. tarsalis*, *Cx. pipiens*, and *Cx. quinquefasciatus* are significant public health concerns because of their widespread distribution throughout the state, their proximity to humans, and their capacity as very efficient vectors.

West Nile Virus

West Nile virus has become an endemic disease in California and like other encephalitic viruses, can cause serious illness. Many people who are infected do not get sick or may have a variety of symptoms that can include fever, head and body aches, nausea, vomiting, swollen lymph glands, and skin rash. Only about one in 150 infected people will develop a serious illness that may require hospitalization. Elderly people are at highest risk of developing the severe form of WNV and are at an increased risk of long-lasting physical and mental disorders. The severe form of the disease can be fatal.

Malaria

Malaria is caused by four species of protozoa. The parasites destroy red blood cells causing severe fever and anemia. Left untreated, malaria can cause kidney failure, coma, and death. Malaria was once a common public health threat in California and much of the southern United States, but it was eradicated by intensive mosquito control efforts and the discovery of anti-malarial drugs. However, the disease still occurs in many other countries worldwide, creating a perpetual risk of re-introduction, especially from infected travelers and immigrants. The *Anopheles* mosquitoes capable of transmitting malaria still occur in many areas of California.

Canine Heartworm

Canine heartworm occurs worldwide. It is caused by a filarial nematode transmitted by *Aedes* and some *Culex* mosquitoes that can infect domestic dogs, wild canines (e.g., foxes, coyotes, wolves), and cats. The tiny worms migrate through the body to the heart and cause thickening and inflammation of the heart, which can lead to difficulty in breathing, chronic cough, vomiting, and can sometimes be fatal.

Appendix B
Compounds Approved for Mosquito Control in California

Pesticides used for mosquito control have been evaluated for this purpose by the U.S. Environmental Protection Agency (EPA) and found to pose minimal risks to human health and the environment when used according to label directions. For updated information on specific products approved for use in California, please refer to the California Department of Pesticide Regulation website: http://www.cdpr.ca.gov/docs/label/labelque.htm.

Mosquito and vector control programs that apply pesticides to a water of the United States for the purpose of controlling any vector are required to obtain a National Pollution Discharge Elimination System (NPDES) Permit for Biological and Residual Pesticide Discharges to Waters of the United States. More information on the permit, issued by the State Water Resources Control Board, can be found at: http://www.waterboards.ca.gov/water_issues/programs/npdes/aquatic.shtml#davcp.

The components of this appendix have been adapted from the California Mosquito-Borne Virus Surveillance and Response Plan; please refer to the following website for more information: http://www.westnile.ca.gov.

The use of pesticides to control mosquitoes should be the last resort after BMPs outlined in this manual have been implemented. Individuals considering applying a pesticide must be adequately trained and always apply pesticides according to label directions. In California, local mosquito control agency employees must pass a testing and certification process through CDPH before they can apply pesticides to control mosquitoes. Similarly, commercial pesticide applicators must be appropriately certified by the California Department of Pesticide Regulation. Private landowners applying general use pesticides to control mosquitoes solely on their own property are not required to be certified; however, landowners have the same legal responsibility with regard to pesticide and environment related laws. Private citizens considering using pesticides should consult their County Agricultural Commissioner and the California Department of Fish and Game before application.

Examples of products containing specific active ingredients are provided below, but this is not an inclusive list nor constitutes product endorsement. For more information on pesticides and mosquito control, please refer to the U.S. EPA website: http://www.epa.gov/pesticides/health/mosquitoes/mosquito.htm.

Larvicides

1. *Bacillus thuringiensis*, subspecies *israelensis* (Bti: e.g., Aquabac 200G, VectoBac® 12AS, Teknar HP-D)
   Use: Approved for most permanent and temporary bodies of water.

Limitations: Only works on actively feeding stages. Does not persist well in the water column.

2. *Bacillus sphaericus* (Bs: e.g., VectoLex® CG)
   Use: Approved for most permanent and temporary bodies of water.
   Limitations: Only works on actively feeding stages. Does not work well on all species. May persist and have residual activity in some sites.

3. Spinosad (bacteria derived natural insecticide: e.g., Natular G)
   Use: Approved for most permanent and temporary bodies of water.
   Limitations: Only works on mosquito larvae.

4. IGRs (Insect Growth Regulators)
   a. (S)-Methoprene (e.g., Altosid® Pellets)
   Use: Approved for most permanent and temporary bodies of water.
   Limitations: Works best on older instars. Some populations of mosquitoes may show some resistance.
   b. Diflurobenzuron (e.g., Dimilin®25W)
   Use: Impounded tail water, sewage effluent, urban drains and catch basins.
   Limitations: Cannot be applied to wetlands, crops, or near estuaries.

5. Larviciding oils (e.g., GB-1111, BVA 2 Mosquito Larvicide Oil)
   Use: Ditches, dairy lagoons, floodwater. Effective against all stages, including pupae.
   Limitations: Consult with the California Department of Fish and Game for local restrictions.

6. Monomolecular films (e.g., Agnique® MMF)
   Use: Most standing water including certain crops.
   Limitations: Does not work well in areas with unidirectional winds in excess of 10 mph.

7. Organophosphate compounds
   Temephos (e.g., Abate® 2-BG)
   Use: Non-potable water; marshes; polluted water sites
   Limitations: Cannot be applied to crops for food, forage, or pasture. This material may not be effective on some *Culex tarsalis* populations in the Central Valley.

Adulticides

1. Organophosphate compounds
   Note: Many *Culex tarsalis* populations in the Central Valley have shown resistance to OP pesticides at approved label rates.
   a. Malathion (e.g., Fyfanon® ULV)
      Use: May be applied by air or ground equipment over urban areas, some

crops including rice, wetlands.
Limitations: Paint damage to cars; toxic to fish, wildlife and bees; crop residue limitations restrict application before harvest.

b. Naled (e.g., Dibrom® Concentrate, Trumpet® EC)
Use: Air or ground application on fodder crops, swamps, floodwater, residential areas.
Limitations: Similar to malathion.

c. Chlorpyrifos (e.g., Mosquitomaster 412)
Use: Air or ground application in urban or recreational areas
Limitations: Not registered for use over agricultural commodities or grazing lands and may be toxic to bees, fish, and some wildlife.

2. Pyrethrins (natural pyrethrin products: e.g., Pyrenone® Crop Spray, Pyrenone® 25-5, Evergreen®)
Use: Wetlands, floodwater, residential areas, some crops.
Limitations: Do not apply to drinking water, milking areas; may be toxic to bees, fish, and some wildlife. Some formulations with synergists have greater limitations.

3. Pyrethroids (synthetic pyrethrin products containing deltamethrin, cyfluthrin, permethrin, resmethrin, sumithrin, or etofenprox: e.g., Suspend® SC, Tempo Ultra SC, Aqua-Reslin®, Scourge® Insecticide, Anvil® 10+10 ULV, and Duet, which also contains the mosquito exciter prallethrin)
Use: All non-crop areas including wetlands and floodwater.
Limitations: May be toxic to bees, fish, and some wildlife; avoid treating food crops, drinking water or milk production.

PESTICIDES USED FOR LARVAL MOSQUITO CONTROL IN CALIFORNIA
LARVICIDES

For updated information on specific products approved for use in California, please refer to the California **Department of Pesticide Regulation website: http://www.cdpr.ca.gov/docs/label/labelque.htm**

Active Ingredient	Trade name	EPA Reg. No.	MFG	Formulation	Application	Pesticide classification
Bacillus sphaericus, (Bs)	Spheratax SPH (50G) and WSP	84268-2	Adapco	Granule and Water soluble packet	Larvae	Biorational
Bacillus sphaericus, (Bs)	VectoLex CG and WSP	73049-20	Valent BioSciences	Granule and Water soluble packet	Larvae	Biorational
Bacillus sphaericus, (Bs)	VectoLex WDG	73049-57	Valent BioSciences	Water dispersible granule	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Aquabac 200G and Consume MP	62637-3	Becker Microbial	Granule	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Aquabac XT	62637-1	Becker Microbial	Liquid	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Bactimos PT	73049-452	Valent Biosciences	Granule	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Fourstar SBG	85685-1	Fourstar Microbials	Granule	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Summit Bti Briquets	6218-47	Summit Chemical	Briquet	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	VectoBac 12AS	73049-38	Valent BioSciences	Liquid	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	VectoBac G and GS	73049-10	Valent BioSciences	Granule	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	VectoBac Tech. Powder	73049-13	Valent BioSciences	Technical powder	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	VectoBac WDG	73049-56	Valent BioSciences	Technical powder	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Teknar HP-D	73049-404	Valent BioSciences	Liquid	Larvae	Biorational
Bacillus thuringiensis var. *israelensis* (Bti)	Teknar SC	73049-435	Valent BioSciences	Liquid	Larvae	Biorational
Bs and Bti	Vectomax G, CG, WSP	73049-429	Valent BioSciences	Granule and Packet	Larvae	Biorational
Bs and Bti	Fourstar Briquettes	83362-3	Fourstar Microbials	Briquette	Larvae	Biorational
Spinosad	Natular G	8329-80	Clarke	Granule	Larvae	Biorational
Spinosad	Natular 2EC	8329-82	Clarke	Liquid	Larvae	Biorational
Spinosad	Natular G30	8329-83	Clarke	Granule	Larvae	Biorational

Active Ingredient	Trade name	EPA Reg. No.	MFG	Formulation	Application	Pesticide classification
Spinosad	Natular T30	8329-85	Clarke	Tablet	Larvae	Biorational
Spinosad	Natular XRT	8329-84	Clarke	Tablet	Larvae	Biorational
Monomolecular film	Agnique MMF	53263-28	Cognis Corp.	Liquid	Larvae and pupae	Surface film
Monomolecular film	Agnique MMF G	53263-30	Cognis Corp.	Granule	Larvae and pupae	Surface film
Monomolecular film	Agnique MMF GPak 35	53263-30	Cognis Corp.	Water soluble packet	Larvae and Pupae	Surface film
Petroleum oil	BVA 2	70589-1	BVA Oils	Liquid	Larvae and pupae	Surface film
Petroleum oil	BVA Spray 13	55206-2	BVA Oils	Liquid	Larvae and pupae	Surface film
Petroleum oil	GB 1111	8329-72	Clarke	Liquid	Larvae and pupae	Surface film
Petroleum oil	Masterline Kontrol	73748-10	Univar	Liquid	Larvae and pupae	Surface film
Diflubenzuron	Dimilin 25W	400-465	Uniroyal Chemical	Wettable powder	Larvae	IGR
S-Methoprene	Altosid ALL	2724-392	Wellmark-Zoecon	Liquid	Larvae	IGR
S-Methoprene	Altosid Liquid Larvicide Concentrate	2724-446	Wellmark-Zoecon	Liquid concentrate	Larvae	IGR
S-methoprene	Altosid Briquets	2724-375	Wellmark-Zoecon	Briquet	Larvae	IGR
S-methoprene	Altosid Pellets	2724-448	Wellmark-Zoecon	Pellet-type granules	Larvae	IGR
S-methoprene	Altosid SBG	2724-489	Wellmark-Zoecon	Granule	Larvae	IGR
S-methoprene	Altosid XR	2724-421	Wellmark-Zoecon	Briquet	Larvae	IGR
S-methoprene	Altosid XR-G	2724-451	Wellmark-Zoecon	Pellet	Larvae	IGR
S-methoprene	Metalarv S-PT	73049-475	Wellmark-Zoecon	Pellet	Larvae	IGR
Temephos	Abate 2-BG	8329-71	Clarke	Granule	Larvae	OP

Active Ingredient	Trade name	EPA Reg. No.	MFG	Formulation	Application	Pesticide classification
Temephos	AllPro Provect 1G Larvicide	769-723	AllPro	Granule	Larvae	OP
Temephos	AllPro Provect 5G Larvicide	769-722	AllPro	Granule	Larvae	OP
Temephos	5% Skeeter Abate	8329-70	Clarke	Granule	Larvae	OP

PESTICIDES USED FOR ADULT MOSQUITO CONTROL IN CALIFORNIA
ADULTICIDES

For updated information on specific products approved for use in California, please refer to the California Department of Pesticide Regulation website: http://www.cdpr.ca.gov/docs/label/labelque.htm

Active Ingredient	Trade name	EPA Reg. No.	MFG	Formulation	Application	Pesticide classification
Malathion	Fyfanon® ULV	67760-34	Cheminova	Liquid	Adults	OP
Naled	Dibrom Concentrate	5481-480	AMVAC	Liquid	Adults	OP
Naled	TrumpetÔ EC	5481-481	AMVAC	Liquid	Adults	OP
Cyfluthrin	Tempo Ultra SC	432-1363	Bayer	Liquid	Adults	Pyrethroid
Deltamethrin	Suspend® SC	432-763	Bayer	Liquid	Adults	Pyrethroid
Permethrin	Aqua-Kontrol	73748-1	Univar	Liquid	Adults	Pyrethroid
Permethrin	Aqualeur 20-20	769-985	Value Garden Supply	Liquid	Adults	Pyrethroid
Permethrin	Aqua-Reslin®	432-796	Bayer	Liquid	Adults	Pyrethroid
Permethrin	Biomist® 4+4 ULV	8329-35	Clarke	Liquid	Adults	Pyrethroid
Permethrin	Biomist® 4+12 ULV	8329-34	Clarke	Liquid	Adults	Pyrethroid
Permethrin	Evoluer 4-4 ULV	760-982	Value Garden Supply	Liquid	Adults	Pyrethroid
Permethrin	Evoluer 30-30 ULV	760-983	Value Garden Supply	Liquid	Adults	Pyrethroid
Permethrin	Kontrol 2-2	73748-3	Univar	Liquid	Adults	Pyrethroid
Permethrin	Kontrol 4-4	73748-4	Univar	Liquid	Adults	Pyrethroid
Permethrin	Kontrol 30-30	73748-5	Univar	Liquid	Adults	Pyrethroid
Permethrin	Permanone® Ready-To-Use	432-1277	Bayer	Liquid	Adults	Pyrethroid
Permethrin	Permanone 31-66	432-1250	Bayer	Liquid	Adults	Pyrethroid
Permethrin	Perm-X UL 4-4	655-898	Prentiss	Liquid	Adults	Pyrethroid
Pyrethrins	Aquahalt	1021-1803	Clarke	Liquid	Adults	Pyrethroid
Pyrethrins	Evergreen 60-6	1021-1770	MGK	Liquid	Adults	Pyrethroid
Pyrethrins	Pyranone® 25-5	432-1050	Bayer	Liquid	Adults	Pyrethroid
Pyrethrins	Pyrenone® Crop Spray	432-1033	Bayer	Liquid	Adults	Pyrethroid
Pyrethrins	Pyrocide® 7067	1021-1199	Adapco	Liquid	Adults	Pyrethroid
Pyrethrins	Pyrocide® 7453	1021-1803	MGK	Liquid	Adults	Pyrethroid

Active Ingredient	Trade name	EPA Reg. No.	MFG	Formulation	Application	Pesticide classification
Pyrethrins	Pyrocide® 7395	1021-1570	MGK	Liquid	Adults	Pyrethroid
Pyrethrins	Pyrocide® 7396	1021-1569	MGK	Liquid	Adults	Pyrethroid
Pyrethrins	Pyronyl Crop Spray	655-489	Prentiss	Liquid	Adults	Pyrethroid
Pyrethrins	Pyronyl Oil 525	655-471	Prentiss	Liquid	Adults	Pyrethroid
Pyrethrins	Pyronyl Oil 3610A	655-501	Prentiss	Liquid	Adults	Pyrethroid
Resmethrin	Scourge® Insecticide (4%)	432-716	Aventis	Liquid	Adults	Pyrethroid
Resmethrin	Scourge® Insecticide (18%)	432-667	Aventis	Liquid	Adults	Pyrethroid
Sumithrin	Anvil® 2+2 ULV	1021-1687	Clarke	Liquid	Adults	Pyrethroid
Sumithrin	Anvil® 10+10 ULV	1021-1688	Clarke	Liquid	Adults	Pyrethroid
Sumithrin	AquaAnvil®	1021-1807	Clarke	Liquid	Adults	Pyrethroid
Prallethrin Sumithrin	Duet	1021-1795	Clarke	Liquid	Adults	Pyrethroid
Prallethrin Sumithrin	AcuaDuet	1021-2562-8329	Clarke	Liquid	Adults	Pyrethroid
Etofenprox	Zenivex E4 RTU	2724-807	Wellmark, Intl.	Liquid	Adults	Pryethroid
Etofenprox	Zenivex E20	2724-791	Wellmark, Intl.	Liquid	Adults	Pryethroid
Lambda-cyhalothrin	Demand CS	100-1066	Syngenta	Liquid	Adults	Pryethroid

Appendix C
Health and Safety Codes Pertinent to Mosquito Control

In California, mosquito and vector control agencies are regulated by sections of the California Health and Safety (H&S) Code, Food and Agriculture Code, California Code of Regulations, and others. The following components of this appendix have been adapted from the Overview of Mosquito Control Practices in California, California Department of Public Health: http://www.westnile.ca.gov/resources.php

Governing laws and regulations

Many federal and state laws govern the activities of vector control agencies, including the Clean Water Act (CWA), the Endangered Species Act (ESA), and the Federal Insecticide Fungicide and Rodenticide Act (FIFRA). Pesticide application by vector control agencies in California is regulated under FIFRA. FIFRA is administered through the U.S. Environmental Protection Agency, and regulates the registration, labeling, and sales of pesticides in the United States.

The California H&S Code encourages the formation of local mosquito control programs to protect the public health, safety, and welfare (H&S Code Section 2001-b) Website link: http://leginfo.ca.gov/cgi-bin/displaycode?section=hsc&group=01001-02000&file=2000-2007. The legal responsibility of landowners in California to avoid causing a public nuisance, including mosquitoes is implied in the section. The potential consequences of failing to prevent a public nuisance are described in the Code sections listed below.

Under the H&S Code, local vector control agencies have the authority to conduct surveillance for vectors, prevent the occurrence of vectors, and legally abate production of vectors or public nuisance defined as “Any water that is a breeding place for vectors” and “Any activity that supports the development, attraction, or harborage of vectors, or that facilitates the introduction or spread of vectors.”(H&S Code Section 2002(j) and 2040). Vector control agencies also have authority to participate in review, comment, and make recommendations regarding local, state, or federal land use planning and environmental quality processes, documents, permits, licenses, and entitlements for projects and their potential effects with respect to vector production. (H&S Code Section 2041) Website link: http://caselaw.lp.findlaw.com/cacodes/hsc/2040-2055.html

Additionally, agencies have broad authority to influence landowners to reduce or “abate” the source of a vector problem. Actions may include imposing civil penalties of up to $1000 per day plus costs associated with controlling the vector. Agencies have authority to “abate” vector sources on private and publicly owned properties. (H&S Code Sections 2060-2065). Website link: http://caselaw.lp.findlaw.com/cacodes/hsc/2060-2067.html

Mosquito and vector control programs that enter into a cooperative agreement with the California Department of Public Health are exempted from some pesticide related laws under Title 3 of the California Code of Regulations Section 6620. Specifically, these agencies are exempted from "Consent to Apply" (Title 3, California Code of Regulations, Section 6616), "Notice" (Title 3, California Code of Regulations, Section 6618), and the "Protection of Persons, Animals, and Property" (Title 3, California Code of Regulations, Section 6614). Essentially, these provisions obviate the vector control agency from having to notify or get permission from landowners prior to applying a pesticide to their property in the interest of preserving the public health. Website link: http://www.cdpr.ca.gov/docs/legbills/calcode/030201.htm#a6620

A vector control technician working at a vector control agency must be a "certified technician" or work under the direct supervision of a "certified technician" to apply pesticides. Vector control technicians achieve certification through an examination process administered by the California Department of Public Health.

Vector control agencies cannot use any pesticide not registered for use in California, and are required to keep detailed records of each pesticide application, including date, location, and amount applied. All pesticides must be applied in accordance with the labeling of the product as registered with the U.S. EPA.

Appendix D
Mosquitoes of California

The biology and key characteristics of the four major mosquito genera in California are described below.

Aedes

There are about 80 species of *Aedes* mosquitoes in the continental United States; 24 species occur in California. Certain species are widespread, may occur in very large numbers, and are among the worst biting pests. *Aedes* mosquitoes do not lay their eggs directly on the surface of standing water. Instead, they lay single eggs on intermittently flooded surfaces such as the damp soil around irrigated pastures and fields, along the edges of coastal tidal marshes, and inside dry treeholes and containers. Eggs are extremely resistant to drying and will lie dormant on dry surfaces until flooding occurs (eggs of *Ae. vexans* have been documented to lie dormant for up to three years). This can lead to many generations of eggs in a given habitat if female mosquitoes lay successive batches of eggs before the area is flooded. When flooding occurs, large numbers of eggs hatch spontaneously and develop rapidly to adults. Although larval developmental sites vary greatly, the most productive include transient ground pools, flooded areas along overflowing streams, flood and stormwater control basins, intermittently flooded agricultural lands, and container habitats such as tree holes, wheel ruts, and discarded tires.

Aedes are primarily summer-breeding mosquitoes. Because of their rapid larval development in newly-flooded habitats, adults often emerge before predators can colonize the water source. Most *Aedes* complete two to several generations per year depending on the frequency of habitat flooding from natural and artificial events. Adults cannot survive in colder weather. Therefore the majority of *Aedes* overwinter as eggs.

Typically, *Aedes* mosquitoes found in California will not enter buildings and homes; however, they are strong fliers and are known to travel many miles from their aquatic developmental sites to search for hosts. *Aedes* mosquitoes are diurnal (i.e., active during the day) during mild weather, especially around shaded areas, but will also bite at dusk. Most *Aedes* females feed on large mammals like cattle and horses, but will readily feed on humans. *Aedes* mosquitoes are aggressive and persistent biters causing people and animals to avoid areas where their numbers are great. One example is the species *Ae. nigromaculis*, which are currently not known to vector disease, but are considered a serious pest because they will seek out human hosts and bite during the day when people are most likely to be outdoors and active.

Anopheles

Approximately 22 species of *Anopheles* are found in the continental United States and of these, 5 occur in California. When feeding, *Anopheles* adults rest with their abdomens positioned at a distinct angle to the surface of the skin, whereas other species orient their bodies parallel. Females lay single floating eggs directly on the surface of permanent or semi-permanent standing water. A female can lay successive batches of up to 300 eggs during the breeding season. Eggs are not resistant to drying and typically hatch within two-three days, although hatching may take up to two-three weeks in colder climates. Larvae develop in 12 to 20 days, but can take longer in cooler weather. Preferred larval habitats include clear, fresh seepage water in sunlit or partly shaded pools, wetlands, roadside ditches, rice fields, and poorly maintained water troughs.

Adult females bite at dusk and dawn and prefer to feed on mammals. Many *Anopheles* mosquitoes prefer to feed on rabbits, but will also feed on large mammals such as livestock and humans. In California, *Anopheles* species may undergo two or more generations per year. Most species over-winter in protected areas as mated females, resuming activity the following spring. These are among the first mosquitoes to emerge and bite humans each year.

Historically, *Anopheles freeborni*, the western malaria mosquito, was a vector of malaria in California. Currently, with the disease eradicated from California and the United States, it is considered a nuisance mosquito. This species is widespread throughout California and females will lay their eggs in any standing fresh water, although it is abundant in rice fields or other wetlands during late summer. While most adult mosquitoes stay within a few miles of their breeding source, they will migrate further when seeking hibernation sites in fall. This can lead to a large influx of mosquitoes from uncontrolled areas to residential areas during September and October.

Culex

Culex, with 11 species found throughout the state is the second largest genus of mosquitoes in California, second only to *Aedes*. Females can lay up to seven rafts of eggs over a two-month life span; each raft contains from 100-300 eggs which are laid on the surface of standing water. *Culex* larvae occur in a broad range of aquatic sites ranging from containers such as discarded tires, water barrels, and flower pots to clogged gutters, catch basins, and water for irrigation and urban wastewater. During summer and periods of drought, areas without regularly flowing water, street drainage systems, and contaminated streams, ponds and pools become productive larval habitats. *Culex* larvae are known for thriving in polluted sources of water with a high organic content.

Culex mosquitoes prefer to take blood meals at dusk or after dark and can be painful and persistent biters. *Culex* preferably feed on birds but also feed on mammals including humans and horses. They readily enter houses and buildings in search of a suitable host. Two or more generations of *Culex* can occur per year. Females that emerge in late summer will mate and overwinter until the following spring or mid-summer.

Several species of *Culex* can transmit viruses that can cause encephalitis (i.e., inflammation of the brain), including WNV, SLE, and WEE. These mosquitoes are efficient and effective vectors of these diseases among birds, humans, horses and many other wild and domestic animals.

Culex tarsalis

Culex tarsalis, the Western encephalitis mosquito, is one of California's most important and efficient vectors of WNV, SLE, and WEE. This species is widespread in California. *Cx. tarsalis* prefer to lay their eggs on fresh or lightly polluted standing water such as rice fields, ditches, pastures, waste water ponds, and seasonal wetlands. Other more urban freshwater sources include ornamental ponds, storm drains, and flood control channels. Larvae usually develop into adults in approximately 8-14 days; warmer water can shorten the developmental period. *Cx. tarsalis* are active from spring through fall; however the population in the Central Valley peaks in June to July with a secondary, smaller peak in September coinciding with flooding of seasonal wetlands. *Cx. tarsalis* survive through the winter as adults in barns, culverts, caves, and similar dark, protected places.

Adult *Cx. tarsalis* can disperse a great distance up to 10-15 miles (16-24 km) in search of blood meals, generally traveling along riparian corridors, but most stay close to the site where they emerged. Adults rest by day in shaded areas such as animal burrows and treeholes. Females prefer feeding between dusk and dawn but may bite during the day in deep shade. Females obtain blood meals from birds or mammals and can transmit diseases between these groups.

Culex pipiens* and *Culex quinquefasciatus

Culex pipiens (the northern house mosquito) and *Culex quinquefasciatus* (the southern house mosquito) appear to be identical. *Cx. quinquefasciatus* occurs in Southern California, whereas *Cx. pipiens* is found along the coastal regions and in Northern California and is the most widely distributed mosquito species in the world. Both species can transmit encephalitis viruses. They are common in and around households and prefer to lay eggs in polluted water that is high in organic content such as dairy runoff, wastewater catchment basins, stormwater ponds, dirty flower pots, bird baths, or any drainage systems where standing water exists.

In California, *Cx. pipiens* and *Cx. quinquefasciatus* typically do not disperse from where they emerged. Females feed at dusk or after dark, readily enter homes and prefer avian hosts but will also feed on large mammals including humans. *Cx. pipiens* and *Cx. quinquefasciatus* are vectors of WNV and SLE virus, and have also been implicated in transmitting canine heartworm.

Other *Culex* mosquitoes.

Culex stigmatosoma, the foul water mosquito, *Cx restuans* and *Cx. erythrothorax* can also be infected with WNV, but their distributions are limited (e.g., *Cx. erythrothorax* is mainly found close to bodies of water with tules).

Culiseta

Only eight species of *Culiseta* mosquitoes occur in the continental United States, of which four are found in California. Females lay clusters of floating eggs (rafts) on the surface of standing water. *Culiseta* mosquitoes are moderately aggressive biters, attacking in the evening hours or in shade during the day. Peak populations occur during the cooler months. These mosquitoes prefer to feed on larger domestic animals, such as cattle and horses, but will also feed on humans. The distribution of *Cs. inornata*, an unusually large mosquito, is widespread and can be found at elevations of up to 10,000 feet. Larvae of *Cs. inornata* develop in permanent water habitats, including shallow marshes, peat bogs, roadside ditches, abandoned gravel pits, and in standing water in soil cavities left by fallen trees. The common name of this mosquito—the Large Winter mosquito—reflects that it is most active in cool weather habitats.

Anopheles species | *Aedes* species | *Culex* & *Culiseta* species

Appendix E
Typical Larval Habitats of California Mosquitoes*

Riparian	Vernal Pools	Foul Water	Salt Marsh	Treehole
Aedes atropalpus	*Aedes bicristatus*	*Culex pipiens*	*Aedes dorsalis*	*Aedes deserticola*
Aedes washinoi	*Aedes campestris*	*Culex restuans*	*Aedes squamiger*	*Aedes purpureipes*
Aedes pullatus	*Aedes fitchii*	*Culex stigmatosoma*	*Aedes taeniorhynchus*	*Aedes sierrensis*
Aedes sticticus	*Aedes hemiteleus*	*Culex tarsalis*	*Anopheles occidentalis*	*Orthopodomyia signifera*
Aedes vexans	*Aedes increpitus*	*Culiseta impatiens*	*Culex tarsalis*	
Anopheles franciscanus	*Aedes niphadopsis*	*Culiseta incidens*	*Culiseta incidens*	
Anopheles occidentalis	*Aedes ventrovittis*	*Culiseta inornata*	*Culiseta inornata*	
Anopheles punctipennis	*Aedes washinoi*			
Culex apicalis	*Culex tarsalis*			
Culex boharti	*Culiseta incidens*			
Culex reevesi	*Culiseta inornata*			
Culex tarsalis	*Psorophora columbiae*			
Culex territans	*Psorophora signipennis*			
Culex thriambus				
Culiseta impatiens				
Culiseta incidens				
Culiseta particeps				
Culiseta inornata				

Small Container	Freshwater Marsh	Rock Pools	Pools and Ponds	Snow Melt Pools
Aedes sierrensis	*Aedes flavescens*	*Aedes sierrensis*	*Aedes sierrensis*	*Aedes cataphylla*
Culex pip/quinq	*Anopheles freeborni*	*Anopheles punctipennis*	*Culex pip/quinq*	*Aedes clivis*
Culiseta incidens	*Anopheles hermsi*	*Culex tarsalis*	*Culex stigmatosoma*	*Aedes communis*
	Anopheles occidentalis	*Culiseta impatiens*	*Culex tarsalis*	*Aedes hexodontus*
	Coquillettidia perturbans	*Culiseta incidens*	*Culiseta impatiens*	*Aedes increpitus*
	Culex erythrothorax		*Culiseta incidens*	*Aedes pullatus*
	Culex tarsalis		*Culiseta inornata*	*Aedes schizopinax*
	Uranotaenia anhydor		*Culiseta particeps*	*Aedes sticticus*
				Aedes tahoensis
				Aedes ventrovittis
				Culiseta incidens

Woodland Pools	Irrigated Pastures	Permanent Ponds		
Aedes bicristatus	*Aedes dorsalis*	*Aedes niphadopsis*		
Aedes increpitus	*Aedes melanimon*	*Aedes schizopinax*		
Aedes washinoi	*Aedes nigromaculis*	*Anopheles occidentalis*		
Aedes punctipennis	*Aedes thelcter*	*Culex anips*		
Culex apicalis	*Aedes vexans*	*Culex erythrothorax*		
Culex tarsalis	*Anopheles freeborni*	*Culex reevesi*		
Culex thriambus	*Culex tarsalis*	*Culex tarsalis*		
Culiseta incidens	*Culiseta inornata*	*Culiseta impatiens*		
Culiseta inornata	*Psorophora columbiae*	*Culiseta incidens*		
Culiseta particeps	*Psorophora signipennis*	*Culiseta particeps*		
		Culiseta inornata		
		Coquillettidia perturbans		
		Uranotaenia anhydor		

*Compiled from: Identification of the Mosquitoes of California. Rev. 1998. Mosquito and Vector Control Association of California.

Appendix F
Insect Repellents

A number of products have been developed and registered by the Environmental Protection Agency for human use that repel adult mosquitoes and thus reduce the chances of mosquito bites. The most commonly used mosquito repellents contain the active ingredient DEET (N,N-diethyl-meta-toluamide), which has been formulated and sold under a variety of trade names. Repellents are available in a variety of concentrations and are formulated as aerosol sprays (most commonly at 15%), lotions, and solids (up to 100%). Spray repellents can be used on outer clothing as well as sparingly on the skin to ensure complete coverage. Repellents should not be used under clothing. The percentage of DEET in the repellent reflects the approximate length of time the product will repel mosquitoes (e.g., 23.8% DEET = about five hours of protection, 20% = about four hours, and 6.6% DEET = about two hours).

Topical repellents that contain picaridin, IR-3535, and oil of lemon eucalyptus are similar in efficacy to those with DEET, but often require more frequent application. Clothing and other materials impregnated with permethrin during manufacture are also available. It is important to always carefully read and understand the benefits and limitations of repellents listed on the product label before use. By law, all repellent products must be used according to their labels.

Appendix G
Additional Resources and Information

Mosquito Biology

Additional information on mosquitoes and mosquito-borne diseases is easily obtainable from a variety of reputable sources. More information on mosquito biology and ecology is available on the American Mosquito Control Association (AMCA) and the Mosquito and Vector Control Association of California (MVCAC) websites. Local mosquito and vector control agencies and their respective websites can provide detailed information about local mosquito species. Information on mosquito-borne diseases is available from the Centers for Disease Control and Prevention (CDC) and the CDPH websites. Contact information for local mosquito and vector control agencies in California can be found through the CDPH website by entering the zip code of the location of interest under "**Locate Your Local Mosquito and Vector Control Agency**" at http://www.westnile.ca.gov/; more information is available on the MVCAC website.

Monitoring Mosquitoes and Diseases

More information about reporting dead birds and WNV surveillance in California can be found at http://www.westnile.ca.gov/.
Methods for sampling adult mosquitoes and guidelines for designing, operating, and processing of traps are discussed in Guidelines for Integrated Mosquito Surveillance (Meyer et al. 2003) and are summarized in Appendix B of the California Mosquito-Borne Virus Surveillance and Response Plan which can be found at: http://www.westnile.ca.gov/resources.php

The Centers for Disease Control and Prevention, Epidemic/Epizootic West Nile Virus in the United States: Guidelines for Surveillance, Prevention and Control http://cdc.gov/ncidod/dvbid/westnile/resources/wnv-guidelines-aug-2003.pdf

- Walton WE. 2005. Protocol for Mosquito Sampling for Mosquito Best Management Practices on State of California-Managed Wildlife Areas. University of California.

Health Department Websites

California Department of Public Health West Nile virus (WNV) website: http://www.westnile.ca.gov

United States Center for Disease Control and Prevention website: http://cdc.gov

US Centers for Disease Control and Prevention – West Nile Virus website: http://cdc.gov/ncidod/dvbid/westnile/index.htm

Disease Surveillance Websites

UC Davis Center for Vectorborne Diseases website: http://cvec.ucdavis.edu

California Vectorborne Disease Surveillance Gateway website: http://www.calsurv.org/

Best Management Practices

Best Management Practices for Mosquito Control on California State Properties: http://www.westnile.ca.gov/resources.php

- For additional information on personal protective measures and the use of chemical repellents, go to the Centers for Disease Control and Prevention (CDC) web site at: http://www.cdc.gov/ncidod/dvbid/westnile/RepellentUpdates.htm
- For more information on evaluating the efficacy of BMPs on state of California-managed Wildlife Areas, see Walton 2005.

Mosquito Control

American Mosquito Control Association website: http://www.mosquito.org

Mosquito and Vector Control Association of California website: http://www.mvcac.org

University of California at Davis Center for Vectorborne Diseases website: http://cvec.ucdavis.edu

University of California IPM Online website: http://www.ipm.ucdavis.edu/

State Water Resources Control Board NPDES General Permits: http://www.waterboards.ca.gov/water_issues/programs/npdes/aquatic.shtml#davcp

Additional Online Resources

Climate Information

National Weather Service – Climate Prediction Center website: http://www.cpc.ncep.noaa.gov/products/predictions

Water Related Information

California Data Exchange Center website: http://cdec.water.ca.gov

Pesticide and Insect Repellent Information

National Pesticide Telecommunications Network website:
http://npic.orst.edu/factsheets/DEETgen.pdf

National Pesticide Information Center website: http://npic.orst.edu/

Agriculture and Crop Related Information

California Agricultural Statistics Service website: http://www.nass.usda.gov/ca

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California Department of Transportation. 2006 Right-of-Way Property Management and Airspace Storm Water Guidance Manual. http://www.dot.ca.gov/hq/row/rwstormwater/index.htm

California Environmental Resources Evaluation System and the California Wetlands Information System. http://ceres.ca.gov/wetlands/

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List of Acronyms

AMCA	American Mosquito Control Association
BMP	Best Management Practices
Bs	Bacillus sphaericus
Bti	Bacillus thuringiensis israelensis
CDC	Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CVEC	Center for Vectorborne Diseases (UC Davis)
DFG	California Department of Fish and Game
CDPR	California Department of Pesticide Regulation
EPA	Federal Environmental Protection Agency
H&S Code	California Health and Safety Code
MVCAC	Mosquito and Vector Control Association of California
NPDES	National Pollution Discharge Elimination System
SLE	St. Louis encephalitis virus
SWRCB	State Water Resources Control Board
UCD	University of California, Davis
WEE	Western equine encephalomyelitis virus
WNV	West Nile virus

ORDINANCE NO. 181899

An ordinance amending Sections 64.70.01 and 64.72 of Article 4.4 of Chapter VI of the Los Angeles Municipal Code to expand the applicability of the existing Standard Urban Stormwater Mitigation Plan (SUSMP) requirements by imposing rainwater Low Impact Development (LID) strategies on projects that require building permits; and amending Section 64.72.05 of Article 1 of Chapter IX of the Los Angeles Municipal Code to collect fees to recover Bureau of Sanitation costs of administering the provisions of this Ordinance.

WHEREAS, the City of Los Angeles is authorized by Article XI, §5 and §7 of the State Constitution to exercise the police power of the State by adopting regulations to promote public health, public safety and general prosperity;

WHEREAS, the City of Los Angeles has authority under the California Water Code to adopt and enforce ordinances imposing conditions, restrictions and limitations with respect to any activity that might degrade the quality of waters of the State;

WHEREAS, the City of Los Angeles has applied an integrated approach to incorporate wastewater, stormwater and runoff, and recycled water management into a single strategy through its Integrated Resources Plan;

WHEREAS, the City of Los Angeles is committed to a stormwater management program that protects water quality and water supply by employing watershed-based approaches that balance environmental and economic considerations;

WHEREAS, the purpose of this Ordinance includes, but is not limited to, rainwater harvesting and stormwater runoff management, water conservation, and recycled water reuse and gray water use, which are all key elements of the City of Los Angeles "Water Supply Action Plan" and are essential to ensuring responsible and sustainable development;

WHEREAS, urbanization has led to increased impervious surface areas resulting in increased water runoff and less percolation to groundwater aquifers causing the transport of pollutants to downstream receiving waters;

WHEREAS, the City of Los Angeles needs to take a new approach to managing rainwater and urban runoff while mitigating the negative impacts of development and urbanization;

WHEREAS, the City of Los Angeles' Los Angeles River Revitalization Plan has identified reduction in peak stormwater runoff in the Los Angeles River as necessary to implement many of the Los Angeles River revitalization projects;

WHEREAS, LID is widely recognized as a sensible approach to managing the quantity and quality of stormwater runoff by setting standards and practices to maintain or restore the natural hydrologic character of a development site, reduce off-site runoff, improve water quality, and provide groundwater recharge; and

WHEREAS, it is the intent of the City of Los Angeles to expand the applicability of the existing Standard Urban Stormwater Mitigation Plan requirements by providing stormwater and rainwater LID strategies for all projects that require building permits.

NOW THEREFORE,

THE PEOPLE OF THE CITY OF LOS ANGELES DO ORDAIN AS FOLLOWS:

Section 1. Section 64.70.01 of Article 4.4 of Chapter VI of the Los Angeles Municipal Code is amended in its entirety to read as follows:

SEC. 64.70.01. DEFINITIONS AND ABBREVIATIONS.

A. Definitions. For the purpose of this Article, the following words and phrases are defined and shall be construed as set out here, unless it is apparent from the context that they have a different meaning:

1. "**Basin Plan**" means a Water Quality Control Plan adopted by the California Regional Water Quality Control Board for a specific watershed or designated area.

2. "**Best Management Practice (BMP)**" means activities, practices, facilities, and/or procedures that when implemented will reduce or prevent pollutants in discharges.

3. "**Board**" means the Board of Public Works of the City of Los Angeles or its duly authorized representative.

4. "**Bureau**" means the Bureau of Sanitation of the City of Los Angeles or its duly authorized representative.

5. "**City**" means the City of Los Angeles or its duly authorized representatives.

6. "**Clean Water Act (CWA)**" means the Federal Water Pollution Control Act enacted in 1972, by Public Law 92-500, and amended by the Water Quality Act of 1987. The Clean Water Act prohibits the discharge of pollutants to Waters of the United States unless the discharge is in accordance with an NPDES permit.

7. "**Commercial Activity**" means any public or private activity involved in the storage, transportation, distribution, exchange or sale of goods and/or commodities or providing professional and/or non-professional services.

8. "**Construction Activity**" means clearing, grading, or excavating that results in soil disturbance. Construction activity does not include routine maintenance to maintain original line and grade, hydraulic capacity, or the original purpose of the facility, nor does it include emergency construction activities required to immediately protect public health and/or safety.

9. "**Control**" means to minimize, reduce or eliminate by technological, legal, contractual or other means, the discharge of pollutants from an activity or activities.

10. **"Development"** means the construction, rehabilitation, redevelopment or reconstruction of any public or private residential project (whether single-family, multi-unit or planned unit development); industrial, commercial, retail and any other non-residential projects, including public agency projects; or mass grading for future construction.

11. **"Development Best Management Practices Handbook"** means such handbook, as may be amended from time to time, adopted by the Board of Public Works.

12. "**Director**" means the Director of the Bureau of Sanitation of the Department of Public Works of the City of Los Angeles or the duly authorized representatives designated to administer, implement and enforce the provisions of this Article.

13. "**Discharge**" means any release, spill, leak, pump, flow, escape, dumping, or disposal of any liquid, semi-solid or solid substance.

14. **"Environmentally Sensitive Areas (ESAs)"** means an area in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which would be easily disturbed or degraded by human activities and developments (See California Public Resources Code § 30107.5). ESAs include, but are not limited to, areas designated as Significant Ecological Areas by the County of Los Angeles (Los Angeles County Significant Areas Study, Los Angeles County Department of Regional Planning (1976) and amendments); areas designated as Significant Natural Areas by the California Department of Fish and Game's Significant Natural Areas Program and field verified by the Department of Fish and Game; and areas listed in the Basin Plan as supporting the "Rare, Threatened, or Endangered Species (RARE)" beneficial use.

15. "**Hazardous Material(s)**" means any material(s) defined as hazardous by Division 20, Chapter 6.95 of the California Health and Safety Code.

16. "**Illicit Connection**" means any man-made conveyance that is connected directly to the storm drain system, excluding roof-drains, and any other similar connection that serves as a pathway for any illicit discharge.

17. "**Illicit Discharge**" means any discharge to the storm drain system that is prohibited under local, state or federal statutes, ordinances, codes or regulations. Illicit discharges include all non-stormwater discharges except discharges pursuant to an NPDES permit or discharges that are exempted or conditionally exempted by the NPDES permit or granted as a special waiver or exemption by the Regional Board.

18. "**Impervious Surface**" means any man-made or modified surface that prevents or significantly reduces the entry of water into the underlying soil, resulting in runoff from the surface in greater quantities and/or at an increased rate, when compared to natural conditions prior to development. Examples of places that commonly exhibit impervious surfaces include parking lots, driveways, roadways, storage areas, and rooftops. The imperviousness of these areas commonly results from paving, compacted gravel, compacted earth, and oiled earth.

19. "**Industrial Activity**" means any public or private activity that is associated with any of the 11 categories of activities defined in 40 CFR 122.26(b)(14) and required to obtain a NPDES permit.

20. "**Industrial/Commercial Facility**" means any facility involved and/or used in either the production, manufacture, storage, transportation, distribution, exchange or sale of goods and/or commodities, and any facility involved and/or used in providing professional and non-professional services. This category of facility includes, but is not limited to, any facility defined by the Standard Industrial Classifications (SIC). Facility ownership (federal, state, municipal, private) and profit motive of the facility are not factors in this Definition.

21. **"LID"** means Low Impact Development.

22. "**Maximum Extent Practicable (MEP)**" means the standard for implementation of stormwater management programs to reduce pollutants in stormwater. MEP refers to stormwater management programs taken as a whole. It is the maximum extent possible taking into account equitable considerations and competing facts, including but not limited to, the gravity of the problem, public health risk, societal concern, environmental benefits, pollutant removal effectiveness, regulatory compliance, public acceptance, ability to implement, cost, and technical feasibility. Section 402(p) of the Clean Water Act requires that municipal permits shall require controls to reduce the discharge of

pollutants to the maximum extent practicable, including management practices, control techniques and systems, design and engineering methods, and other provisions as the Administrator or the State determines appropriate for the control of these pollutants.

23. "**National Pollutant Discharge Elimination System (NPDES)**" means a permit issued by the U.S. EPA, State Water Resources Control Board, or the California Regional Water Quality Control Board pursuant to the Clean Water Act that authorizes discharges to Waters of the United States and requires the reduction of pollutants in the discharge.

24. "**Non-Stormwater Discharge**" means any discharge to a municipal storm drain system that is not composed entirely of stormwater.

25. "**Person**" means any individual, partnership, co-partnership, firm, company, corporation, association, joint stock company, trust, estate, governmental entity or any other legal entity, or their legal representatives, agents or assigns. The masculine gender shall include the feminine and the singular shall include the plural where indicated by the context.

26. "**Pollutant**" means any "pollutant" defined in Section 502(6) of the Federal Clean Water Act or incorporated into the California Water Code Sec. 13373. Pollutants may include, but are not limited to the following:

(a) Commercial and industrial waste (such as fuels, solvents, detergents, plastic pellets, hazardous substances, fertilizers, pesticides, slag, ash, and sludge);

(b) Metals (such as cadmium, lead, zinc, copper, silver, nickel, chromium, and non- metals such as phosphorus and arsenic);

(c) Petroleum hydrocarbons (such as fuels, lubricants, surfactants, waste oils, solvents, coolants, and grease);

(d) Excessive eroded soil, sediment, and particulate materials in amounts that may adversely affect the beneficial use of the receiving waters, flora or fauna of the State;

(e) Animal wastes (such as discharge from confinement facilities, kennels, pens, recreational facilities, stables, and show facilities); and

(f) Substances having characteristics such as pH less than 6 or greater than 9, or unusual coloration or turbidity, or excessive levels of fecal coliform, or fecal streptococcus, or enterococcus.

27. "**Receiving Waters**" means all surface water bodies within Los Angeles County that are identified by the Regional Board in a Basin Plan.

28. **"Redevelopment"** means land-disturbing activity that results in the creation, addition, or replacement of 500 square feet or more of impervious surface area on an already developed Site. Redevelopment includes, but is not limited to: the expansion of a building footprint; addition or replacement of a structure; replacement of impervious surface area that is not part of routine maintenance activity; and land disturbing activity related to structural or impervious surfaces. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility, nor does it include emergency construction activities required to immediately protect public health and safety.

29. "**Regional Board**" means the California Regional Water Quality Control Board, Los Angeles Region.

30. "**Rules and Regulations**" shall mean Rules and Regulations adopted by the Board of Public Works Governing Pollution Control of Discharges into the Storm Drain System.

31. **"Site"** means land or water area where any "facility or activity" is physically located or conducted, including adjacent land used in connection with the facility or activity.

32. "**Storm Drain System**" means any facilities or any part of those facilities, including streets, gutters, conduits, natural or artificial drains, channels and watercourses that are used for the purpose of collecting, storing, transporting or disposing of stormwater and are located within the City of Los Angeles.

33. "**Storm Water or Stormwater**" means water that originates from atmospheric moisture (rainfall or snow melt) and that falls onto land, water, or other surfaces. Without any change in its meaning, this term may be spelled or written as one word or two separate words.

34. "**Stormwater Pollution Prevention Plan (SWPPP)**" means a plan required by and for which contents are specified in the State of California General Permit for Storm Water Discharges Associated with Industrial Activities or for Stormwater Discharges Associated with Construction Activities.

35. "**Stormwater Runoff**" means that part of precipitation (rainfall or snowmelt) which travels across a surface to the storm drain system or receiving waters.

36. "**Toxic Materials**" For purposes of compliance with the Los Angeles County Municipal Stormwater Permit, the term "toxic materials" means

any material(s) or combination of materials that directly or indirectly cause either acute or chronic toxicity in the water column.

37. "**Untreated**" means non stormwater runoff, wastewater or wash waters that have not been subjected to any applicable Treatment Control, Best Management Practices or are not in compliance with conditions of a separate or general NPDES permit.

38. "**Urban Runoff**" means surface water flow produced by storm and non-storm events. Non-storm events include flow from residential, commercial or industrial activities involving the use of potable and non-potable water.

Sec. 2. Section 64.72 of Article 4.4 of Chapter VI is amended to read as follows:

SEC. 64.72. STORMWATER POLLUTION CONTROL MEASURES FOR DEVELOPMENT PLANNING AND CONSTRUCTION ACTIVITIES

(A) Objective. The provisions of this Section contain requirements for construction activities and facility operations of Development and Redevelopment projects to comply with the requirements of the Standard Urban Stormwater Mitigation Plan, integrate LID practices and standards for stormwater pollution mitigation, and maximize open, green and pervious space on all Developments and Redevelopments consistent with the City's landscape ordinance and other related requirements in the Development Best Management Practices Handbook. LID shall be inclusive of SUSMP requirements.

(B) Scope. This Section contains requirements for stormwater pollution control measures in Development and Redevelopment projects and authorizes the Board to further define and adopt stormwater pollution control measures, develop LID principles and requirements, including but not limited to the objectives and specifications for integration of LID strategies, collect Best Management Practices compliance plan check fees, grant waivers from the requirements of the Standard Urban Stormwater Mitigation Plan, collect funds for projects that are granted waivers, conduct inspections, cite violators for infractions, and impose fines. Except as otherwise provided herein, the Board shall administer, implement and enforce the provisions of this Section.

(C) LID Requirements. All Developments and Redevelopments shall comply with the following:

1. Development or Redevelopment Involving four or Fewer Units Intended for Residential Use.

a. Development or Redevelopment less than one acre shall implement LID BMP alternatives identified in the Development Best Management Practices Handbook; and

b. Development or Redevelopment one acre or greater shall comply with the standards and requirements of this Article and with the Development Best Management Practices Handbook.

2. Development or Redevelopment Involving Nonresidential Use or five or More Units Intended for Residential Use.

a. Development or Redevelopment resulting in an alteration of at least fifty percent (50%) or more of the impervious surfaces on an existing developed Site, the entire Site must comply with the standards and requirements of this Article and with the Development Best Management Practices Handbook; and

b. Development or Redevelopment resulting in an alteration of less than fifty percent (50%) of the impervious surfaces of an existing developed Site, only such incremental Development shall comply with the standards and requirements of this Article and with the Development Best Management Practices Handbook.

3. A Development or Redevelopment of any size that would create 2,500 square feet or more of impervious surface area and is located partly or wholly within an ESA shall comply with the standards and requirements of this Article and with the Development Best Management Practices Handbook.

4. The Site for every Development or Redevelopment shall be designed to manage and capture stormwater runoff, to the maximum extent feasible, in priority order: infiltration, evapotranspiration, capture and use, treated through high removal efficiency biofiltration/biotreatment system of all of the runoff on site. High removal efficiency biofiltration/biotreatment systems shall comply with the standards and requirements of the Development Best Management Practices Handbook. A LID Plan shall be prepared to comply with the following:

a. Stormwater runoff will be infiltrated, evapotranspired, captured and used, treated through high removal efficiency Best Management Practices, onsite, through stormwater management techniques that comply with the provisions of the Development Best Management Practices Handbook. To the maximum extent feasible, onsite stormwater management techniques must be properly sized, at a minimum, to infiltrate, evapotranspire, store for use, treat through high removal efficiency biofiltration/biotreatment system, without any storm water runoff leaving the Site for at least the volume of water produced by the quality design storm event that results from:

(i) The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or

(ii) The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in the California Stormwater Best Management Practices Handbook – Industrial/Commercial, (2003); or

(iii) The volume of runoff produced from a 0.75 inch storm event.

For purposes of compliance with the LID requirements, and without changing the priority order of design preferences identified in this Section, all runoff from the water quality design storm event, as identified in Paragraph (a) of this Subdivision, that has been treated through an onsite high removal efficiency biofiltration/biotreatment system shall be deemed to have achieved 100% infiltration regardless of the runoff leaving the Site from an onsite high removal efficiency biofiltration/biotreatment system, and thus any runoff volume shall not be subject to the offsite mitigation requirement of this Article.

b. Pollutants shall be prevented from leaving the Site for a water quality design storm event as defined in Paragraph (a) of this Subdivision unless it has been treated through an onsite high removal efficiency biofiltration/biotreatment system.

c. Hydromodification impacts shall be minimized to natural drainage systems as defined in the MS4 Permit.

5. When, as determined by the Director, the onsite LID requirements are technically infeasible, partially or fully, as defined in the Development Best Management Handbook, the infeasibility shall be demonstrated in the submitted LID Plan, shall be consistent with other City requirements, and shall be reviewed in consultation with the Department of Building and Safety. The technical infeasibility may result from conditions that may include, but are not limited to:

a. Locations where seasonal high groundwater is within ten feet of surface grade;

b. Locations within 100 feet of a groundwater well used for drinking water;

c. Brownfield Development sites or other locations where pollutant mobilization is a documented concern;

d. Locations with potential geotechnical hazards;

e. Locations with impermeable soil type as indicated in applicable soils and geotechnical reports; and

f. Other site or implementation constraints identified in the Development Best Management Practices Handbook.

6. If partial or complete onsite compliance of any type is technically infeasible, the project Site and LID Plan shall be required to comply with all applicable Standard Urban Stormwater Mitigation Plan (SUSMP) requirements in order to maximize onsite compliance. For the remaining runoff that cannot feasibly be managed onsite, the project shall implement offsite mitigation on public and/or private land within the same sub-watershed out of the following five sub-watersheds: Upper Los Angeles River, Lower Los Angeles River, Ballona Creek, Santa Monica Bay, and Dominguez Channel. This shall include construction and perpetual maintenance of projects that will achieve at least the same level of runoff retention, infiltration and/or use, and water quality. All City Departments will assist the developer, when and where feasible, in the design, permitting and implementation of LID BMP projects within the public right of way, with a preference for utilizing the public right of way immediately adjacent to the subject development.

7. A Multi-Phased Project may comply with the standards and requirements of this Section for all of its phases by: (a) designing a system acceptable to the Bureau of Sanitation to satisfy these standards and requirements for the entire Site during the first phase, and (b) implementing these standards and requirements for each phase of Development or Redevelopment of the Site during the first phase or prior to commencement of construction of a later phase, to the extent necessary to treat the stormwater from such later phase. For purposes of this Section, "Multi-Phased Project" shall mean any Development or Redevelopment implemented over more than one phase and the Site of a Multi-Phased Project shall include any land and water area designed and used to store, treat or manage stormwater runoff in connection with the Development or Redevelopment, including any tracts, lots, or parcels of real property, whether Developed or not, associated with, functionally connected to, or under common ownership or control with such Development or Redevelopment.

8. The Director shall prepare, maintain, and update, as deemed necessary and appropriate, the Development Best Management Practices Handbook to set LID standards and practices and standards for stormwater pollution mitigation, including urban and stormwater runoff quantity and quality control development principles and technologies for achieving the LID standards. The Development Best Management Practices Handbook shall also include technical feasibility and implementation parameters, alternative compliance for

technical infeasibility, as well as other rules, requirements and procedures as the Director deems necessary for implementing the provisions of this Section of the Los Angeles Municipal Code. The Board of Public Works shall adopt the Development Best Management Practices Handbook no later than 90 days after the adoption of this Ordinance by the City Council and the Mayor.

9. The Director of the Bureau of Sanitation shall develop as deemed necessary and appropriate, in cooperation with other City departments and stakeholders, informational bulletins, training manuals and educational materials to assist in the implementation of the LID requirements.

10. The applicant can appeal the Director's determination of compliance with the provisions of this Article to the Board of Public Works within 30 days of the date of the determination.

11. Any Development or Redevelopment that is exempted from LID requirements under section D has the option to voluntarily opt in and incorporate into the project the LID requirements set forth herein. In such case, the Best Management Practices plan check fee associated with the project shall be waived and all LID related plan check processes shall be expedited.

12. Any Development or Redevelopment exempted from this Ordinance under section D shall comply with all applicable SUSMP requirements.

(D) Exceptions to LID Requirements. The provisions of this Section do not apply to any of the following:

1. A Development or Redevelopment that only creates, adds or replaces less than 500 square feet of impervious area;

2. A Development or Redevelopment involving only emergency construction activity required to immediately protect public health and safety;

3. Infrastructure projects within the public right-of-way;

4. A Development or Redevelopment involving only activity related to gas, water, cable, or electricity services on private property;

5. A Development or Redevelopment involving only re-striping of permitted parking lots;

6. A project involving only exterior movie or television production sets, or facades on an existing developed site.

(E) Other Agencies of the City of Los Angeles. All City of Los Angeles departments, offices, entities and agencies, shall establish administrative procedures necessary to implement the provisions of this Article on their Development and Redevelopment projects and report their activities annually to the Board of Public Works.

Sec. 3. Section 64.72.05 of Article 4.4 of Chapter VI of the Los Angeles Municipal Code is amended to read:

SEC. 64.72.05. LID PLAN CHECK FEES.

(A) Before review and approval of a set of plans and specifications for checking, the applicant shall pay a Best Management Practices plan check fee.

(B) The fee schedule for providing Best Management Practices plan check services for LID Implementation Plan, Standard Urban Stormwater Mitigation Plan (SUSMP), or Site Specific Mitigation Plan (SSMP) is as follows:

DEVELOPMENT CATEGORY	FEES
Development or Redevelopment less than 500 square feet	Exempt
Residential, 4 Units or Less:	
For Development or Redevelopment greater than or equal to 500 square feet and less than 2,500 square feet	$20 / Project
For Development or Redevelopment greater than or equal to 2,500 square feet	$200 / Project
Development or Redevelopment of any size that would create 2,500 square feet or more of impervious surface area and is located partly or wholly within an ESA*	$700 / Project
Nonresidential Use or 5 or More Units Intended for Residential Use:	
For Redevelopment that results in an alteration of less than fifty (50) percent of the impervious surfaces of an existing developed Site	$800 / Project
For new Development or where Redevelopment that results in an alteration of at least fifty (50) percent or more of the impervious surfaces of an existing developed Site	$1,000 / Project

* Projects located in, adjacent to, or discharging directly to a designated Environmentally Sensitive Area (ESA)

(C) At the discretion of the Bureau of Sanitation, a large scale project may be categorized as a Special Project and billed on actual cost incurred by the City.

(D) Off-hour Plan Check Fee. An applicant may apply to have the Bureau of Sanitation provide plan check services at other than normal working hours. If the Bureau approves an expedited application, the applicant must pay to the Bureau, in addition to the fees identified in Subsection B of this Section, an additional fifty percent of the fees owed.

(E) All entities, including City Departments and other public agencies, are required to pay the fees identified in Subsection B of this Section.

(F) All monies collected pursuant to the provisions of this Section shall be placed and deposited into the Stormwater Pollution Abatement Fund, under a separate account for each sub-watershed, established by Section 64.51.11 of this Code.

Sec. 4. The provisions of this Ordinance shall be operative 180 days after the effective date of the Ordinance, except that the provisions shall not apply to any of the following:

1. Any Development or Redevelopment for which the Department of Building and Safety accepted a permit application before the effective date of this Ordinance, and for which the permit applicant paid, before the effective date of this Ordinance, to the Department of Building and Safety all fees required by the Department to process the permit application; or

2. Any Development or Redevelopment for which a required entitlement application was filed with the Department of City Planning, and for which Department review of the application, with the exception of CEQA review, was deemed complete by the Department before the operative date of this Ordinance.

Sec. 5. If any provision of this Ordinance is found to be unconstitutional or otherwise invalid by any court of competent jurisdiction, such invalidity shall not affect the validity or enforceability of the remaining provisions of this Ordinance, and the provisions of this Ordinance are declared to be severable.

Sec. 6. The City Clerk shall certify to the passage of this ordinance and have it published in accordance with Council policy, either in a daily newspaper circulated in the City of Los Angeles or by posting for ten days in three public places in the City of Los Angeles: one copy on the bulletin board located at the Main Street entrance to the Los Angeles City Hall; one copy on the bulletin board located at the Main Street entrance to the Los Angeles City Hall East; and one copy on the bulletin board located at the Temple Street entrance to the Los Angeles County Hall of Records.

I hereby certify that this ordinance was passed by the Council of the City of Los Angeles, at its meeting of SEP 27 2011.

JUNE LAGMAY, City Clerk

By [signature]
Deputy

Approved OCT 07 2011

[signature]
Mayor

Approved as to Form and Legality:

CARMEN A. TRUTANICH, City Attorney

By John A. Carvalho (PBE)
JOHN A. CARVALHO
Deputy City Attorney

Date Aug 5, 2011

File No. 09-1554

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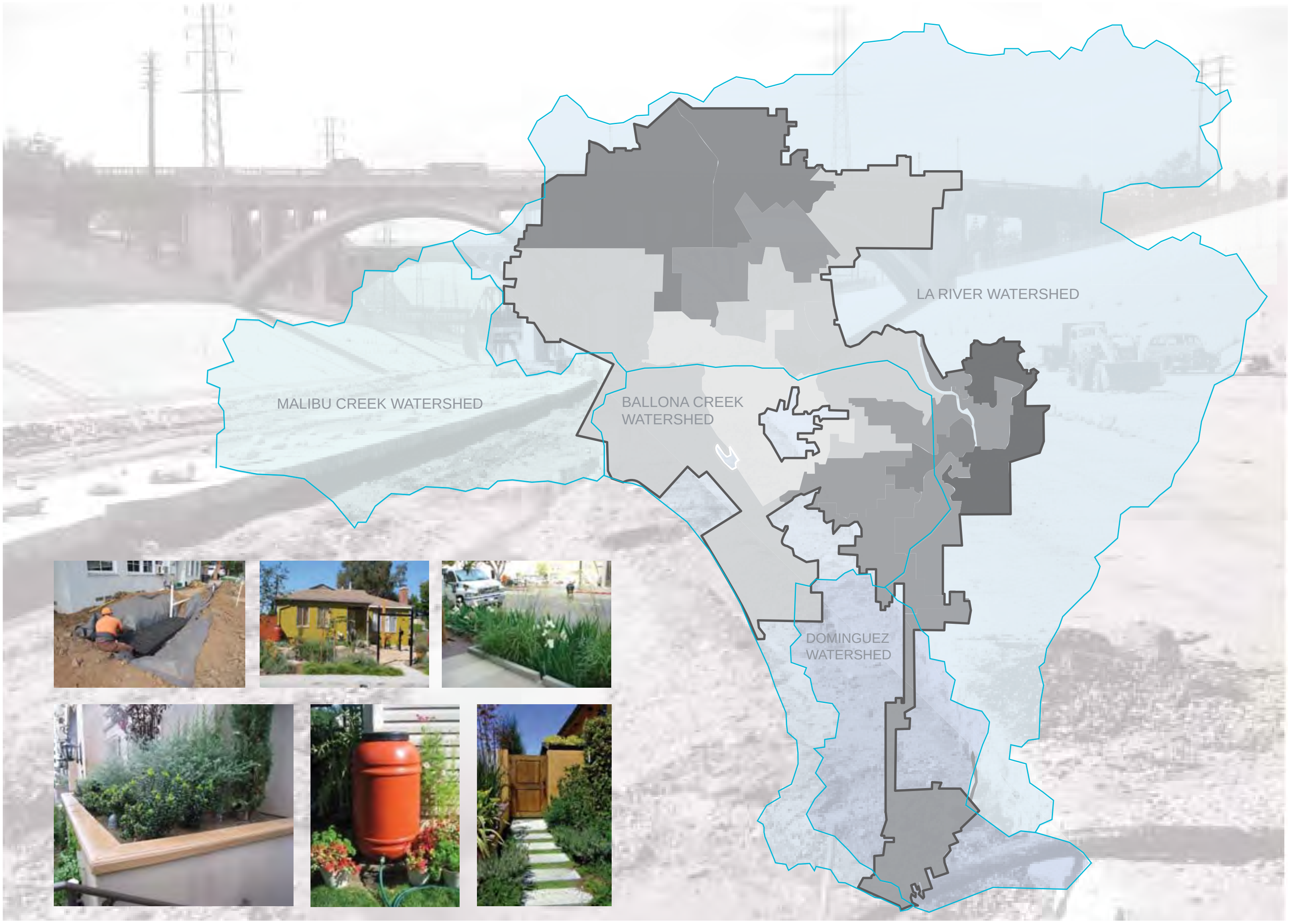

DEVELOPMENT BEST MANAGEMENT PRACTICES HANDBOOK

WORKING DRAFT OF LID MANUAL

June 2011

PART B
PLANNING ACTIVITIES
FOURTH EDITION

WATERSHED PROTECTION DIVISION

CITY OF LOS ANGELES
SANITATION
DEPARTMENT OF PUBLIC WORKS

CITY OF LOS ANGELES FOUNDED 1781

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For conformance with the National Pollutant Discharge Elimination System (NPDES) Permit for Municipal Stormwater and Urban Runoff Discharges – Development Planning Program requirements, a significant portion of this handbook's information has been copied verbatim from documents issued by the State of California Regional Water Quality Control Board - Los Angeles Region (Regional Board) and the Los Angeles County Department of Public Works (LACDPW), and modified to suit the needs of the City of Los Angeles. These documents include the National Pollutant Discharge Elimination System Permit (NPDES No. CAS004001, Board Order No. 01-182), the Standard Urban Stormwater Mitigation Plan (SUSMP) (Board Resolution No. R-00-02) issued by the Regional Board to the County of Los Angeles and its co-permittees, and the LACDPW Development Planning Manual for Stormwater Management (Manual for the Standard Urban Stormwater Mitigation Plan).

This 4th edition is a revision to the 3rd edition to reflect the newly adopted Low Impact Development (LID) requirements that take effect [Date XX, XXXX]. The handbook was created under the direction of the City of Los Angeles, who is fully responsible for the content within.

This Development Best Management Practices Handbook, Part B Planning Activities, 4th edition was adopted by the City of Los Angeles, Board of Public Works on Date XX, XXXX] as authorized by Section 64.72 of the Los Angeles Municipal Code approved by Ordinance No. XXXXX.

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ACRONYMS AND ABBREVIATION

ASCE	American Society of Civil Engineers
BMP	best management practices
BOS	Bureau of Sanitation
CEQA	California Environmental Quality Act
CZARA	Coastal Zone Act Reauthorization Amendments of 1990
C&A	Covenant and Agreement
DCP	Los Angeles Department of City Planning
DPW	Los Angeles Department of Public Works
EAF	environmental assessment form
EIR	Environmental Impact Report
EPA	United States Environmental Protection Agency
CGPL	California General Plan Law
HC	hydrocarbons
LADBS	Los Angeles Department of Building and Safety
LID	Low Impact Development
MEP	Maximum Extent Practicable (statutory standard)
MND	Mitigated Negative Declaration
NPDES	National Pollutant Discharge Elimination System
O&G	oil and grease
O&M	operation and maintenance
RGO	retail gasoline outlets
RWQCB	Los Angeles Regional Water Quality Control Board
sf	square feet
SIC	Standard Industrial Classification
SWRCB	State Water Resources Control Board (California)
SUSMP	Standard Urban Stormwater Mitigation Plan
ULARA	UpperLos AngelesRiver Area
ULARWM	UpperLos AngelesRiver Water Master
WEF	Water Environment Federation
WPD	Watershed Protection Division

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SECTION 1: INTRODUCTION

1.1 BACKGROUND

Urban runoff discharged from municipal storm drain systems has been identified by local, regional, and national research programs as one of the principal causes of water quality impacts in most urban areas. Non-point source pollution, the diffuse pollution not traceable to a specific source, causes public health risks and safety concerns. Urban runoff potentially contains a host of pollutants such as trash and debris, bacteria and viruses, oil and grease, sediments, nutrients, metals, and toxic chemicals. These contaminants can adversely affect receiving and coastal waters, associated biota, and public health. While the impact of urban runoff pollution may not be immediately realized, the eventual effects can be dramatic. Urban runoff pollution is not only a problem during rainy seasons, but throughout the entire year due to all types of urban water use.

Stormwater pollution affects human life and aquatic plant and animal life. Potentially harmful viruses and bacteria are now found in our coastal waters along with soil particles, solids/ debris, litter, oil, grease, and chemical compounds. An epidemiological study (Haile, 1999) by the Santa Monica Bay Restoration Project, a project approved by Governor Pete Wilson and the United States Environmental Protection Agency (EPA), was conducted to investigate possible health effects of swimming in Santa Monica Bay. Study results indicated that individuals swimming near flowing storm drain outlets have a greater risk of developing various symptoms of illnesses compared to those swimming 400 yards away from the same drains (Haile, 1999). These pollutants also impact the natural aquatic habitat.

Oil and grease from parking lots, leaking petroleum or other hydrocarbon products, leachate from storage tanks, pesticides, cleaning solvents, and other toxic chemicals can contaminate stormwater and be transported downstream into water bodies and receiving waters. Fertilizer constituents from lawns and golf courses or leaking septic tanks can cause algal blooms. Disturbances of the soil from construction can allow silt to wash into storm channels and receiving waters, making them muddy, cloudy, and inhospitable to natural aquatic organisms. Heavy metals are toxic to aquatic organisms and many artificial surfaces of the urban environment such as galvanized metal, paint, or preserved wood containing metals contribute to stormwater pollution as the surfaces corrode, flake, dissolve, or decay.

Land development and construction activities significantly alter drainage patterns and contribute pollutants to urban runoff primarily through erosion and removal or change of existing natural vegetation. When homes, work places, recreational areas, roads, parking lots, and structures are built, and as other land disturbances occur, waterways can become altered. Water, potentially loaded with pollutants, flows preferentially through the new pathways. As the amount of impervious surface increases, water that once percolated into the soil now flows over the land surface. Accordingly, increases in impervious surfaces can increase the frequency and intensity of stormwater flows through a watershed. Flow from rainstorms and other water uses wash rapidly across the impervious landscape, scouring the surface of various kinds of urban pollutants such as automotive fluids, cleaning solvents, toxic or hazardous chemicals, detergents, sediment, metals, pesticides, oil and grease, and food wastes. These pollutants, unfiltered and unfettered, flow through stormwater infrastructure and ultimately contaminate receiving waters.

1.2 USERS OF THE HANDBOOK

This handbook provides guidance for individuals involved in new development and redevelopment projects. The target audience for this handbook includes developers, designers, contractors, homeowners, and other City of Los Angeles departments who are involved in site development, as well as the general public that may have an interest in stormwater pollution control.

1.3 HANDBOOK PURPOSE AND SCOPE

The purpose of this handbook is to assist developers in complying with the requirements of the Development Planning Program regulations of the City's Stormwater Program. This handbook summarizes the City's project review and permitting process, identifies stormwater mitigation measures, and references source and treatment control BMP information. This handbook also contains the necessary forms and worksheets required to be completed by the developer for approval.

1.4 LEGAL FRAMEWORK

With public concern growing over urban runoff and stormwater pollution, local, state, and federal agencies have devised plans to control and/or treat stormwater-related pollution before it reaches receiving waters.

The Federal Clean Water Act is the principal vehicle for control of stormwater pollution. Other programs dealing with stormwater pollution include the State of California General Plan Law (CGPL) for Municipalities and the California Environmental Quality Act (CEQA). Under the Federal Clean Water Act, each municipality throughout the nation is issued a stormwater permit through the National Pollutant Discharge Elimination System (NPDES) program. The primary goal of each permit is to stop polluted discharges from entering the storm drain system and local receiving and coastal waters. In California, the NPDES stormwater permitting program is administered by the State Water Resources Control Board (SWRCB) through its nine Regional Boards.

On July 5, 1996, the Los Angeles Regional Water Quality Control Board (Regional Board or RWQCB) adopted Order No. 96-054- the NPDES Stormwater Permit (Permit) for the County of Los Angeles and cities within (NPDES No. CAS614001). The Permit was issued to Los Angeles County and 84 permittee cities to reduce pollutants discharged from their Municipal Separate Storm Sewer Systems (MS4) to the Maximum Extent Practicable (MEP) statutory standard. The Permit is issued every five years. On December 13, 2001, the Regional Board adopted a new Permit (Order No. 01-182, NPDES Permit No. CAS004001) and amended it in 2007. Under this new Permit, the County of Los Angeles is designated as the Principal Permittee and the 84 cities, including the City of Los Angeles, as Permittees.

The requirement to implement the Permit is based on federal and state statutes, including Section 402(p) of the Federal Clean Water Act, Section 6217 of the Coastal Zone Act Reauthorization Amendments (CZARA) of 1990, and the California Water Code. The Federal Clean Water Act amendments of 1987 established a framework for regulating stormwater discharges from municipal, industrial, and construction activities under the NPDES program. The primary objectives of the stormwater program requirements are to:

- Effectively prohibit non-stormwater discharges, and
- Reduce the discharge of pollutants from stormwater conveyance systems to the MEP statutory standard.

Based on the Permit issued by the Regional Board, the County and its co-permittees are required to develop and implement a number of stormwater management programs designed to reduce pollutants in stormwater and urban runoff. These programs are the Public Information and Participation Program, Industrial/Commercial Facilities Program, Illicit Connections and Illicit Discharges Elimination Program, Development Planning Program, Development Construction Program, Public Agency Activities Program, and the Monitoring and Reporting Program.

One of these programs, the Development Planning Program, focuses on preventing pollutants that could be generated from new development and redevelopment projects from reaching stormwater conveyance systems and receiving waters.

A relatively recent stormwater management approach aimed at achieving this goal is the use of Low Impact Development (LID). Over the past 10 years, LID practices have received increased attention and implementation, becoming a leading practice for stormwater pollution prevention. In recognition of this, recent actions by the RWQCB, SWRCB, and US EPA have prioritized the use of LID as the preferred approach to stormwater management, including for the purpose of water quality compliance.

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Low Impact Development is a stormwater management strategy that seeks to mitigate the impacts of increases in runoff and stormwater pollution as close to its source as possible. LID comprises a set of site design approaches and Best Management Practices (BMPs) that promote the use of natural systems for infiltration, evapotranspiration, and use of stormwater. These LID practices can effectively remove nutrients, bacteria, and metals from stormwater while reducing the volume and intensity of stormwater flows. With respect to urban development and redevelopment projects, it can be applied onsite to mimic the site's predevelopment drainage characteristics. Through the use of various infiltration techniques, LID is geared towards minimizing surface area that produces large amounts of runoff and does not allow water to infiltrate into the ground. Where infiltration is infeasible, the use of bioretention, rain gardens, vegetated rooftops, and rain barrels that will store, evaporate, detain, and/or treat runoff can be used.

The City of Los Angeles is adopting LID standards and practices for the purpose of:

- Requiring the use of LID standards and practices in future developments and redevelopments to encourage the beneficial use of rainwater and urban runoff;
- Reducing stormwater/urban runoff while improving water quality;
- Promoting rainwater harvesting;
- Reducing offsite runoff and providing increased groundwater recharge;
- Reducing erosion and hydrologic impacts downstream; and
- Enhancing the recreational and aesthetic values in our communities.

In addition to LID requirements, the City must also comply with the Los Angeles Regional Water Quality Board requirements for Standard Urban Stormwater Mitigation Plan (SUSMP) which requires specific development and redevelopment categories to mitigate (either infiltrate or treat) stormwater runoff. The City of Los Angeles institutionalized the use of LID techniques for development and redevelopment projects by the adoption of Stormwater LID Ordinance XXXXXX. With the adoption of Stormwater LID Ordinance XXXXXX, this handbook has been amended to require stormwater mitigation for a much larger number of development projects.

Also, the California CGPL and CEQA provide a basis for municipalities to review and comment on all projects within their jurisdiction. Under the CGPL, municipalities are required to develop policies and regulations that guide development within the municipality. Each development project is reviewed for conformance with these policies. Under CEQA, projects are also subject to review and comment for potential adverse environmental impacts, including impacts from stormwater discharges.

1.5 DEVELOPMENT PLANNING PROGRAM

The Development Planning Program is, in order of priority, comprised of a LID Plan, and/or a Standard Urban Stormwater Mitigation Plan (SUSMP), and/or a Site Specific Mitigation Plan. This handbook provides guidance for compliance with the LID, SUSMP, and Site Specific Mitigation Plan requirements. Project applicants will be required to incorporate stormwater mitigation measures into their design plans and submit the plans to the City for review and approval as described in Section 2.

1.5.1 Low Impact Development Plan

Adopted by the City of Los Angeles on [DATE], the Stormwater LID Ordinance XXXXX requires stormwater mitigation for a much larger number of development and redevelopment projects than was previously required under SUSMP. Prior to the implementation of the LID Ordinance, the City's SUSMP program required only specific development and redevelopment categories to incorporate stormwater BMPs. The Stormwater LID Ordinance has expanded these categories to include all development and redevelopment projects that create, add, or replace 500 square feet or more of impervious area.

The Stormwater LID Ordinance applies to all development and redevelopment in the City of Los Angeles that requires building permits within the City after the ordinance effective date except for the following:

- Any development and redevelopment that creates, adds, or replaces less than 500 square feet of impervious area;
- Any development or redevelopment not requiring a building permit;
- Any building alteration or addition that does not expand the building footprint;
- Use of Land Permits that require no addition to or alteration of existing impervious surfaces;
- Re-striping of permitted parking lots;
- Any development and redevelopment involving emergency construction activities required to immediately protect public health and safety;
- Infrastructure projects within the public right-of-way, and utilities on private property (gas, water, cable, telephone, electric, etc.);
- Exterior movie and television production sets and/or facades on existing developed sites;
- Any development or redevelopment for which plans and complete application are accepted by the Department of Building and Safety for plan check and the appropriate fee is paid prior the effective date of the stormwater LID ordinance; and

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- Any entitlement application for a Development or Redevelopment filed with the Department of City Planning and deemed complete with the exception of CEQA review prior to the effective date of this Stormwater LID ordinance.

1.5.2 Standard Urban Stormwater Mitigation Plan (SUSMP)

The SUSMP was adopted by the Regional Board on March 8, 2000 under Resolution No. R-00-02, and was further amended by the SWRCB on October 5, 2000 under State Water Board Order WQ 2000-11. The SUSMP was developed as part of the municipal stormwater program to address stormwater pollution from new development and redevelopment projects.

The NPDES Permit cites the categories of new development and redevelopment projects that require stormwater mitigation measures and outlines the necessary BMPs applicable to each category. The following project categories require a SUSMP:

1. Single-family hillside residential developments[1]
2. Housing developments (including single-family homes, multi-family homes, condominiums, and apartments) of ten or more units
3. Industrial/Commercial[2] developments of one acre or more of impervious surface area
4. Automotive service facilities (SIC 5013, 5014, 5541, 7532-7534, and 7536-7539)
5. Retail gasoline outlets
6. Restaurants (SIC 5812)
7. Parking lots with 5,000 square feet or more of surface area, including accessory driveways, or with 25 or more parking spaces
8. Projects located in, adjacent to, or discharging directly to a designated Environmentally Sensitive Area (ESA)

1Single-family hillside developments less than one are excluded from the numerical Structural and Treatment Control BMP design standard requirements.

2 Commercial Development: any development that is not heavy industrial or residential. The category includes, but is not limited to: hospitals, laboratories and other medical facilities, educational institutions, recreational facilities, plant nurseries, car wash facilities, mini-malls and other business complexes, shopping malls, hotels, office buildings, public warehouses and other light industrial complexes.

Industrial/Commercial Facility: any facility involved and/or used in the production, manufacturing, storage, transportation, distribution, exchange or sale of goods and/or commodities, and any facility involved and/or used in providing professional and non-professional services. This category of facilities includes, but is not limited to, any facility defined by the Standard Industrial Classifications (SIC).

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1.5.3 Site Specific Mitigation Plan

New development and/or redevelopment projects not requiring a LID or SUSMP but which may potentially have adverse impacts on stormwater quality must incorporate a Site Specific Mitigation plan to mitigate stormwater pollution. Such projects may have, but are not limited to, one or more of the following characteristics:

1. Vehicle or equipment fueling areas
2. Vehicle or equipment maintenance areas, including washing and repair
3. Commercial or industrial waste handling or storage
4. Outdoor handling or storage of hazardous materials
5. Outdoor manufacturing areas
6. Outdoor food handling or processing
7. Outdoor animal care, confinement, or slaughter
8. Outdoor horticulture activities
9. Major transportation projects

Projects with one or more of the above characteristics or any project that is subject to the Site Specific Mitigation requirement will be required to incorporate appropriate stormwater mitigation measures or apply either LID or SUSMP to satisfy stormwater requirements.

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SECTION 2: PROJECT REVIEW AND PERMITTING PROCESS

2.1 PLAN APPROVAL PROCESS

The requirement to incorporate stormwater pollution control measures into the design plans of new development and redevelopment projects in order to mitigate stormwater quality impacts is implemented through the City's plan review and approval process. During the review process, the plans will be reviewed for compliance with the City's General Plans, zoning ordinances, and other applicable local ordinances and codes, including stormwater requirements. Plans and specifications will be reviewed to ensure that the appropriate BMPs are incorporated to address stormwater pollution prevention goals. The reviewer will also determine if project designs need to be modified to address stormwater pollution prevention objectives.

New development and redevelopment projects are mainly processed through the Department of City Planning (DCP) and the Department of Building and Safety (LADBS). Entitlement approvals are processed by DCP and these projects require discretionary action. Building/Grading Permit approvals are processed by LADBS.

2.1.1 Department of City Planning Process

The Permit requirements are incorporated into the CEQA process for discretionary projects. As outlined in Section 1.5 of this handbook, certain project categories are considered to be potentially harmful to stormwater quality.

The CGPL and CEQA provide a basis for municipalities to review and comment on all projects within their jurisdiction. Under the CGPL, municipalities are required to develop policies and regulations that guide developments within their municipalities. Each development project is then reviewed for conformance with these policies. Under CEQA, projects are also subject to review for any adverse impacts the projects may have on the environment, including those impacts from stormwater discharges. These project types (e.g., zone variances, conditional use permits, plan amendments, site plan reviews, etc.) are considered discretionary review projects requiring review by an elected or appointed decision-making body. Mitigation measures for stormwater quality impacts (such as stormwater BMPs) will be incorporated into the project during environmental and project reviews. The project will be reviewed to ensure that required stormwater BMPs are included. Planning approvals for discretionary projects will not be granted until stormwater mitigation measures are incorporated into the project plans.

All applications for DCP's discretionary decisions are required to be accompanied by an environmental clearance (e.g., Categorical Exemption, Negative Declaration, Mitigated Negative

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Declaration, or Environmental Impact Report). When an applicant files an application for a discretionary project, DCP staff at the public counter will determine whether the project qualifies for an exemption from CEQA. If the project is not exempt and could possibly have a significant impact, the applicant files an Environmental Assessment Form (EAF).

The DCP Environmental Review Section prepares the Initial Study and Checklist. DCP will indicate if the project will impact water absorption rates, drainage patterns, urban runoff or other water quality issues. If no significant effect upon the environment is found, a Negative Declaration will be issued for the project. If mitigation measures are needed, a Mitigated Negative Declaration (MND) is issued for the project, or an Environmental Impact Report (EIR) is required. Stormwater mitigation measures (as shown in Appendix B) will be added to the MND or the EIR for the decision-maker to impose as conditions.

The project applicant must incorporate stormwater pollution control measures into the design plans and submit these plans to the Department of Public Works, Bureau of Sanitation, Watershed Protection Division (WPD) for review and approval. See Appendix Cfor contact information. Upon satisfaction that all stormwater requirements have been met, WPD staff will stamp the plan approved. Following approval by DCP, building/grading permits are obtained from LADBS.

2.1.2 Department of Building and Safety Process

Applicants must submit design plans to LADBS personnel for review and approval prior to issuance of building/grading permits. LADBS personnel determine if the project requires stormwater mitigation measures and refer applicable projects to WPD for review and approval. LADBS issues the applicant a “Clearance Worksheet” that identifies all of the outstanding approvals from City agencies (see Appendix D). A building/grading permit will be issued once all corrections have been completed and clearances are obtained, including for stormwater requirements.

Outlined below are some guidelines for project applicants to follow in submitting design plans for review and approval.

Step One- Submit design plans

The project applicant submits the design plans to LADBS. During the plan review process, LADBS will refer projects needing discretionary action to DCP for additional processing.

Step Two - Define the project category

The plan check engineer will review the design plans and determine if the project falls under any of the SUSMP categories or meets any of the characteristics identified under Site Specific

Mitigation or LID requirements. If the project falls into any one of the SUSMP categories or characteristics cited under Site Specific Mitigation or LID, the plan check engineer will refer the applicant to WPD.

2.1.3 Department of Public Works / Bureau of Sanitation Process

To ensure compliance with all City Codes, it is recommended that the architect, civil engineer, plumbing engineer, and/ or landscape engineer coordinate at the early stage of the project design.

Step One - Identify appropriate BMPs

Identify, evaluate, and incorporate into the plan documents the appropriate BMP(s) for the project categories listed in Section 3.1 (LID), Section 3.2 (SUSMP), or Section 3.3 (Site Specific Mitigation) of this handbook, whichever is applicable.

To assist the residents in small scale residential development / redevelopment projects (4 units or less) Appendix E contains prescriptive methods detailing BMPs to be incorporated into the design plans. The advantage of the prescriptive methods is they are designed as pre-approved “boiler plates.” Use of prescriptive methods for these types of project categories will dramatically reduce plan preparation and review time.

Approval for development projects and building/grading permits will not be granted/issued until appropriate and applicable stormwater BMPs are incorporated into the project design plans. Also, a plumbing permit from LADBS will be required for certain treatment control BMPs such as grease traps, sump pumps, and clarifiers. For all projects other than small scale residential developments (4 units or less), if an infiltration BMP is chosen for treatment control, a soils report to address the feasibility of infiltration will be required to be submitted with the plan for review and approval.

Step Two– Submit LID, SUSMP, and/or Site Specific Mitigation plans to WPD

The following is a list of the minimum submittal requirements for Small Scale Residential Developments (4 units or less):

- Three sets of full plans (plot, elevation, utility, mechanical, plumbing, architectural, and landscape plans). WPD keeps one set of plans.
- Plans must include at least the following:
    - Location, size, and capacity of all BMPs on plans
    - Landscaping areas

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The following is a list of the minimum submittal requirement for all other projects:

- Three sets of grading and/or site plans (may need plumbing, architectural, and landscape plans). WPD keeps one set of plans.
- Plans must be wet-stamped and signed by an engineer or architect.
- Plans must include at least the following:
    - Location of all BMPs on plans, including elevations and drainage patterns.
    - Detailed drawings of all BMPs, including model, size, and capacity
    - Stenciling note and/or detail
    - Trash enclosure location and details
    - Landscaping areas
- Flow calculations identifying flow rate or volume of stormwater runoff that must be treated (see Appendix F). Submit the manufacturer's product specifications to verify that the selected BMP model can adequately handle the design flow rate.
- Covenant & Agreement Form with an Operation & Maintenance Plan (see Appendix D)

Step Three – WPD Approval

Once all LID/SUSMP/Site Specific Mitigation requirements have been met, WPD staff will stamp the plans approved, sign the applicant's clearance worksheet, and clear the project in the LADBS plan check tracking system, known as the Plan Check and Inspection System (PCIS).

2.2 INSPECTION PROCESS

To ensure that all stormwater related BMPs are constructed and/or installed in accordance with the approved SUSMP, Site Specific Mitigation Plan, or LID plan. The City may require a Stormwater Observation Report (SOR) be submitted to the City prior to the issuance of the Certificate of Occupancy (see Appendix D). This is particularly true for complex projects. The SOR shall be prepared, signed, and stamped by the engineer of record (for example, a California-licensed civil engineer or qualified professional) responsible for the approved LID/SUSMP/Site Specific Mitigation Plan, certifying that:

1. He/she is the engineer or architect responsible for the approved LID/SUSMP/Site Specific Mitigation Plan and
2. He/she or the designated staff under his/her responsible charge has performed the required site visits at each significant construction stage and at completion to verify that

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the BMPs shown on the approved plan have been constructed and installed in accordance with the approved LID/SUSMP/Site Specific Mitigation Plan.

The Certificate of Occupancy will be issued after all required clearances are obtained; the project has been determined, through the normal inspection process, to be built in accordance with the approved plan, including the construction and/or installation of appropriate stormwater-related BMPs; and the project has been determined to comply with all applicable codes, ordinances, and other laws.

2.3 BMP MAINTENANCE COVENANT AND AGREEMENT

A Covenant and Agreement (C&A) document shall be submitted, along with the design plans showing the project's stormwater measures, during the plan review and approval process, and must be signed by the legal owner or authorized agent of the property. The C&A shall also be recorded with the County Recorder. The City will withhold the grading and/or building permit for the development application until this requirement is satisfied. A sample form of the C&A is provided in Appendix D.

Maintenance is crucial for proper and continuous operation, effectiveness, and efficiency of a structural or treatment control BMP. The cost of long-term maintenance should be evaluated during the BMP selection process. By signing a maintenance C&A, the legal property owner affirms he/she will perform regular and long-term maintenance of all BMPs installed onsite. For residential properties where the structural or treatment control BMPs are located within a common area and will be maintained by a homeowner's association, language regarding the responsibility for maintenance must be included in the project's conditions, covenants and restrictions (CC&Rs). The C&A is bound to the property and transfers to the new owner with any subsequent sale of the property. Attached to the C&A will be an Operation and Maintenance (O&M) Plan (see Appendix D for a sample) describing the BMP operation and maintenance procedures, employee training program and duties, operating schedule, maintenance frequency, routine service schedule, and other activities. A Maintenance Log shall be maintained at the facility to document all of the activities mentioned above. These documents may be inspected by the City of Los Angeles at any time and shall be made available to the City upon request.

2.4 MUNICIPAL PROJECTS

Stormwater mitigation measures are required for all projects subject to the LID, SUSMP, or Site Specific Mitigation Plan. City projects that will be processed through DCP and/or LADBS will be subject to the review and approval process described in Section 2.1. For other City projects that do not undergo the plan review and approval process with DCP and/or LADBS, the public agency may use this handbook to incorporate the required stormwater mitigation measures into their projects.

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2.5 OTHER PUBLIC AGENCY PROJECTS

Public agency projects other than from the City of Los Angeles, such as from Caltrans, the Metropolitan Transit Authority, etc., that are subject to the SUSMP or Site Specific Mitigation and require a permit from the City of Los Angeles are required to implement stormwater mitigation measures. Examples of such projects include the Alameda Corridor, Metro Rail stations, airport runways, and busways. Such projects must incorporate stormwater BMPs into their design plans and specifications, which must be submitted to WPD for review and approval.

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SECTION 3: STORMWATER MANAGEMENT MEASURES

3.1 LOW IMPACT DEVELOPMENT (LID) PLAN

Project applicants for all developments and redevelopments will be required to incorporate stormwater mitigation measures into their design plans and submit the plans to the City for review and approval. The design plans will be subjected to a review process as indicated in Section 2, prior to the issuance of approvals for building and/or grading permits.

Projects that are part of a larger common plan of development involving five units or more will be subject to the requirements for "All Other Development", as set forth in Section 3.1.2. This includes projects that are subject to one common grading permit and projects that have phased schedules or are intended to be sectioned-off for sale to individual homeowners.

Project applicants for all developments and redevelopments will also be required incorporate the following performance measures and practices into their design plans.

Conserve Natural Areas

Each project site possesses unique topographic, hydrologic and vegetative features, some of which are more suitable for development than others. Locating development on the least sensitive portion of a site and conserving naturally vegetated areas can minimize environmental impacts in general and stormwater runoff impacts in particular.

If applicable and feasible for the given site conditions, the following measures are required and should be included in the project site layout:

1. Concentrate or cluster improvements on the least-sensitive portions of the site, while leaving the remaining land in a natural undisturbed state;
2. Limit clearing and grading of native vegetation at the site to the minimum area needed to build the home, allow access, and provide fire protection;
3. Maximize trees and other vegetation at the site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought-tolerant plants; and
4. Preserve riparian areas and wetlands.

Protect Slopes and Channels

Erosion of slopes and channels can be a major source of sediment and associated pollutants, such as nutrients, if not properly protected and stabilized.

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Slope Protection
Slope protection practices must conform to design requirements or standards set forth by local permitting agency erosion and sediment control standards and design standards. The post-construction design criteria described below are intended to enhance and be consistent with these local standards.

1. Slopes must be protected from erosion by safely conveying runoff from the tops of slopes.
2. Slopes must be vegetated with first consideration given to native or drought-tolerant species.

Channel Protection
The following measures should be implemented to provide erosion protection to unlined receiving streams on the project site. Activities and structures must conform to applicable permitting requirements, standards and specifications of agencies with jurisdiction (e.g., U.S. Army Corps of Engineers, California Department of Fish and Game, or Regional Water Quality Control Board).

1. Utilize natural drainage systems to the maximum extent practicable, but minimize runoff discharge to the maximum extent practicable.
2. Stabilize permanent channel crossings.
3. Install energy dissipaters, such as rock riprap, at the outlets of storm drains, culverts, conduits or channels that discharge into unlined channels.

Provide Storm Drain System Stenciling and Signage
Storm drain message markers or placards are required at all storm drain inlets within the boundary of the project. The marker should be placed in clear sight facing toward anyone approaching the inlet from either side. All storm drain inlet locations must be identified on the development site map.

Some local agencies within the City have approved storm drain message placards for use. Consult local permitting agency stormwater staff to determine specific requirements for placard types and methods of application.

3.1.1 SMALL SCALE RESIDENTIAL DEVELOPMENTPROJECTS (4 UNITS AND LESS)

Small scale residential projects include all projects that increase impervious area by more than 500 square feet (i.e., residential development of 4 units or less and all other developments that are not subject to Section 1.5.2). These projects are not required to complete formal hydrologic analysis or to get approval from the Upper Los Angeles River Water Master (ULARWM). The

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basic objectives for these projects include reducing a site's impervious surfaces, improving a site's ability to infiltrate stormwater, conserving stormwater runoff for other on-site water demand uses, and reducing negative impacts downstream.

REQUIREMENTS:

i. For new development less than 1 acre (including hillside development and redevelopment), the development shall implement adequately sized LID BMP alternatives as defined and listed in Appendix E; or

ii. For new developments that are one acre or larger, the development shall comply with the standards and requirements of Section 3.1.2 - All Other Developments; or

iii. For all new development and redevelopment projects ≥2,500 square feet that lie within an ESA, the development shall comply with the standards and requirements of Section 3.1.2 - All Other Developments.

BEST MANAGEMENT PRACTICES (BMPS):

Upon filing an application for a Building Permit with LADBS, a separate plot plan identifying the LID BMPs that are used (including size) and drainage area tributary to each BMP shall be shown in accordance with the prescriptive methods.

The following LID BMPs have been established as prescriptive LID improvement features to be employed on a qualifying small scale project. These BMPs are presented in the form of Fact Sheets in Appendix E with the intent of providing self-contained BMP background context and sizing requirements to facilitate a permit applicant to follow and comply with the City of Los Angeles' Stormwater LID Ordinance. Applicants may choose from one or more of the prescriptive BMPs to comply with the ordinance.

The specific small scale BMPs include the following:

1. Rain Barrels & Small Cisterns
2. Permeable Pavements (or Porous Pavement Systems)
3. Planter Boxes
4. Rain Gardens
5. Dry Wells

Figure 3.1 demonstrates the use of all five of these small scale residential BMPs at a residence.

Figure 3.1- Small Scale Residential BMP Schematic

3.1.2 ALL OTHER DEVELOPMENTS

Any new development or redevelopment project that does not meet the requirements of Section 3.1.1 – Small Scale Residential Development Projects shall comply with this section.

A LID Plan shall be prepared to comply with the following:

1. Stormwater runoff will be infiltrated, evapotranspired, captured and used, and/or treated through high removal efficiency Best Management Practices onsite, through stormwater management techniques as identified in Section 4.1. The onsite stormwater management techniques must be properly sized, at a minimum, to infiltrate, evapotranspire, store for use, and/or treat through a high removal efficiency biofiltration/biotreatment system, without any stormwater runoff leaving the site to the maximum extent feasible, for at least the volume of water produced by the water quality design storm event that results from:

    i. The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour drawdown time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or

    ii. The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in the California Stormwater Best Management Practices Handbook – Industrial/Commercial, (2003); or

    iii. The volume of runoff produced from a 0.75 inch storm event.

2. Pollutants shall be prevented from leaving the development site for a water quality design storm event as defined above unless it has been treated through an onsite high removal efficiency biofiltration/biotreatment system.

3. Hydromodification impacts shall be minimized to natural drainage systems.

REQUIREMENTS:

All other developments (residential developments of 5 units or more and nonresidential developments) shall adhere to the following requirements:

i. For new development or where redevelopment results in an alteration of at least fifty percent or more of the impervious surfaces of an existing developed site, the entire site shall comply with the standards and requirements of Section 3.1.2; or

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ii. Where the redevelopment results in an alteration of less than fifty percent of the impervious surfaces of an existing developed site, only such incremental development shall comply with the standards and requirements of Section 3.1.2.

If partial or complete onsite compliance of any type is technically infeasible, the project Site and LID Plan shall be required to comply with, at a minimum, all applicable SUSMP requirements (Appendix G) in order to maximize onsite compliance. Any remaining runoff that cannot feasibly be managed onsite must be mitigated under the Offsite Mitigation Option. Figure 3.2 is a schematic which depicts the design requirements for small scale residential projects, while Figure 3.3 depicts the design requirements for all other developments.

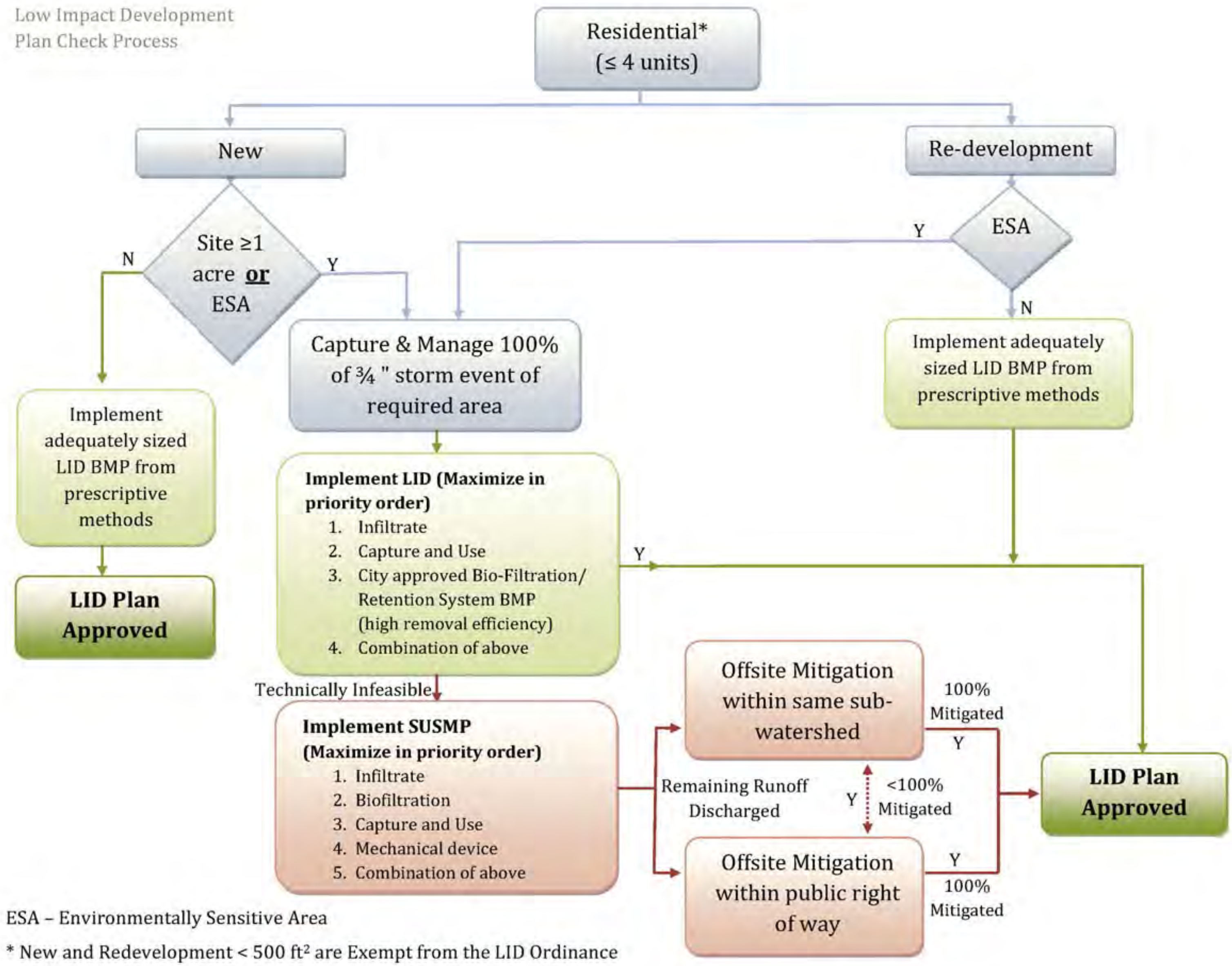

Figure3.2- Requirements for Residential Development of 4 Units or Less

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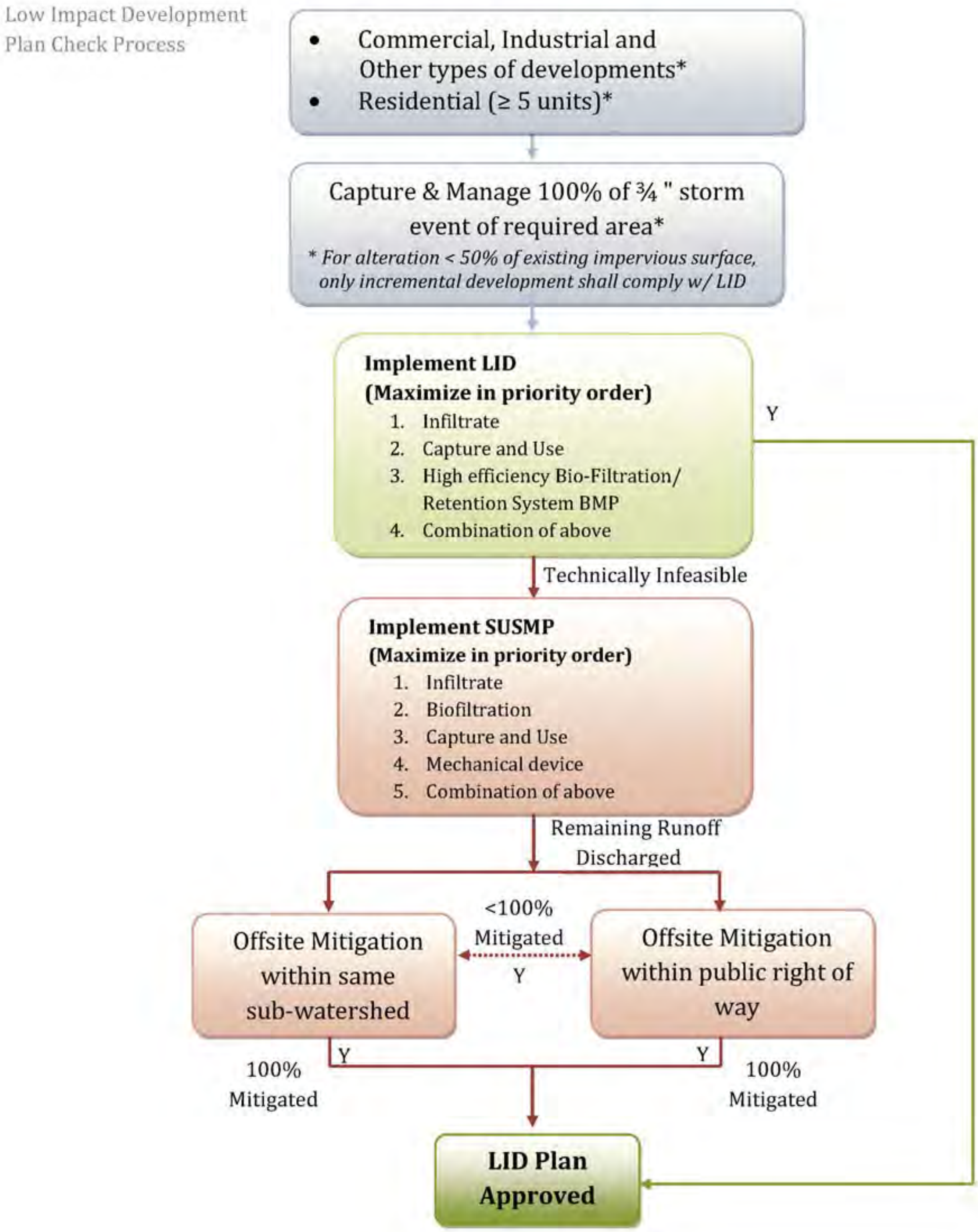

* New and Re-development < 500 ft^2 are exempt from the LID Ordinance

Figure 3.3 – Requirements for Residential Developments of 5 Units or More and All Other Development

3.2 STANDARD URBAN STORMWATER MITIGATION PLAN (SUSMP)

Any project that cannot comply with the LID requirements in Section 3.1.2 shall be required to comply with, at a minimum, all applicable SUSMP requirements (Appendix G) in order to maximize onsite compliance.

Project applicants will be required to incorporate stormwater mitigation measures into their design plans and submit the plans to the City for review and approval. The design plans will be subjected to a review process as indicated in Section 2, prior to the issuance of approvals for building and/or grading permits.

3.3 SITE SPECIFIC MITIGATION

Site Specific Project applicants will be required to submit to the City a design plan that incorporates appropriate stormwater mitigation measures and details the source and treatment control BMP(s), and must also submit the O&M plan for the treatment control BMPs. All maintenance agreements should refer the Covenant and Agreement forms in Appendix D. The design plans will be subject to the review and approval process described in Section 2, prior to the issuance of building or grading permits.

3.4 SOURCE CONTROL MEASURES

Source Control Measures are low-technology practices designed to prevent pollutants from contacting stormwater runoff or to prevent discharge of contaminated runoff to the storm drainage system. This section addresses site-specific, structural type Source Control Measures consisting of specific design features or elements. Non-structural type Source Control Measures, such as good housekeeping and employee training, are not included in the LID Handbook. The California Industrial Best Management Practice Manual may be consulted for this type of practice (SWQTF, 1993). The governing stormwater agency may require additional Source Control Measures not included in the LID Handbook for specific pollutants, activities or land uses.

This section describes control measures for specific types of sites or activities that have been identified as potential significant sources of pollutants in stormwater. Each of the measures specified in this section should be implemented in conjunction with appropriate non-structural Source Control Measures to optimize pollution prevention.

The measures addressed in this section apply to both stormwater and non-stormwater discharges. Non-stormwater discharges are the discharge of any substance, such as process wastewater, to the storm drainage system or water body that is not composed entirely of stormwater. Stormwater that is mixed or commingled with other non-stormwater flows is considered non-stormwater. Discharges of stormwater and non-stormwater to the storm drainage system or a water body may be subject to local, state, or federal permitting prior to

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discharge. The appropriate agency should be contacted prior to any discharge. Discuss the matter with the stormwater staff if you are uncertain as to which agency should be contacted.

Some of the measures presented in this section require connection to the sanitary sewer system. Connection and discharge to the sanitary sewer system without prior approval or obtaining the required permits is prohibited. Contact the stormwater staff of the governing agency to obtain information regarding obtaining sanitary sewer permits from the various agencies within the City of Los Angeles. Discharges of certain types of flows to the sanitary sewer system may be cost prohibitive. The designer is urged to contact the appropriate agency prior to completing site and equipment design of the facility.

3.4.1 Source Control Measure Descriptions

Site-specific Source Control Measures and associated design features specified for various sites and activities are summarized in Table 3.1. Fact Sheets are presented in Appendix H for each source control measure. These sheets include design criteria established by the Approval Agencies to ensure effective implementation of the required Source Control Measures:

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Table 3.1: Summary of Site-Specific Source Control Measure Design Features

Site-Specific Source Control Measure [(a)]	**DESIGN FEATURE OR ELEMENT**						
	Signs, placards, stencils	Surfacing (compatible, impervious)	Covers, screens	Grading/berming to prevent run-on	Grading/berming to provide secondary containment	Sanitary sewer connection	Emergency Storm Drain Seal
Storm Drain Message and Signage (S-1)	X						
Outdoor Material Storage Area Design (S-2)		X	X	X	X		X
Outdoor Trash Storage and Waste Handling Area Design (S-3)		X	X	X		X	
Outdoor Loading/Unloading Dock Area Design (S-4)		X	X	X	X		
Outdoor Repair/Maintenance Bay Design (S-5)		X	X	X	X		X
Outdoor Vehicle/Equipment/ Accessory Washing Area Design (S-6)		X	X	X	X	X	X
Fueling Area Design (S-7)		X	X	X	X		X

(a) Refer to Fact Sheets in Appendix H for detailed information and design criteria.

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SECTION 4: BMP PRIORITIZATION AND SELECTION

4.1 PRIORITIZATION OF BMP SELECTION

BMPs shall be designed to manage and capture stormwater runoff. Infiltration systems are the first priority type of BMP improvements as they provide for percolation and infiltration of the stormwater into the ground, which not only reduces the volume of stormwater runoff entering the MS4, but in some cases, can contribute to groundwater recharge. If stormwater infiltration is not possible based on one or more of the project site conditions listed below, the developer shall utilize the next priority BMP.

The order of priority specified below shall apply to all projects categorized as"all other developments" in accordance with Section 3.1.2. Each type of BMP shall be implemented to the maximum extent feasible when determining the appropriate BMPs for a project.

1. Infiltration Systems
2. Stormwater Capture and Use
3. High Efficiency Biofiltration/Bioretention Systems
4. Combination of Any of the Above

For purposes of compliance with the LID requirements, and without changing the priority order of design preferences as mentioned in this section, all runoff from the water quality design storm event, as determined in Section 3.1.2 above, that has been treated through an onsite high removal efficiency biofiltration system shall be credited as equivalent to 100% infiltration regardless of the runoff leaving the site from the onsite high removal efficiency biofiltration system and that runoff volume shall not be subject to the offsite mitigation requirements.

If partial or complete onsite compliance of any type is technically infeasible, the project Site and LID Plan shall be required to comply with, at a minimum, all applicable SUSMP requirements in order to maximize onsite compliance. Under this option a mechanical / hydrodynamic unit may be used. Any remaining runoff that cannot feasibly be managed onsite must bemitigated under the offsite mitigation option. In order to mitigate the remaining volume using the offsite mitigation option a LID BMP waiver must be obtained by the Department of Public Works, and if necessary, a SUSMP waiver must be obtained from the Department of Public Works and the Los Angeles Regional Water Quality Control Board and/or Regional Board Executive Officer.

Existing conditions of a project site may prevent the proposed development from implementing onsite stormwater pollution reduction or flow control to the standards specified. To utilize alternative compliance measures, the project applicant must demonstrate that compliance with the LID requirements would be technically infeasible by submitting a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional civil engineer, geotechnical engineer or geologist.

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4.2 INFILTRATION FEASIBILITY SCREENING

The implementation of infiltration BMPs may be deemed infeasible at a project site due to existing site conditions. To assist in the determination of compliance feasibility, a categorical screening of specific site information shall be carried out to assess site conditions.

The first category of screening shall consist of specific site conditions which, if present at the site, would deem the specified BMP-type “feasible”.The second category of screening shall consist of specific site conditions which, if present at the site,would deem the BMP-type “potentially feasible”. Project locations passing this screening category may still be able to utilize the screened compliance measure, though the implementation of such a measure may require supplementary actions (for example, an infiltration trench with a building set-back of only 7 feet may be approved if an impermeable membrane is installed at the foot of the building and extended vertically to prevent seepage). The third category of screening shall consist of site conditions which, if present at the site, would deem a specified BMP-type “infeasible”. This type of screening can generally be carried out in the pre-planning stage of a project. These categorical screenings must be verified by a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer or geologist.

To assist in the determination of site feasibility for infiltration BMPs, Table 4.1 has been created.

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	Category 1 Screening (Feasible)	Category 2 Screening (Potentially Feasible)	Category 3 Screening (Infeasible)
Description	1. Underlying Groundwater ☐ Depth of bottom of infiltration facility to seasonal high groundwater is > 10 ft 2. Site Soils ☐ Infiltration rate is > 0.5 in/hr ☐ Geotechnical hazards are not a potential near the site 3. Site Surroundings ☐ Buildings or structures are at least 10 ft away from the potential infiltration BMP ☐ Site is not located on or within 50 feet upgradient of a steep slope (15% or greater) ☐ No continuous presence of dry weather flows	1. Underlying Groundwater ☐ Depth from bottom of infiltration facility to seasonal high groundwater is ≤ 10 ft ☐ Unconfined aquifer is present with beneficial uses that may be impaired by infiltration. Full treatment required if this is the case ☐ Groundwater is known to be polluted. Infiltration must be determined to be beneficial 2. Site Soils ☐ Infiltration rate is ≤ 0.5 in/hr but potential connectivity to higher K_{sat} soils is feasible ☐ Geotechnical hazards such as liquefaction are a potential near the site 3. Site Surroundings ☐ Buildings or structures are within 10 ft of the potential infiltration BMP ☐ High-risk areas such as service/gas stations, truck stops, and heavy industrial sites. Full treatment is required if this is the case, or high-risk areas must be separate from stormwater runoff mingling	1. Underlying Groundwater ☐ Depth from bottom of infiltration facility to seasonal high groundwater is ≤ 5 ft ☐ Sites with soil and/or groundwater contamination** 2. Site Soils ☐ Infiltration rate (K_{sat}) is ≤ 0.3 in/hr and connectivity to higher K_{sat} soils is infeasible ☐ Building sites designated “Landslide” or “Hillside Grading” areas as specified by the Department of City Planning’s Zone Information and Map Access System (ZIMAS) ☐ Geotechnical hazards such as liquefaction, collapsible soils, or expansive soils exist 3. Site Surroundings ☐ Site is located on a fill site (10 ft min) ☐ Site is located on or within 50 feet upgradient of a steep slope (20% or greater) and has not been approved by a professional geotechnical engineer or geologist
Instructions	If all of the above boxes are checked, they shall be confirmed by a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer or geologist, verifying that infiltration BMPs are feasible at the site*. Otherwise, proceed to Category 2 screening.	If all of the above boxes are checked,or if corresponding boxes in Category 1 are checked in combination with the above boxes, a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer or geologist shall be carried out to approve infiltration measures*. Otherwise, proceed to Category 3 screening.	If any of the above boxes are checked, a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer or geologist shall be submitted to prove infiltration practices are not feasible. *

Table 4.1: Infiltration Feasibility Screening

* See Geotechnical Report Requirements herein.

** The presence of soil and/or groundwater contamination and/or the presence of existing or removed underground storage tanks shall be documented by CEQA or NEPA environmental reports, approved geotechnical reports, permits on file with the City, or a review of the State of California’s Geotracker website.

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Assessing Site Infiltration Feasibility

Assessing a site's potential for implementation of Low Impact Development best management practices (LID BMPs) and infiltration BMPs requires both the review of existing information and the collection of site-specific measurements. Available information regarding site layout and slope, soil type, geotechnical conditions, and local groundwater conditions should be reviewed as discussed below. In addition, soil and infiltration testing is required to be conducted to determine if stormwater infiltration is feasible and to determine the appropriate design parameters for the infiltration BMP.

Geotechnical Considerations and Report Requirements:

As determined by the City of Los Angeles, Department of Building and Safety, Grading Division, a geotechnical report will be required for projects that will incorporate infiltration as part of the drainage system. Geotechnical reports shall be signed by a professional Geotechnical or Civil Engineer licensed in the State of California and/or a Certified Engineering Geologist.

Refer to Building & Safety information bulletin, "Guidelines for Stormwater Infiltration" for additional information, Appendix I.

http://ladbs.org/LADBSWeb/LADBS_Forms/InformationBulletins/IB-P-BC2008-118StormwaterInfiltn.pdf

Site Conditions

Slope:

The site's topography should be assessed to evaluate surface drainage, topographic high and low points, and to identify the presence of steep slopes that qualify as hillside locations, all of which have an impact on what type of infiltration BMPs will be most beneficial for a given project site. Stormwater infiltration is more effective on level or gently sloping sites. On hillsides, infiltrated runoff may seep a short distance downslope, which could cause slope instability depending on the soil or geologic conditions, or result in nuisance seepage. Figure E-1 in Appendix E provides general guidance of the City with slopes greater than 20%.

Soil Type and Geology:

The site's soil types and geologic conditions should be determined to evaluate the site's ability to infiltrate stormwater and to identify suitable, as well as unsuitable locations for locating infiltration-based BMPs.

In addition, available geologic or geotechnical reports on local geology should be reviewed to identify relevant features such as depth to bedrock, rock type, lithology, faults, and hydrostratigraphic or confining units. These geologic investigations may also identify shallow water tables and past groundwater issues that are important for BMP design (see below). Figure E-5 in Appendix E provides general guidance identifying parts of the City that have well-draining soil conditions.

Groundwater Considerations:

The depth to groundwater beneath the project during the wet season may preclude infiltration. A minimum of five feet of separation to the seasonal (December through April) high ground water level and mounded groundwater level is required. For projects located in the Upper Los Angeles River Area, ten feet of separation is required.

Infiltration on sites with contaminated soils or groundwater that could be mobilized or exacerbated by infiltration is not allowed, unless a site-specific analysis determines the infiltration would be beneficial. A site-specific analysis may be conducted where groundwater pollutant mobilization is a concern to allow for infiltration-based BMPs. Areas with known groundwater impacts include sites listed by the Los Angeles Regional Water Quality Control Board's Leaking Underground Storage Tanks (LUST) program and Site Cleanup Program (SCP). The California State Water Resources Control Board maintains a database of registered contaminated sites through their 'Geotracker' Program. Registered contaminated sites can be identified in the project vicinity when the site address is typed into the "map cleanup sites" field. Mobilization of groundwater contaminants may also be of concern where contamination from natural sources is prevalent (e.g., marine sediments, selenium rich groundwater, to the extent that data is available). Figure E-3 in Appendix E provides general guidance identifying parts of the City that may be in areas of concern.

<u>Upper Los Angeles River Watermaster Requirements</u>

Infiltration projects located in the San Fernando Valley Watershed must comply with the requirements of the Upper Los Angeles River Watermaster. See Appendix J for requirements and approval process.

<u>Managing Offsite Drainage</u>

Locations and sources of offsite run-on to the site must be identified early in the design process. Offsite drainage must be considered when determining appropriate BMPs for the site so that the drainage can be managed. By identifying the locations and sources of offsite drainage, the volume of water running onto the site may be estimated and factored into the siting and sizing of onsite BMPs. Vegetated swales or storm drains may be used to intercept, divert, and convey offsite drainage through or around a site to prevent flooding or erosion that might otherwise occur.

4.3 CAPTURE AND USE FEASIBILITY SCREENING

Capture and use, commonly referred to as rainwater harvesting, collects and stores stormwater for later use, thereby reducing the quantity of stormwater runoff. Partial capture and use can also be achieved as part of a treatment train by directing the overflow to a bioretention system to provide additional volume reduction and water quality treatment in instances where the quantity of runoff from a storm event exceeds the volume of the collection tank.

In the City of Los Angeles, the use of collected stormwater will primarily be limited to subsurface drip irrigation of landscaped surfaces. However, as new guidelines and guidance becomes available the potential for other uses of collected stormwater will be considered. Capture and use BMPs that are designed with the intent to use captured stormwater for indoor or consumptive purposes will be reviewed on a case-by-case basis to ensure that all treatment, plumbing, and Building and Safety codes are met.

At a minimum, capture and use BMPs must be designed and maintained to ensure adequate capacity is available to capture the stormwater quality design volume within 3 days of a storm event. BMPs sized to capture only the runoff produced from the 0.75 inch storm event, or BMPs designed to capture less than this volume if being used in conjunction with other BMPs, must therefore drawdown their entire captured volume within 3 days of a storm event. Capture and use BMPs designed for storm events larger than 0.75 inches are not required to disperse their entire captured volume within 3 days of capture; rather, the requirement mandates that enough water be dispersed from the BMP to ensure that adequate capacity is available to capture the next storm event up to 0.75 inches. This drawdown time requirement must be fulfilled without dispersing water to surrounding landscaped areas within the first 24 hours following a storm event.

The implementation of capture and use BMPs may be deemed infeasible at a project site due to existing site conditions. To assist in the determination of compliance feasibility, a categorical screening of specific site information shall be carried out to assess site conditions. This screening approach follows the same general guidelines as those designed for the infiltration feasibility screening. Table 4.2 has been created to help determine site feasibility for capture and use BMPs.

	Category 1 Screening (Feasible)	Category 2 Screening (Potentially Feasible)	Category 3 Screening (Infeasible)
Description	1. Landscaped Area ☐ Landscaped area categorization of 3 exists in accordance with Table 4.3 2. Site Soils ☐ Geotechnical hazards are not a potential near the site 3. Drawdown Time ☐ Demands and conditions indicate the site is capable of meeting the 72-hour maximum drawdown requirement 4. Vector Control ☐ Approved vector control measures will be implemented	1. Landscaped Area ☐ Landscaped area categorization of 2 exists in accordance with Table 4.3 2. Site Soils ☐ Geotechnical hazards such as liquefaction are a potential near the site ☐ Soil hydraulic conductivities are sufficient for the designed water application rate; if not, soil amendments will be implemented 3. Drawdown Time ☐ Demands and conditions indicate the site is capable of meeting the 72-hour maximum drawdown requirement, though this may require water application that is not immediately used (e.g. overwatering)	1. Landscaped Area ☐ Landscaped area categorization of 1 exists in accordance with Table 4.3 2. Site Soils ☐ Geotechnical hazards such as landsliding, collapsible soils, or expansive soils exist 3. Site Surroundings ☐ Site is located on or within 50 feet of a steep slope (20% or greater) as determined by the Department of Building and Safety; irrigation within 3 days of a rain event could cause geotechnical instability 4. Drawdown Time ☐ Demands and conditions indicate the site is incapable of meeting the 72-hour maximum drawdown requirement
Instructions	If all of the above boxes are checked, they shall be confirmed by a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional civil engineer, geotechnical engineer, geologist, or landscape architect, verifying that capture and use BMPs are feasible at the site.* Otherwise, proceed to Category 2 screening.	If all of the above boxes are checked,or if corresponding boxes in Category 1 are checked in combination with the above boxes, a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional civil engineer, geotechnical engineer, geologist, or landscape architect, shall be carried out to approve capture and use measures.*Otherwise, proceed to Category 3 screening.	If any of the above boxes are checked, a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer, geologist, or landscape architect shall be submitted to prove capture & use practices are not feasible. *

Table 4.2: Capture and Use Feasibility Screening

* See Geotechnical Report Requirements contained in the Infiltration Feasibility section.

Table 4.3 has been created to help determine site feasibility for capture and use BMPs based on the local infiltration rate as well and the percent of the project that is landscaped. The table is to be used in conjunction with Table 4.2 to determine site feasibility.

Table 4.3: Landscaped Area Categorization

	Percent of Project that is Landscaped					
Local Infiltration Rate	0-5%	5-10%	10-20%	20-30%	30-50%	>50%
0.3 - 0.5 in/hr	2	2	2	1	1	1
0.2 - 0.3 in/hr	3	2	2	2	1	1
0.1 - 0.2 in/hr	3	3	2	2	2	1
0 - 0.1 in/hr	3	3	3	2	2	2

Assessing Site Capture and Use Feasibility

As with infiltration BMPs, assessing a site's potential for implementation of capture and use BMPs requires both the review of existing information and the collection of site-specific measurements. Available information regarding the site's landscaped area should be reviewed as discussed below. In addition, human health concerns should be prioritized, particularly with regards to vector control issues arising from the addition of standing water on site.

<u>Landscaped Area Assessment</u>

For capture and use BMPS, captured rainfall is stored during rain events and used for irrigation purposes at a later time, thereby offsetting potable water demand and reducing pollutant loading to the storm drain system. Therefore, sufficient landscaped area with appropriate water demand is needed for the captured runoff to be directed to. A properly sized cistern should be able to contain the runoff generated from the design storm event and discharge that water for irrigation use within a specified drawdown time.

In the City of Los Angeles, cisterns will primarily be sized to capture the runoff generated from the 0.75" storm while meeting the drawdown time requirement (72 hours in most cases). A site's landscaped area must therefore be able to retain this volume of water within the appropriate drawdown time. Depending on the type of irrigation application that is desirable at a site, two different methods exist to determine if a site has adequate landscaped cover for capture and use feasibility:

1. For sites with sufficient agronomic demand to meet or exceed the captured supply of stormwater within the drawdown time, Category 1 Feasibility may apply. Agronomic demand must be calculated and reported by a professional landscape architect or qualified professional.
2. For sites with sufficient landscaped area and dispersal capacity (i.e. ability to receive irrigation water without generating runoff) to meet or exceed the captured supply of

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stormwater within the drawdown time, Category 2 Feasibility may apply. The dispersal capacity can be assumed to be equal to the infiltration capacity of the site soil for simplicity. The infiltration rate must be calculated and reported by a professional landscape architect, civil engineer, geotechnical engineer, or geologist.

The above criteria must be assessed assuming that no irrigation occurs within the first 24 hours immediately following a storm. This means that a drawdown time of 72 hours must consider only 48 hours of active application. Agronomic demands and infiltration rates must be assessed within 3 days of a storm event to account for resulting diminished demands.

BMPs designed for extended holding times shall be reviewed on a case-by-case basis for feasibility. A site not meeting the minimum landscaped area criteria is not feasible for capture and use BMPs (See Table 4.3 in conjunction with Table 4.2).

Los Angeles County Department of Public Health Requirements

Projects that are implementing rainfall or urban runoff capture and distribution systems must obtain approval from the County of Los Angeles, Department of Public Health. See Appendix K for the Policy and Operation Manual.

Vector Control Considerations

A vector is any insect, arthropod, rodent, or other animal that is capable of harboring or transmitting a causative agent of human disease. In the City of Los Angeles, the most significant vector population related to stormwater is mosquitoes.

Vector sources occur where conditions provide habitat suitable for breeding, particularly any source of standing water. This means that stormwater BMPs, especially those of the capture and use type, can be breeding grounds for mosquitoes and other vectors resulting in adverse public health effects related to vectors and disease transmission. Because of this, efforts shall be made to design capture and use BMPs that do not facilitate the breeding of vectors. Vectors should be considered during the preparation of stormwater management and maintenance plans and during preconstruction planning to avoid creating possible public health hazards.

Minimizing mosquito production potential requires that standing water not be available for sufficient time to permit eggs to develop to adult mosquitoes. For stormwater BMP's, this can be achieved in one of three ways: 1) discharge of all captured water within 72 hours, 2) deny mosquitoes access to standing water (this is known as "exclusion"), or 3) make the habitat less suitable for mosquito breeding. The most effective design strategy to exclude vectors from LID practices is to design the system to ensure that water is discharged within 72 hours, thereby eliminating the potential vector breeding source. The capture and use feasibility screening shall

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consider the site’s ability to disperse of the captured storage volume within this recommended drawdown time.

Oversized capture and use BMPs designed to hold captured stormwater for periods longer than 72 hours will require additional treatment such as filtration or disinfection to protect the collection tanks from fouling, to prevent the breeding of vectors, and/or to improve the quality of water for reuse applications.These BMPs must have appropriate vector control measures incorporated into the design of the system to exclude vector access and breeding (i.e., observation access for vector inspection and treatment).They should be approved by the County of Los Angeles Department of Public Health. These scenarios will be reviewed on a case-by-case basis.

If vector breeding is taking place at a site as a result of contained stormwater or inadequately maintained BMPs, the Greater Los Angeles County Vector Control District has the ability to fine site owners for violating the California Health and Safety Code (Section 2060 – 2067).

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4.4 INFILTRATION BMPS

Infiltration refers to the physcial process of percolation, or downward seepage, of water through a soil's pore space. As water infiltrates, the natural filtration, adsorption, and biological decomposition properties of soils, plant roots, and micro-organisms work to remove pollutants prior to the water recharging the underlying groundwater. Infiltration BMPs include infiltration basins, infiltration trenches, infiltration galleries, bioretention without an underdrain, dry wells, and permeable pavement. Infiltration can provide multiple benefits, including pollutant removal, peak flow control, groundwater recharge, and flood control. However, conditions that can limit the use of infiltration include soil properties, proximity to building foundations and other infrastructure, geotechnical hazards (e.g., liquefaction, landslides), and potential adverse impacts on groundwater quality (e.g industrial pollutant source areas, contaminated soils, groundwater plumes)[3]. To ensure that infiltration would be physcially feasible and desireable (i.e., not have adverse impacts), a categorical screening of site feasibility criteria must be completed prior to the use of infiltration BMPs following the guidelines presented in Section 4.2.

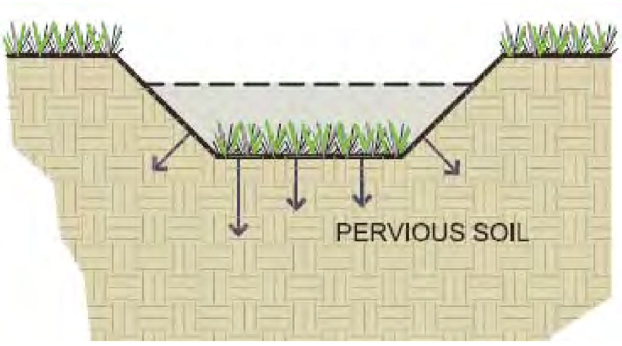
4.4.1 Infiltration BMP Types

<u>**Surface Infiltration BMPs**</u>

These BMPs rely on infiltration in a predominantly vertical (downward) direction and depend primarily on soil characteristics in the upper soil layers. These infiltration BMPs include:

Infiltration Basins

An infiltration basin consists of an earthen basin constructed in naturally pervious soils with a flat bottom typically vegetated with dry-land grasses or irrigated turf grass. An infiltration basin functions by retaining the design runoff volume in the basin and allowing the retained runoff to percolate into the underlying native soils over a specified period of time.



Infiltration Trenches

Infiltration trenches, which are similar to basins, are long, narrow, gravel-filled trenches, often vegetated, that infiltrate stormwater runoff from small drainage areas. Infiltration trenches may include a shallow depression at the surface, but the majority of runoff

3 Depending on the design of the infiltration practice, Federal Underground Injection Control (UIC) Rules (40 CFR 144) may apply, which may further restrict the use of infiltration facilities in some locations.

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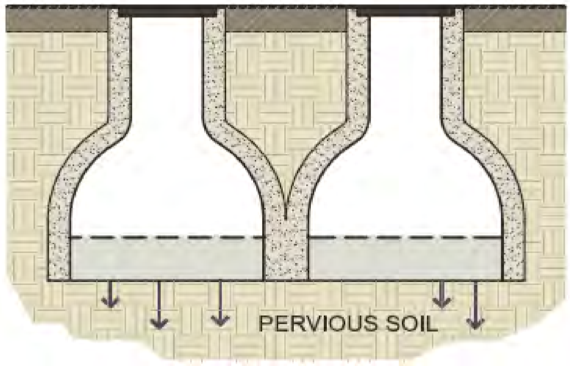
is stored in the void space within the gravel and infiltrates through the sides and bottom of the trench.

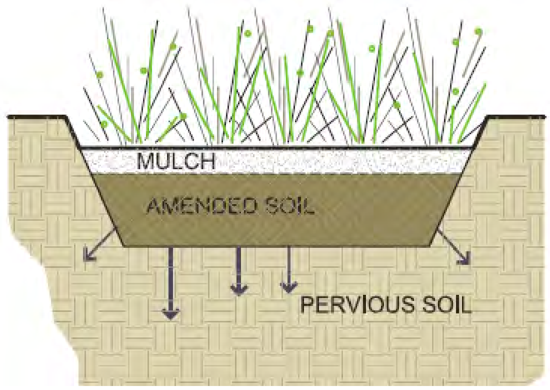
Infiltration Galleries

Infiltration galleries are open-bottom, subsurface vaults that store and infiltrate stormwater. A number of vendors offer prefabricated, modular infiltration galleries that provide subsurface storage and allow for infiltration. Infiltration galleries come in a variety of material types, shapes and sizes.



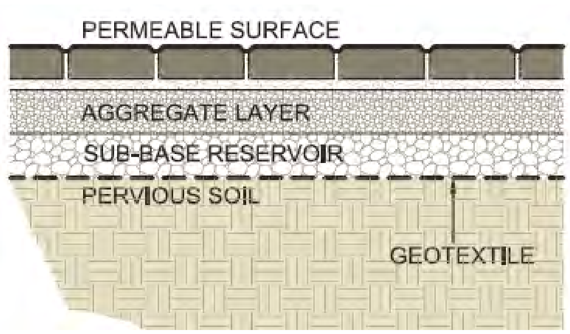
Bioretention

Bioretention stormwater treatment facilities are landscaped shallow depressions that capture and filter stormwater runoff. These facilities function as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. The facilities normally consist of a ponding area, mulch layer, planting soils, plantings, and, optionally, a subsurface gravel reservoir layer.



Permeable Pavements

Permeable (or pervious) pavements contain small voids that allow water to pass through to a stone base. They come in a variety of forms; they may be a modular paving system (concrete pavers, modular grass or gravel grids) or poured-in-place pavement (porous concrete, permeable asphalt). All permeable pavements with a stone reservoir base treat stormwater and remove sediments and metals to some degree by allowing stormwater to percolate through the pavement and enter the soil below.



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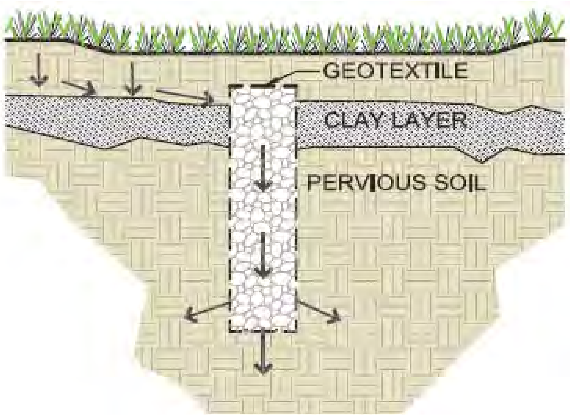
Multi-Directional Infiltration BMPs

These BMPs take advantage of the hydraulic conductivities (K_{sat}) of multiple soil strata and infiltration in multiple directions. They may be especially useful at locations where low K_{sat} values are present near the surface and soils with higher permeabilities exist beneath. A Multi-Directional Infiltration BMP may be implemented to infiltrate water at these lower soil layers, thus allowing infiltration to occur at sites that otherwise would be infeasible. These infiltration BMPs typically have smaller footprints and include, but are not limited to:

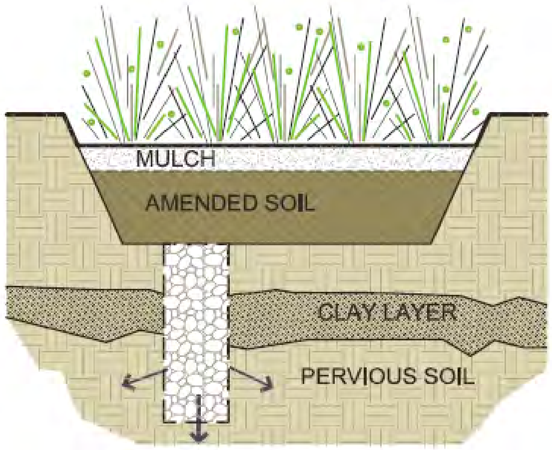
Dry Wells

A dry well is defined as an excavated, bored, drilled, or driven shaft or hole whose depth is greater than its width. Drywells are similar to infiltration trenches in their design and function, as they are designed to temporarily store and infiltrate runoff, primarily from rooftops or other impervious areas with low pollutant loading. A dry well may be either a drilled borehole filled with aggregate or a prefabricated storage chamber or pipe segment.



Hybrid Bioretention/Dry Wells

A bioretention facility with dry wells is useful in areas with low surface-level hydraulic conductivities that would normally deem a bioretention BMP infeasible but have higher levels of permeability in deeper strata. By incorporating drywells underneath the bioretention facility, water is able to be infiltrated at deeper soil layers that are suitable for infiltration, if present. This hybrid BMP combines the aesthetic and filtration qualities of a bioretention facility with the enhanced infiltration capabilities of a dry well.



4.4.2 Siting Requirements and Opportunity Criteria

Drainage areas implementing infiltration BMPs must pass the Category 1 or Category 2 Screening in accordance with the siting requirements set forth in Table 4.1. This screening process must be approved by a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional geotechnical engineer or geologist.

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Additionally, drainage areas that will result in high sediment loading rates to the infiltration facility shall require pretreatment to reduce sediment loads and avoid system clogging. Examples of appropriate pretreatment may include: sedimentation/settling basins, baffle boxes, hydrodynamic separators, media filters, vegetated swales, or filter strips.

4.4.3 Calculating Size Requirements for Infiltration BMPs

The main challenge associated with infiltration BMPs is preventing system clogging and subsequent infiltration inhibition. In addition, infiltration BMPs must be designed to drain in a reasonable period of time so that storage capacity is available for subsequent storms and so that standing water does not result in vector risks or plant mortality. Infiltration BMPs should be designed according to the requirements listed in Table 4.4 and outlined in the text following.

Infiltration facilities must be sized to completely infiltrate the design capture volume within 48 hours. Steps for the simple sizing method are provided below.

Step 1: Calculate the Design Volume

Infiltration facilities shall be sized to capture and infiltrate the design capture volume (V_{design}) based on the runoff produced from a 0.75-inch (0.0625 ft) storm event.

$$V_{design} \text{ (cu ft)} = 0.0625 \times \textit{Catchment Area} \text{ (sq ft)}$$

Where:

Catchment Area = (Impervious Area x 0.9) + [(Pervious Area + Undeveloped Area) x 0.1]

For catchment areas given in acres, multiply the above equation by 43,560 sq. ft./acre.

Table 4.4: Infiltration BMP Design Criteria

Design Parameter	Unit	Basins and Trenches	Galleries	Bioretention	Permeable Pavement	Dry Well	Hybrid Bioretention/ Dry Well
Design Capture Volume, $V_{capture}$	cubic feet	0.0625 x Catchment Area (sq. ft.)[a]					
Design Surface Drawdown Time	hr	48					
Setbacks and Elevations	feet	In accordance with the Infiltration Feasibility Criteria, Section 4.2					
Pretreatment	-	Appropriate Treatment Control Measure shall be provided as pretreatment for all tributary surfaces other than roofs					
Hydraulic Conductivity, $K_{sat,measured}$	in/hr	Measured hydraulic conductivity at the location of the proposed BMP at the depth of the proposed infiltrating surface (or effective infiltration rate when multi directional infiltration is occurring					
Factor of Safety, FS[b]	-	3					
Facility geometry	-	Bottom slope ≤ 3% (basins); side slope shall not exceed 3:1 (H:V)	Flat bottom slope	Bottom slope ≤ 3%; side slope shall not exceed 3:1 (H:V)	Pavement slope ≤ 5%; If ≥ 2%, area shall be terraced	Typical 18 – 36 inch diameter; flat bottom slope	Bioretention: Bottom slope ≤ 3%; side slope shall not exceed 3:1 Drywell: flat bottom
Ponding Depth	inch	18 (maximum)[c]					
Media Depth	feet	2 (min) 8 (max)	-	2 (min) 8 (max)	2 (min) 8 (max)	-	2 (min) 8 (max)
Gravel media diameter	inch	1 – 3	-	-	1 - 2	3/8 – 1	3/8 - 1
Inlet erosion control	-	Energy dissipater to reduce velocity					
Overflow device	-	Required if system is on-line and does not have an upstream bypass structure.Shall be designed to handle the peak storm flow in accordance with the Building and Safety code and requirements					

a: Catchment area = (impervious area x 0.9) + [(pervious area + undeveloped area) x 0.1]

b:Listed FS values to be used only if soil infiltration / percolation test was performed and a detailed geotechnical report from a professional geotechnical engineer or engineering geologist is provided. A FS of 6 will be assigned if only a boring was done.

c: Ponding depth may vary for galleries (which have a storage depth) and may be different from one vendor to another. Ponding depth is not necessarily applicable to permeable pavement.

Step 2: Determine the Design Infiltration Rate

The infiltration rate will decline between maintenance cycles as the surface becomes clogged with particulates and debris. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the sizing of facilities depending on a site's infiltration rate and expected surface loading. Where applicable, the measured infiltration rate discussed here is the infiltration rate of the underlying soils and not the infiltration rate of the filter media bed or engineered surface soils.Facility maintenance is required to maintain the infiltration rate for the life of the project.Infiltration rates used for design must be divided by the appropriate factors of safety.

$$K_{sat,design} = K_{sat,measured}/FS$$

Where:

FS = Infiltration factor of safety, in accordance with Table 4.4

Measured infiltration rates shall be determined by in-ground, site specific infiltration tests or can be based on laboratory tests conducted on soil samples collected during the exploratory work for a site-specific geotechnical report.

Step 3: Calculate the BMP Surface Area

Determine the size of the required infiltrating surface by assuming the design capture volume will fill the available ponding depth plus the void spaces based on the porosity of the gravel fill (normally about 30 - 40%[4]) or amended soil (normally about 20 – 30%).

Determine the maximum depth of runoff that can be infiltrated within 48 hours as follows:

$$D_{eff} = (T \times K_{sat,design}) / (12 \times n)$$

Where:

D_{eff} = Effective trench depth (ft)

T = Drawdown time (hours), which is assumed to be 48 hours

n = Void ratio (use 0.40 for gap graded gravel; 0.3 for amended soil)

Determine the minimum infiltrating surface area necessary to infiltrate the design volume:

$$A_{min} = V_{design} / D_{eff}$$

Where:

A_{min} = Minimum infiltrating surface area (ft^2)

The calculated minimum BMP surface area only considers the surface area of the BMP where infiltration can occur. For dry wells, the calculated surface area is the total surface area of the well lying in soils with $K_{sat,measured}$ values > 0.3 in/hr. In other words, the portion of the dry well

4Terzaghi and Peck stated that in the densest possible arrangement of cohesionless spheres, the porosity is equivalent to 26%; in the loosest possible arrangement, the porosity is equal to 47% (Terzaghi K. and Peck R. Soil Mechanics in Engineering Practice. 2cnd ed. New York: John Wiley and Sons; 1967).

that extends through impermeable layers should not be considered part of the infiltrating area. For the hybrid bioretention/dry well BMP design, the calculated BMP surface area applies to the combined surface area of the bioretention facility and the infiltrating portion of the underlying dry well(s).

For infiltration trenches and basins, the surface area should be calculated as the surface area at mid-ponding depth.

Note that A_{min} represents the minimum calculated surface area. It is up to the discretion of the developer if A_{min} will be exceeded to allow for less media storage.

Step 4: Calculate the Media Storage Depth

Determine the depth of the infiltration unit to be filled with media for capturing the design capture volume. The depth shall not exceed 8 feet.

$$D_{media} = [V_{design} - (K_{sat,design} \times T \times A_{min} / 12)] / (A_{min} \times n) \leq 8$$

Where:

D_{media} = Minimum media storage depth of the infiltration facility (ft)

If D_{media} is calculated as greater than 8 feet, the design infiltration area (A_{design}) shall be increased and the depth of media shall be recalculated until it is less than 8 feet.

Many project developers may elect to in increase the design infiltration area such that $A_{design}>A_{min}$. This is especially feasible where infiltration rates are relatively high (leading to a low A_{min} value). The depth of media (D_{media}) should be calculated using the actual design area in Step 4 above. For projects with designed infiltration areas significantly higher than A_{min}, it may be feasible to have no media storage (i.e. D_{media} = 0 ft). For this to apply, the following condition must be met:

$$A_{design} \geq (V_{design} \times 12) / (K_{sat,design} \times T)$$

Infiltration Sizing Example

Given: 30,000 ft^2 apartment complex (including parking) with 10,000 ft^2 of landscaped area. An infiltration test has resulted in a $K_{sat,measured}$value of 0.5 in/hr; Factor of Safety = 4. Design an infiltration trench meeting the sizing requirements. Assume the trench is full of gap-graded gravel with a porosity of 0.3.

1) Determine V_{design}
   Catchment Area = (30,000ft^2 x 0.9) + [(10,000 ft^2) x 0.1] = 28,000 ft^2
   $\boldsymbol{V_{design}}$ = 0.0625 * 28,000 ft^2 = **1,750 ft^3**

2) Determine $K_{sat,design}$
   $\boldsymbol{K_{sat,design}}$ = (0.5 in/hr) /4 = **0.125 in/hr**

3) Determine A_{min}
   D_{eff} = (48 hrs x 0.125 in/hr) / (12 x 0.3) = 1.67 ft
   $\boldsymbol{A_{min}}$ = 1,750ft^3 / 1.67 ft = **1,050ft^2**

4) Determine D_{media}
   $\boldsymbol{D_{media}}$= [1,750 ft^3 – (0.125 in/hr x 48 hrs x 1,050 ft^2)/(12)] / (1,050 ft^2 x 0.3) = **3.9 ft**

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The trench should therefore be designed with a minimum of 1,050 ft^2 of infiltrating surface area. At this minimum surface area, the gravel media depth should be at least 3.9 feet.

4.4.4 Design Criteria and Requirements

Unless specifically stated, the following criteria and requirements listed below are required for the implementation of all infiltration BMPs. Provisions not met must be approved by the City of Los Angeles.

Permeable Pavement Application
Los Angeles World Airports Parking

- Infiltration BMPs have been designed and constructed to promote uniform ponding and infiltration.
- Where necessary, a sediment forebay or separate pretreatment unit (e.g. vegetated swale, filter strip, hydrodynamic device, etc.) is located between the inlet and infiltration BMP. The sediment forebay has a volume greater than or equal to 25% of the total design volume.
- Sediment forebay has a minimum length to width ratio of 2:1 and is designed to conduct flow to the infiltration BMP.
- Any embankment slopes (interior and exterior) are not steeper than 3:1 (H:V) unless approved by the City of Los Angeles.
- The bottom of the infiltration bed is native soil and has been over-excavated to at least one foot in depth. It is recommended that the excavated soil be amended with 2 – 4 inches of coarse sand (e.g., 2 – 5 mm sand) before being replaced uniformly without compaction.
- The hydraulic conductivity (Ksat) of the subsurface layers is sufficient to ensure the maximum drawdown time of 48 hours.
- Where Ksat values are greater than 2.4 in/hr, pretreatment is provided to address pollutants of concern prior to infiltration to protect groundwater quality; pretreatment may be considered to be addressed in the amended media or sand layers within the BMP if provided.
- Provided overflow safely conveys flows to the downstream stormwater conveyance system, an additional BMP, or an alternatively acceptable discharge point.
- Where the infiltration system is placed underground, an observation well is provided for inspection/mainteance purposes.
- Porous pavement facilities consist of various layers of material. The top layer consists of either asphalt or concrete with a percentage of voids of at least 15%. This layer is

followed by a stone reservoir layer or a thick layer of aggregate with 25-35% voids. Two transition layers are also present. The depth of each layer and the specific materials used shall be determined by a licensed civil engineer.

- Dry wells shall be filled with washed 3/4 – 1 inch crushed rock, recycled concrete aggregate, or open-graded gravel (i.e. gravel with a small percentage of small particles). If a perforated pipe has been installed in the well, perforations are 3/8" and are smaller than the fill gravel. A woven geotextile shall be placed over the top of the drywell to prevent sediment clogging.

4.4.5 Soil and Vegetation Requirements

Soil and vegetation to be incorporated in infiltration facilities shall be selected by a licensed landscape architect. In general, drought and flood resistant plant species native to California should be selected when possible. Soil media should be selected to not restrict performance requirements. Selected soils shall therefore have a higher hydraulic conductivity than the underlying soil, shall be able to support the selected plant palette, and shall be graded to provide adequate filtration as to not clog underlying soils.

4.4.6 Construction Requirements

To preserve and avoid the loss of infiltration capacity, the following construction guidelines shall be adhered to:

Underground Infiltration Units
Lowe's, Pacoima

- The entire area draining to the infiltration facility is stabilized before construction of the infiltration facility begins, or a diversion berm is placed around the perimeter of the infiltration site to prevent sediment entrance during construction.
- Infiltration BMPs shall not be used as sediment control facilities during construction.
- Compaction of the subgrade with vehicles and/or equipment is minimized. If the use of heavy equipment on the base of the facility cannot be avoided, the infiltrative capacity shall be restored by tilling or aerating prior to placing the infiltrative bed.
- Where pervious pavement is to be installed, installation of the pavement shall be scheduled as the the last installation at a development site. Vehicular traffic is prohibited for at least 2 days following installation. Site materials shall not stored on pervious pavement.

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4.4.7 Operations and Maintenance

- Frequent inspections of the infiltration facilities shall occur to ensure that surface ponding infiltrates into the subsurface completely within the design drawdown time following storms. If vector breeding is taking place at a site as a result of contained stormwater or inadequately maintained BMPs, the Greater Los Angeles County Vector Control District has the ability to fine site owners for violating the California Health and Safety Code (Section 2060 – 2067).
- Regular inspections shall take place to ensure that the pretreatment sediment removal BMP/forebay is working efficiently. Sediment buildup exceeding 50% of the forebay sediment storage capacity shall be removed.
- The infiltration facility shall be maintained to prevent clogging. Maintenance activities include checking for debris/sediment accumulation and removal of such debris.
- Facility soil (if applicable) shall be maintained. Flow entrances, ponding areas, and surface overflow areas will be inspected for erosion periodically. Soil and/or mulch will be replaced as necessary to maintain the long-term design infiltration rate for the life of the project.
- Site vegetation shall be maintained as frequently as necessary to maintain the aesthetic apperance of the site as well as the filtration capabilities (where applicable). This includes the removal of fallen, dead, and/or invasive plants, watering as necessary, and the replanting and/or reseeding of vegetation for reestablishment as necessary.
- Pervious pavement areas that are damaged or clogged shall be replaced/repaired per manufacture’s recommendation as needed.

4.5 CAPTURE AND USE BMPS

Capture and Use refers to a specific type of BMP that operates by capturing stormwater runoff and holding it for efficient use at a later time. On a commercial or industrial scale, capture and use BMPs are typically synonomous with cisterns, which can be implemented both above and below ground. Cisterns are sized to store a specified volume of water with no surface discharge until this volume is exceeded. The primary use of captured runoff is for subsurface drip irrigation purposes. The temporary storage of roof runoff reduces the runoff volume from a property and may reduce the peak runoff velocity for small, frequently occurring storms. In addition, by reducing the amount of stormwater runoff that flows overland into a stormwater conveyance system, less pollutants are transported through the conveyance system into local streams and the ocean. The onsite use of the harvested water for non-potable domestic purposes conserves City-supplied potable water and, where directed to unpaved surfaces, can recharge groundwater in local aquifers.

4.5.1 Siting Requirements and Opportunity Criteria

Drainage areas implementing capture and use BMPs must pass the Category 1 or Category 2 Screening in accordance with the siting requirements set forth in Section 4.3. This screening process must be approved by a site-specific geotechnical investigation report and/or hydrologic analysis conducted and certified by a State of California registered professional civil engineer, geotechnical engineer, geologist, or other qualified professional.

4.5.2 Calculating Size Requirements for Capture and Use BMPs

At a minimum, capture and use BMPs must be designed and maintained to ensure adequate capacity is available to capture the stormwater quality design volume within 3 days of a storm event. BMPs sized to capture the runoff produced from the 0.75 inch storm event, or BMPs designed to capture less than this volume if being used in conjunction with other BMPs, must therefore drawdown their entire captured volume within 3 days of a storm event. Capture and use BMPs designed for storm events larger than 0.75 inches are required to disperse enough water from the BMP within 3 days of a storm to ensure that adequate capacity is available to capture the next storm event up to 0.75 inches.Capture and use BMPs designed for these extended holding times will require additional treatment such as filtration or disinfection to protect the collection tanks from fouling, to prevent the breeding of vectors, and/or to improve the quality of water for reuse applications.These scenarios will be reviewed on a case-by-case basis.

Calculate the Minimum Capture Volume for a 72-hour Holding Time

Assuming that demands and conditions at a site indicate that the 72-hour drawdown time requirement will be met, all cisterns shall be sized to capture the runoff generated from the 0.75-inch storm event at a minimum[5]:

$$V_{design} \text{ (gallons)} = 0.4675 * \textit{Catchment Area} \text{ (sq. ft.)}$$

Where:

Catchment Area = (Impervious Area x 0.9) + [(Pervious Area + Undeveloped Area) x 0.1]

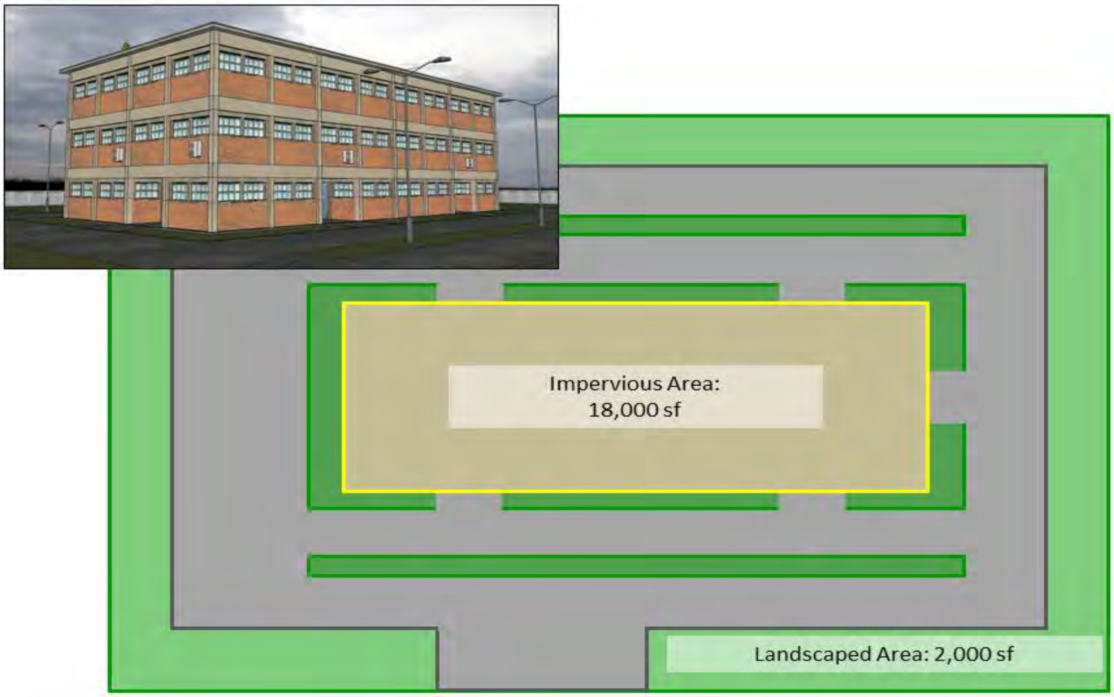
For catchment areas given in acres, multiply the above equation by 43,560 sq. ft./acre.

The capture volume V_{design} represents not only the minimum volume a cistern must be sized to to fully satisfy the requirements of Section 3.1.2, but alsorepresents the cistern capacity that must be available within 72 hours following a storm event. BMPs sized to capture the 0.75-inch storm event or less must therefore drawdown their entire captured volume within 72 hours of a storm event. Calculations must be provided with the project submittal to demonstrate that V_{design}canbe discharged within 72 hours following a 0.75-inch (and larger) storm event without causing or contributing to dry weather runoff or additional wet weather runoff.

5Capture and use BMPs used in combination with other BMP types to collectively meet the water quality design storm standard set forth in Section 3.1.2 may be sized to capture less than V_{design}. The entire capture capacity of these BMPs must be emptied within 72 hours of a storm event to allow for the capture of the next storm event.

Capture and Use Sizing Example

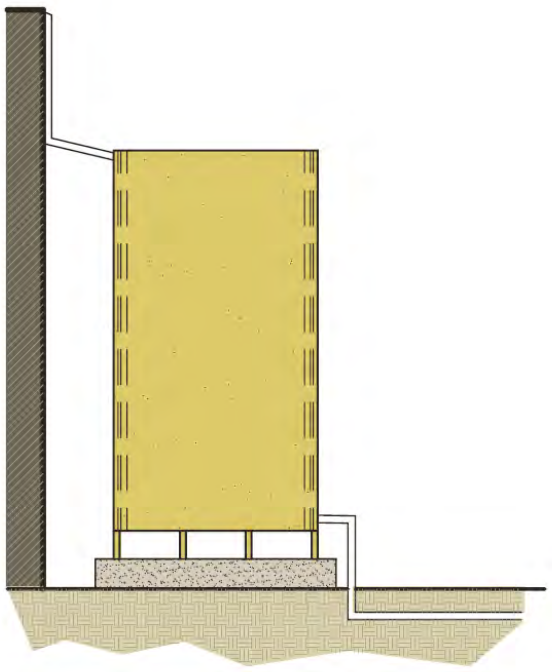
Given: 20,000 ft^2 warehouse building with parking lot, 90% impervious, 10% landscaped. Design a cistern meeting the minimum sizing requirements to capture the entire 0.75-inch storm event.



1) Determine V_{design}
   Catchment Area = (18,000ft^2 x 0.9) + [(2,000 ft^2) x 0.1] = 16,400ft^2
   $\boldsymbol{V_{design}}$ = 0.4675 * 16,400ft^2 = **7,670 gallons**

For a full capture system, the cistern should be designed with a minimum storage capacity of 7,670 gallons. If a larger cistern is desired, the facility must be maintained to ensure that a capacity of 7,670 gallons is available within 3 days of the most recent storm event.

4.5.3 Design Criteria and Requirements



- Unless specifically stated, the following criteria and requirements listed below are required for the implementation of all capture and use BMPs. Provisions not met must be approved by the City of Los Angeles.
- Fertilizers, pesticides, or herbicides on landscaped areas shall be minmized.
- Above-ground cisterns are secured in place and designed to meet seismic requiremnts for tanks.
- Overflow outlet is provided upstream of the tank inlet and is designed to disperse overflow onsite and through stable vegetated areas where erosion or suspension of sediment is minimized. Dispersion will take place at least 3 feet from public sidewalks, at least 5 feet from property lines and foundations, and at least 6 feet away from basement walls. Overflow from the tank into the storm drain system is not allowed.
- For landscape applications, a subsurface drip irrigation system has been aproved and installed to adequately discharge the captured water[6].
- If a pumping system is used, a reliable pump capable of delivering 100% of the design capacity is provided. Pump is accessible for maintenance. Pump has been selected to operate within 20% of its best operating efficiency. A high/low-pressure pump shut off system is installed in the pump discharge piping in case of line clogging or breaking.
- If an automated harvesting control system is used, it is complete with a rainfall or soil moisture sensor. The automated system has been programmed to not allow for continuous application on any area for more than 2-hours.
- Dispersion is directed so as not to knowingly cause geotechnical hazards related to slope stability or triggering expansive (clayey) soil movement.
- Cisterns do not allow UV light penetration to prevent algae growth.

6If alternative distribution systems (such as spray irrigation) are approved, the City will establish guidelines to implement these new systems.

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- Cistern placement allows easy access for regular maintenance. If cistern is undergrond, manhole shall be accessible, operational, and secure.
- Refer to County of Los Angeles , Department of Health Services for additional guidelines and requiremnets.
- Provide observation access for vector inspection and treatment.

4.5.4 Operations and Maintenance

- Cistern components, including spigots, downspouts, and inlets will be inspected 4 times annually to ensure proper functionality. Parts will be repaired or replaced as needed.
- Cisterns and their components will be cleaned as necessary to prevent algae growth and the breeding of vectors.
- Dispersion areas will be maintained to remove trash and debris, loose vegetation, and rehabilitate any areas of bare soil.
- Effective energy dissipation and uniform flow spreading methods will be employed to prevent erosion and facilitate dispersion.
- Cisterns will be emptied as necessary to prevent standing water from remaining for more than 72 hours following the conclusion of a storm event, unless exclusion devices are implemented to prevent vector access. If vector breeding is taking place at a site as a result of contained stormwater or inadequately maintained BMPs, the Greater Los Angeles County Vector Control District has the ability to fine site owners for violating the California Health and Safety Code (Section 2060 – 2067).

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4.6 BIOFILTRATION BMPS

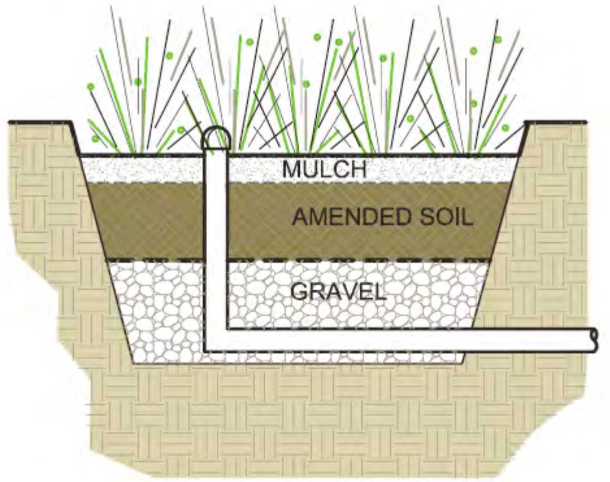
Projects that have demonstrated they cannot manage 100% of the water quality design volume onsite through infiltration and/or capture and use BMPs may manage the remaining volume through the use of a high removal efficiency biofiltration/biotreatment BMP. A high removal efficiency biofiltration/biotreatment BMP shall be sized to adequately capture 1.5 times the volume not managed through infiltration and/or captureanduse.

Biofiltration BMPs are landscaped facilities that capture and treat stormwater runoff through a variety of physical and biological treatment processes. Facilities normally consist of a ponding area, mulch layer, planting soils, plants, and in some cases, an underdrain. Runoff that passes through a biofiltration system is treated by the natural adsorption and filtration characteristics of the plants, soils, and microbes with which the water contacts. Biofiltration BMPs include vegetated swales, filter strips, planter boxes, high flow biotreatment units, bioinfiltration facilities, and bioretention facilities with underdrains. Biofiltration can provide multiple benefits, including pollutant removal, peak flow control, and low amounts of volume reduction through infiltration and evapotranspiration.

4.6.1 Biofiltration BMP Types

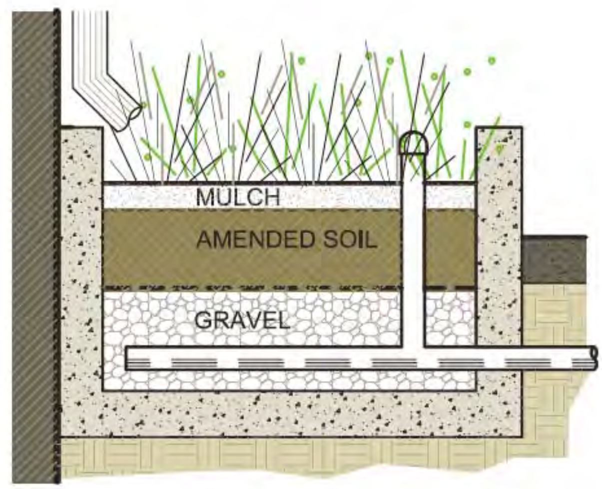
Biofiltration BMPs rely on various hydraulic residence times and flow-through rates for effective treatment. As a result, a variety of BMPs are available.

Bioretention with Underdrain



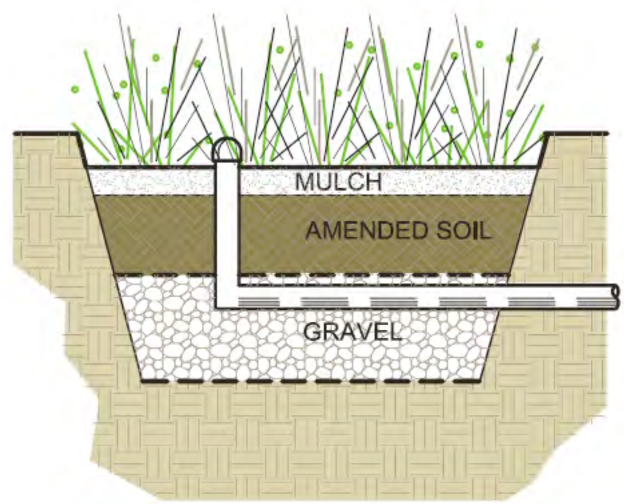
Bioretention facilities are landscaped shallow depressions that capture and filter stormwater runoff. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants. Because they are not contained within an impermeable structure, they may allow for infiltration. For sites not passing the infiltration feasibility screening for reasons other than low infiltration rates (such as soil contamination, expansive soils, etc.), an impermable liner may be needed to prevent incidental infiltration.

Planter Boxes



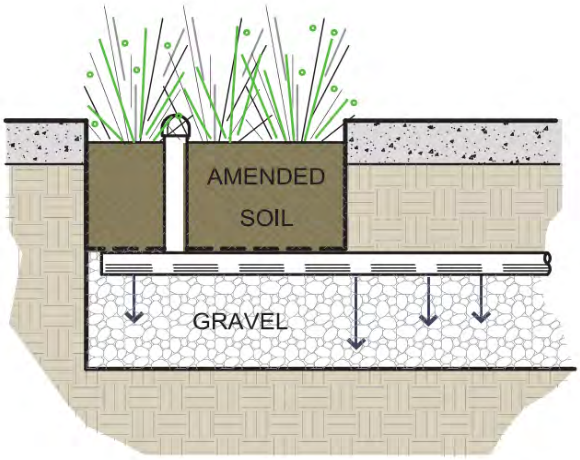
Planter boxes are bioretention treatment control measures that are completely contained within an impermeable structure with an underdrain (they do not infiltrate). They are similar to bioretention facilities with underdrains except they are situated at or above ground and are bound by impermeable walls. Planter boxes may be placed adjacent to or near buildings, other structures, or sidewalks.

Bioinfiltration



Bioinfiltration facilities are designed for partial infiltration of runoff and partial biotreatment. These facilities are similar to bioretention devices with underdrains but they include a raised underdrain above a gravel sump designed to facilitate infiltration and nitrification/denitrification. These facilities can be used in areas where there are little to no hazards associated with infiltration, but infiltration screening does not allow for infiltration BMPs due to low infiltration rates or high depths of fill.

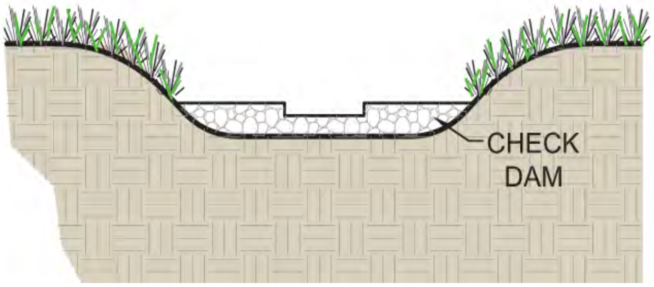
High-Flow Biotreatment with Raised Underdrain



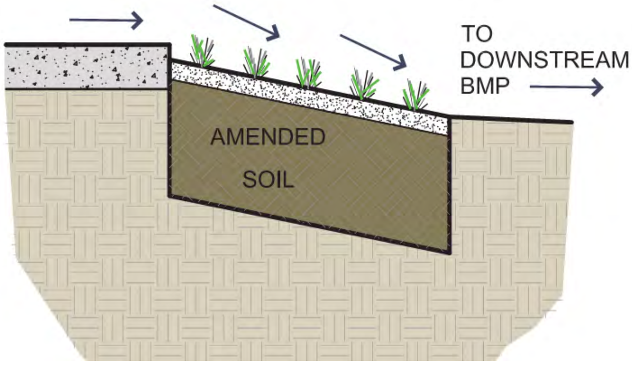
High-flow biotreatment devices are proprietary treatment BMPs that incorporate plants, soil, and microbes engineered to provide treatment at higher flow rates and with smaller footprints than their non-proprietary counterparts. Like bioinfiltration devices, they should incorporate a raised underdrain above a gravel sump to facilitate incidental infiltration where feasible.They must be shown to have pollutant removal efficiencies equal to or greater than the removal efficiencies of their non-proprietary counterparts. Proof of this performance must be provided by adequate third party field testing.

Vegetated Swales

Vegetated swales are open, shallow channels with dense, low-lying vegetation covering the side slopes and bottom that collect and slowly convey runoff to downstream discharge points. An effective vegetated swale achieves uniform sheet flow through the densely vegetated area for a period of several minutes. The vegetation in the swale can vary depending on its location and is the choice of the designer. Most swales are grass-lined.



Filter Strips (to be used as part of a treatment train)



Filter strips are vegetated areas designed to treat sheet flow runoff from adjacent impervious surfaces such as parking lots and roadways, or intensive landscaped areas such as golf courses. While some assimilation of dissolved constituents may occur, filter strips are generally more effective in trapping sediment and particulate-bound metals, nutrients, and pesticides. Filter strips are more effective when the runoff passes through the vegetation and thatch layer in the form of shallow, uniform flow. Filter strips are primarily used to pretreat runoff before it flows to an infiltration BMP or another biofiltration BMP.

4.6.2 Siting Requirements and Opportunity Criteria

Sites with plans to implement high removal efficiency biofiltration/biotreatment systems for the management of stormwater must first be screened for infiltration and capture and use BMP feasibility. Biofiltration should be implemented to treat all runoff onsite to the maximum extent feasible at sites incapable of implementing infiltration and/or capture and use BMPs as a result of the feasibility screening process set forth in this handbook.

Sites implementing biofiltration BMPs must have sufficient area available to ensure that BMPs produce adequate contact time for filtration to occur. For biofiltration BMPs with underdrains, sufficient vertical relief must exist to permit vertical percolation through the soil media to the underdrain below. For biofiltration BMPs with incidental infiltration, it must be demonstrated that there are no hazards associated with infiltration (i.e. infiltration screening does not allow for infiltration BMPs due to low infiltration rates or high depths of fill).

4.6.3 Calculating Size Requirementsfor Biofiltration BMPs

Biofiltration BMPs should be designed according to the requirements listed in Table 4.5 and outlined in the section below.

Table 4.5: Biofiltration BMP Design Criteria

Design Parameter	Unit	Bioretention with Underdrain	Planter Box	Bioinfiltration	High Flow Biotreatment[a]	Vegetated Swale	Filter Strip
Design Capture Volume, $V_{capture}$	cubic feet	1.5 x 0.0625 * Catchment Area (sq. ft.)[b]					-
Design Drawdown Time	hr	48 (surface); 96 (total)				-	-
Factor of Safety[c]	-	2				-	
Soil Media Infiltration Rate	in/hr	5 (max)			Per manufacturer's standards	-	
Design Contact Time	min	-				≥ 7	
Slope in Flow Direction	%	-				1% (min) 6% (max)	2% (min) 33% (max)
Design Flow Velocity	ft/sec	-				≤ 1	
Max Ponding/Flow Depth	inch	18	12	18	-	5	1
Soil Depth	ft	2 (3 preferred)	2 (3 preferred)	2 (3 preferred)	-	2	-
Underdrain	-	Slotted PVC pipe within 6" of bottom of facility	Slotted PVC pipe within 6" of bottom of facility	Slotted PVC pipe at least 2' above bottom of facility	Per manufacturer's standards	N/A	Not required
Inlet erosion control	-	Energy dissipater to reduce velocity					
Overflow device	-	Required if system is on-line and does not have an upstream bypass structure. Shall be designed to handle the peak storm flow in accordance with the Building and Safety code and requirements					Not Required

a: High flow biotreatment BMP design criteria displayed in Table 4.5 are general guidelines. Specific designs will vary depending on the vendor, design type, size, etc. High flow biotreatment BMPs must be sized to treat the design capture volume specified. They must be shown (by third party field testing) to have a pollutant removal efficiency equal to or greater than their non-proprietary counterparts.

b: Catchment area = (impervious area x 0.9) + [(pervious area + undeveloped area) x 0.1]

c: Listed FS values to be used only if soil infiltration / percolation test was performed and a detailed geotechnical report from a professional geotechnical engineer or engineering geologist is provided A FS of 6 will be assigned if only a boring was done.

Bioretention, Planter Box, Bioinfiltration, and High-Flow Biotreatment Sizing

With the exception of swales and filter strips, biofiltration facilities can be sized using one of two methods: a simple sizing method or a hydrologic routing modeling method. With either method the design capture volume must be completely infiltrated within the drawdown time shown in Table 4.5. Steps for the simple sizing method are provided below.

Step 1: Calculate the Design Volume

Biofiltration facilities shall be sized to capture and treat 150% of the design capture volume (V_{design}) based on the runoff produced from a 0.75-inch (0.0625 ft) storm event.

$$V_{design} \text{ (cu ft)} = 1.5 * 0.0625 \text{ ft} * \textit{Catchment Area} \text{ (sq. ft.)}$$

Where

Catchment area = (Impervious Area x 0.9) + [(Pervious Area + Undeveloped Area) x 0.1]

Step 2: Determine the Design Infiltration Rate

The infiltration rate will decline between maintenance cycles as the surface and underlying soil matrix becomes clogged with particulates and debris. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the sizing of facilities depending on a site's infiltration rate and expected surface loading. Unlike infiltration BMPs, the measured infiltration rate discussed here is the infiltration rate of the filter media bed or engineered surface soils in the biofilter. A target long-term$K_{sat,media}$of 5 in/hr is recommended for non-proprietary amended soil media. Facility maintenance is required to maintain the infiltration rate for the life of the project. Infiltration rates used for design must be divided by the appropriate factors of safety.

$$K_{sat,design} = K_{sat,media}/FS$$

Step 3: Calculate the BMP Ponding Depth

Select a ponding depth (d_p) that satisfies geometric criteria and is congruent with the constraints of the site. The ponding depth must satisfy the maximum ponding depth constraint shown in Table 4.5 as well as the following:

$$d_p \text{ (ft)} = (K_{sat,design} \times T) / 12$$

Where:

d_p = Ponding depth (ft)

$K_{sat,design}$= Design infiltration rate of filter media (in/hr)

T = Required surface drain time (hrs), from Table 4.5

Step 4: Calculate the BMP Surface Area

Calculate infiltrating surface area (filter bottom area) required:

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$$A_{min} = \frac{V_{design}}{[(T_{fill}K_{sat,design}/12) + d_p]}$$

Where:

A_{min} = Design infiltrating area (ft^2)

T_{fill}= Time to fill to max ponding depth with water (hrs) [unless a hydrologic routing model is used, assume a maximum of 3 hours]

The calculated BMP surface area only considers the surface area of the BMP where infiltration through amended media can occur. The total footprint of the BMP should include a buffer for side slopes and freeboard.

Bioinfiltration BMPs and high-flow biotreatment devices should incorporate a raised underdrain above the gravel sump to facilitate incidental infiltration where feasible. For these instances, infiltration screening in accordance with Section 4.2 must be carried out to show thatinfiltration BMPs are not allowed due to low infiltration rates or high depths of fill (i.e. there are not hazards associated with infiltration). These BMPs are not suitable for project sites that do not pass infiltration feasibility screening due to associated hazards of infiltration (e.g. high groundwater table, contaminated soil or groundwater, landslide zones, etc.)

Swale Sizing

Swales shall be designed with a trapezoidal channel shape with side slopes of 3:1 (H:V). They shall incorporate at least two feet of soil beneath the vegetated surface. The following steps shall be followed for swale sizing. As is the case with other biofiltration BMPs, the sizing criteria presented in Table 4.5 must be met.

Step 1: Determine the Swale Base Width and Corresponding Unit Length

The base width of a swale must be between 2 and 10 feet. The designer may select the base width that is most appropriate for the site, but the swale length (per unit catchment area) must meet the minimum requirements as shown in Table 4.6 below.

Table 4.6: Swale Base Length (Per Unit Catchment Area)

Base of Swale	ft	2	3	4	5	6	7	8	9	10
Minimum Swale Length per Acre of Catchment Area	ft/acre	770	635	535	470	415	370	335	305	285

Step 2: Determine the Distance Between Check Dams

For volume storage, swales must incorporate check dams at specified intervals depending on the longitudinal slope of the swale, which must be between one and six percent. The check dams must be 12 inches in height and include a 6 inch deep notch in the middle of the check dam that is between one and two feet wide. All check dam structures shall extend across the entire base of the swale. They may be designed using a number of different materials including concrete blocks, gabions, gravel bags, rip rap, or earthen berms. The distance between successive check dams shall be determined from the longitudinal slope of the swale in the flow direction. Table 4.7 summarizes the design distances between check dams based on slope.

Table 4.7: Check Dam Spacing Requirements for Swales

Slope	%	1	2	3	4	5	6
Distance Between Checkdams	ft	100	50	33	25	20	17

For intermediary slopes not shown in Table 4.7, linear interpolation may be used to calculate the distance between check dam structures.

Step 3: Determine the Total Swale Length

The total length of the swale (L_{swale}) is a function of the catchment area and unit swale length from Table 4.6. Total swale length is calculated as follows:

L_{swale} (ft) = *Catchment Area* (ft^2) x (1 acre/43,560 ft^2) x
Swale Length per Acre of Catchment Area (ft/acre)

Where

Catchment area = (Impervious Area x 0.9) + [(Pervious Area + Undeveloped Area) x 0.1]

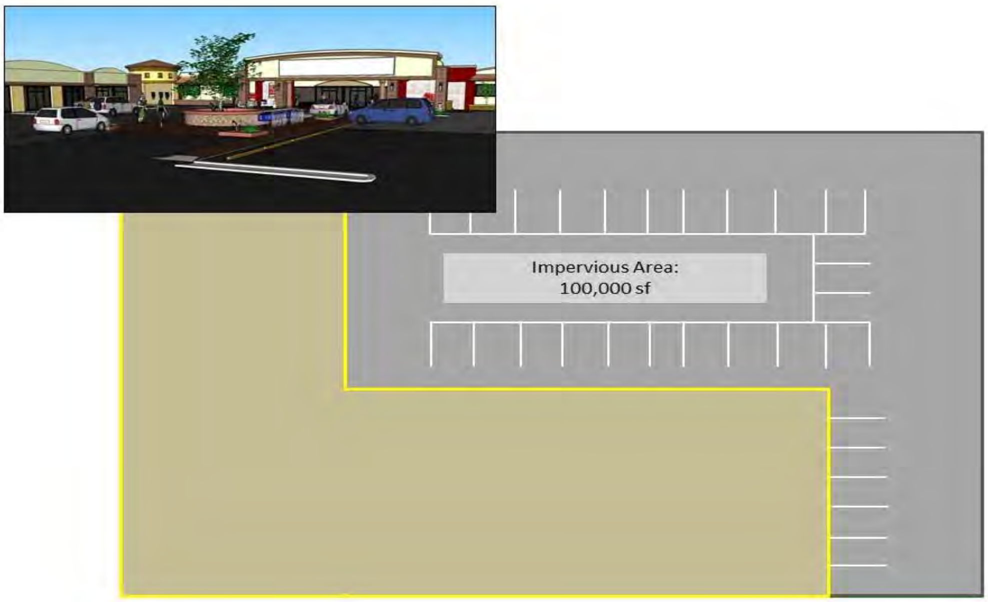
If there is adequate space on the site to accommodate a larger swale, consider using a greater length to increase the hydraulic residence time and improve the swale's pollutant removal capability. If the calculated length is too long for the site, the layout may be modified by meandering the swale or increasing the base width of the swale up to 10 feet. The total swale length shall never be less than 100 feet.

Filter Strip Sizing

Because filter strips are most often used for pretreatment purposes, their design will depend on the desired flow-rate to be treated and the type of BMP downstream, among other factors. As a result, filter strip sizing is not covered in this handbook, but will be determined on a case-by-case basis by the City of Los Angeles.

Bioinfiltration Sizing Example

Given: 100,000 ft^2 commercial development, 100% impervious (negligible landscaping). Design a bioinfiltration BMP to treat runoff from the entire development ($K_{sat,media}$= 5 in/hr; Factor of Safety = 2.).



1) Determine V_{design}
   Catchment Area = (100,000ft^2 x 0.9) = 90,000ft^2
   $\boldsymbol{V_{design}}$ = 1.5 x 0.0625 x 90,000ft^2 = **8,500 ft^3**

2) Determine $K_{sat,design}$
   $\boldsymbol{K_{sat,design}}$ = (5 in/hr) /2 = **2.5 in/hr**

3) Determine d_p
   d_p = (2.5 in/hr * 48 hrs)/12 = 10.0 ft

   Adhering to the max ponding depth requirements of Table 4.5, $\boldsymbol{d_p}$ **= 1.50 ft**

4) Calculate the infiltrating surface area, A_{min}

$$\mathbf{A_{min}} = \frac{8{,}500\, cuft}{[(3hr * 2.5\, in/hr\ /12) + 1.5\ ft]} = \mathbf{4{,}000\ ft^2}$$

For a full capture system, bioinfiltration units must be designed with a combined surface area of 4,000 ft^2.

4.6.4 Design Criteria and Requirements

Unless specifically stated, all criteria and requirements listed below are required for the implementation of all biofiltration BMPs. Provisions not met must be approved by the City of Los Angeles.

- Where applicable, biofiltration BMPs shall be constructed with a minimum planting soil depth of 2 feet (3 feet preferred).
- Where applicable, biofiltration BMPs shall be designed to drain below the planting soil in less than 48 hours and completely drain from the underdrains in 96 hours.
- Underdrains shall be constructed of slotted PVC pipe, sloped at a minimum of 0.5%, placed on a 6-inch minimum bed of washed aggregate, and covered with 6 inches of the same aggregate. Underdrain drains freely to a downstream stormwater conveyance system, an additional BMP, or an alternatively acceptable discharge point.
- If system is online, an overflow is present. The overflow safely conveys flows to the downstream stormwater conveyance system, an additional BMP, or an alternatively acceptable discharge point.
- Inflow to swales shall be directed towards the upstream end of the swale.
- Bioinfiltration BMPs and high-flow biotreatment BMPs designed for secondary infiltration shall pass the infiltration feasibility screening for all hazardous criteria. If necessary, weep holes shall be used to increase infiltration.
- Swales shall be constructed with a bottom width between 2 and 10 feet. Check dams shall be incorporated at the appropriate distances as specified in Table 4.7. Check dams are 12 inches in height and include a 6 inch deep notch in the middle of the check dam that is 1-2 feet wide. Each check dam extends across the entire width of the swale's base.
- Filter strips shall be constructed to extend across the full width of the tributary area. They shall be designed with sufficient slope in the flow direction to prevent ponding. They shall have a minimum length of 4 ft in the flow direction when sized for pretreatment purposes.

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4.6.5 Soil and Vegetation Requirements

Soil and vegetation to be incorporated in biofiltration facilities shall be selected by a licensed landscape architect. In general, drought and flood resistant plant species native to Southern California should be selected when possible. Soil media should be selected to facilitate vigorous plant growth and not restrict performance requirements. Where the project receiving waters are impaired for nutrients or a nutrient-related TMDL is in place, media should be selected to minimize the potential for leaching of nutrients from biofiltration systems.

4.6.6 Operations and Maintenance

Biofiltration areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, biofiltration maintenance requirements are typical landscape care procedures. The following operations and maintenance practices will be adhered to:

- Facility soil will be maintained. Flow entrances, ponding areas, and surface overflow areas will be inspected for erosion periodically. Soil and/or mulch will be replaced as necessary to maintain an infiltration rate at or near the initial $K_{sat,design}$value for the duration of the project.
- Site vegetation will be maintained as frequently as necessary to maintain fire protection, public safety, and the aesthetic appearance of the site as well as the filtration capabilities. This includes the removal of fallen, dead, and/or invasive plants, watering as necessary, and the replanting and/or reseeding of vegetation for reestablishment as necessary. Swales and filters will be mowed as necessary.
- BMP inlets will be inspected and maintained to ensure even flow enters the facility. Sediment collecting at the inlet will be removed as necessary.
- Proprietary devices will be inspected and maintained in accordance with the requirements of the manufacturer.

SECTION 5: OFFSITE MITIGATION MEASURES

5.1 OFFSITE MITGATION MEASURES

The option for offsite mitigation shall only be exercised after the following conditions have been met:

1. All the stormwater management techniques allowed (i.e., in priority order of infiltration, capture and use, treated through high removal efficiency biofiltration system) have been exhausted (i.e. are deemed technically infeasible), and;

2. All applicable Standard Urban Stormwater Mitigation Plan (SUSMP) requirements are implemented in order to maximize onsite compliance, and;

3. A LID, and if necessary, SUSMP BMP waiver is obtained from the Department of Public Works, Bureau of Sanitation.

Offsite project BMPs should be located as close as possible to the project site, on private and/or public land, and should address a mix of land uses similar to thoseincluded in the proposed project. The offsite project shall not be located within waters of the US and it shall be demonstrated that equivalent pollutant removal is accomplished prior to discharge to waters of the US.

For the remaining runoff that cannot feasibly be managed onsite, the project shallimplement offsite mitigation in either:

(1) The public right of way immediately adjacent to the subject development and/or;

(2) Within the same sub-watershed (as defined as draining to the same hydrologic area as defined in the Basin Plan) as the proposed project

Construction of an offsite mitigation project(s) shall achieve at least the same level of water quality protection as if all of the runoff were retained onsite and also be sized to mitigate the volume from the onsite and the tributary area from the adjacent street (from the crown of the street to the curb face for the entire length of the development site). All City Departments will assist the developer, when and where feasible, permitting and implementation of LID BMP projects within the public right of way.

Construction work in the public right-of-way will be the responsibility of the developer, and requires a "Revocable Permit"from the Department of Public Works, Bureau of Engineering (BOE). The developer will also be required to file a covenant and agreement with the county

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recorder's office to insure the owner assumes full responsibility for perpetual maintenance of the onsite and offsite BMP(s) executed by a covenant and agreement. The type of BOE permitrequired depends on the scope of construction work. Additional permit information and detailed flowcharts can be found at: http://eng.lacity.org/techdocs/permits/index.htm

Green Infrastructure Projects

In an effort to assist developers the City has recently approved and adopted a series of green street standard plans. The plans provide a series of standards that developers can implement utilizing the public right of way immediately adjacent to the development. These standard plans provide general requirements for green streets, parkway swales in major/secondary highways, parkway swales in local/collector streets, parkway swales with no street parking, vegetated stormwater curb extensions, and interlocking pavers for vehicular and pedestrian alleys. The green street standard plans can be obtained from the Bureau of Engineering's Website at:

http://eng.lacity.org/techdocs/stdplans/s-400.htm

http://eng.lacity.org/techdocs/stdplans/Pdfs/Green%20Street%20Standard%20Plans%20FAQ%20Sheet_091010.pdf

Additional information on the City's Green Streets and Green Alleys design Guidelines can be found at:http://www.lastormwater.org/Siteorg/program/green.htm

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RB-AR32778

Community Conservancy International

2554 Lincoln Blvd.
Suite 223
Los Angeles, CA 90291
USA

310.398.8584
fax 310.398.8564
www.CCINT.org

The Green Solution Project

Creating and restoring park, habitat, recreation and open space on public lands to naturally clean polluted urban and stormwater runoff

EXECUTIVE SUMMARY AND MAPS

Coastal Conservancy

bay restoration foundation
STEWARDS OF SANTA MONICA BAY

Santa Monica Mountains Conservancy

San Gabriel & Lower Los Angeles
RIVERS AND MOUNTAINS
CONSERVANCY

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For a complete copy of the report, go to www.ccint.org/greensolution.html

Community Conservancy International (CCI) is a 501(c)(3) nonprofit, tax-exempt organization dedicated to solving the complex problems created where people and nature intersect. For more information, contact us at:

2554 Lincoln Boulevard, Suite 223 Los Angeles, CA 90291 (310) 398-8584 www.ccint.org

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RB-AR32780

Community Conservancy International

2554 Lincoln Blvd.
Suite 223
Los Angeles, CA 90291
USA

310.398.8584
fax 310.398.8564
www.CCINT.org

Board of Directors
James Burks
Dr. Thomas Chapin
Jim Edmondson
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The Honorable
Laurene Weste

The Green Solution Project

Creating and restoring park, habitat, recreation and open space on public lands to naturally clean polluted urban and stormwater runoff

EXECUTIVE SUMMARY AND MAPS

Directed and Produced by

Community Conservancy International

March 2008

Funded by

Community Conservancy International
Coastal Conservancy
bay restoration foundation
STEWARDS OF SANTA MONICA BAY
Santa Monica Mountains Conservancy
San Gabriel & Lower Los Angeles RIVERS AND MOUNTAINS CONSERVANCY
THE TRUST for PUBLIC LAND

Executive Summary

Green Solution Projects *improve water quality by using soil, plants, and natural processes to capture, filter and clean polluted urban and stormwater runoff, while creating new parks, natural habitat, recreation and other open space lands.*

This Executive Summary presents a synopsis of Community Conservancy International's (CCI) **Green Solution Project** study and presents CCI's findings, conclusions and recommendations on the potential of using existing public lands to help improve water quality while creating a network of new, green open space lands throughout Los Angeles County. As part of CCI's on-going efforts to develop practical solutions to difficult environmental problems that affect both people and nature, we are pleased to present this compilation of our research results on innovative and effective methods for addressing polluted urban and stormwater runoff that plagues the rivers, streams, lakes, beaches, bays and coastal waters of L.A. County (*see Polluted Waters Map of Los Angeles County at end of this section*). CCI's Executive Summary is based on the methodology and data described in the Technical Report prepared by Geosyntec Consultants, with Geographic Information System (GIS) data analysis provided by GreenInfo Network. For a copy of the complete report, go to www.ccint.org/greensolution.html.

Nearly all of the county's waters are in violation of federal and state water quality standards. CCI's **Green Solution Project** study presents a creative, practical and fresh approach to these problems by focusing on unpaving concrete and impervious areas and retrofitting pervious areas on existing public lands throughout Los Angeles County, so that these lands can act as natural filters while also providing important and badly-needed park, habitat and recreation opportunities.

The results of this study are quite exciting, as they show that there is indeed a substantial amount of land throughout every watershed in the county – up to 20,000 acres - suitable for Green Solution projects. These findings are particularly important as the need for innovative solutions to both water quality problems and the lack of park, habitat and open space in urban areas continue to grow.

As part of Community Conservancy International's focus on critical problems affecting people and the environment, CCI identified polluted urban and stormwater runoff as an increasingly serious and pressing need in California, and especially in Los Angeles County, where extensive urbanization has resulted in vast areas of paved surfaces and daily high volumes of contaminated runoff. These same urbanized areas are among the most park-poor in the United States, lack natural open space that serve as a healthy respite to city dwellers from urban congestion, and have lost nearly all of their native habitat lands.

The long-term, damaging impacts of polluted urban and stormwater runoff on beaches, aquatic life, and human health and on the health of oceans, birds and marine mammals worldwide have been well documented. This **Green Solution** approach is essential to effectively address water pollution produced throughout the nation, and particularly in areas where the natural functions of watersheds, rivers and the soil itself have been dramatically altered. CCI initiated, designed and directed the **Green Solution Project** study, provided the initial funding, and secured the public and private grants to fund this work. This study focused on the water pollution clean-up needs within the watersheds of the L.A. County Flood Control District[i]. (*See Watersheds and Drain Outlets map at end of this section.)*

Green Solution projects focus on combining land conservation with water quality improvements to:

- **Create** new habitat and open space to naturally clean up polluted runoff
- **Re-green** urban areas
- **Restore** native habitat to cultivated landscapes
- **Develop** new recreation opportunities
- **Protect** threatened creeks and rivers, as well as the ocean and coastal waters

To be considered a **Green Solution**, projects must:

- **Convert** paved, impervious areas to pervious lands that allow water to filter into soil and plants
- **Retrofit** existing pervious areas to effectively catch, filter, clean, store, and, reduce runoff
- **Create multiple benefits, such as** parks, recreation, habitat, and other open space opportunities

Green Solution Projects are essential to help Los Angeles County cities within the county meet water quality improvement goals and increasingly strict legal requirements to clean up polluted urban and stormwater runoff. CCI's **Green Solution Project** study provides quantified data necessary to guide project selection to effectively address urgent water quality problems due to runoff. The project provided the research and technical analysis necessary to quantify the amount of acreage needed in each watershed for retrofitting or for conversion from concrete to pervious Green Solution, multi-benefit projects to help meet the water quality improvement requirements established by the Regional Water Quality Control Board.

Until CCI's **Green Solution Project** study, the conventional assumption made in examining how to improve water quality using natural Green Solutions in L.A. County was that this approach was not really feasible, as very little land was believed available for these types of solutions. Part of this perception was due to the assumption that only existing open space or vacant lands were suitable for conversion to Green Solutions.

The CCI study found that there is a wide range of existing public lands, in a variety of land uses, that are in fact potentially suitable for creative multiple-benefit, Green Solution projects.

A Fresh and Practical Approach: Green Solutions on Existing Public Lands

The **Green Solution** approach can be implemented in any area that needs to address urban runoff pollution problems. Conventional thought has often been that, in heavily urbanized areas, very little land is available or suitable for conversion to green, multiple-benefit projects that can naturally filter and clean urban runoff. This study shows that many types of land uses can be utilized for these multiple-benefit projects, and that the benefits – including variations by land use - can be quantified. Community Conservancy International's fresh approach focused on how to make best use of lands already in public ownership that are potentially suitable for both water quality improvement and "green" multiple-benefit projects. We found that a significant amount of land does exist that is suitable for Green Solutions – and that there are also a surprising number of large (greater than 10 acres) parcels that could be effectively utilized.

The CCI Team's analysis found that nearly 40% of the polluted runoff clean-up needs in the county could be met by implementing Green Solution projects on existing public lands (based on average need and acres of suitable land). The CCI Team's analysis showed 10,027 parcels of public lands with some portion suitable for Green Solution projects. The team's analysis found that an average of 39,000 acres are needed county-wide for Green Solution projects, and that a net average of 15,000 acres of existing public lands in the county are in fact suitable for Green Solution Projects. By implementing Green Solution projects on these public lands, an average 360,000 acres of drainage area could be treated. We found a maximum of 20,000 suitable public acres with Green Solution project potential. (*See maps of Opportunity Public Parcels by size, owner and land use at end of this section.*)

While **Green Solution Projects** can be implemented on both public and private lands, focusing on existing public lands offers a cost-effective and readily available solution not only to the increasingly serious water quality problems in Los Angeles County, but also to the demand to make communities healthier and more livable by creating a green network of park, native habitat, recreation and other open space lands, as well as to the growing need to address drought and global warming issues by capturing, conserving and recycling our increasingly precious water resources.

The Problem: Polluted Urban Runoff Impacts L.A. County's Rivers, Bays and Beaches & Ocean Waters Worldwide

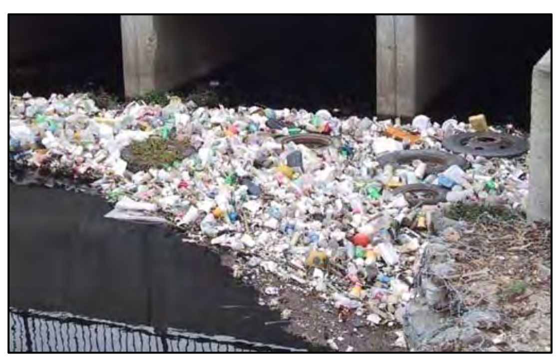
There is an urgent and growing need to clean up polluted runoff to improve water quality throughout Los Angeles County (*see Polluted Waters map at end of this section*). Serious water pollution from stormwater and daily urban runoff plagues all of the rivers, streams, lakes, coastal waters, bays and beaches in the county, endangering the health of people, animals and the aquatic and marine life dependent on these waters for survival, closing beaches, causing grave economic impacts, and polluting ocean waters around the world.

Pollution associated with stormwater and daily urban (dry weather) runoff can only be solved by addressing the generation of pollutants, and the flow and treatment of runoff throughout each watershed, and by taking full advantage of all opportunities for conversion of paved, impervious surfaces to pervious surfaces that allow soil and plants to naturally infiltrate and clean water.

Almost 100 different pollutants are found in L.A. County's waters in amounts significantly above federal and state public health standards. Nearly all water bodies in Los Angeles County - rivers, streams, lakes, bays, ocean - are in violation of the U.S. Clean Water Act, which sets water quality standards intended to protect human health and marine and aquatic life. These pollutants have contaminated over 300 miles of rivers and streams, 160,000 acres of lakes, both Santa Monica and San Pedro Bays and the entire county coastline.[ii] UCLA and Stanford University scientists found that up to 1.5 million people get sick each year from infections and gastrointestinal illnesses caused by bacteria at L.A. County beaches.[iii] L.A. County had the worst beach water quality record in California in 2005, as well as the five most polluted beaches in the state[iv].

The pollution impacts from urban runoff is endangering oceans and marine life around the world[v]. **Sixteen million tons of trash end up on L.A. County's beaches every year**[vi] – and this does not count the additional millions of tons that are carried by ocean currents and which accumulate in huge floating "rafts" of plastic trash in the Pacific Ocean between California and Japan. The largest of these is twice the size of Texas. Trash chokes one million seabirds worldwide every year; plastic is found in the stomachs of seabirds, turtles and marine mammals around the worlds, and toxic pollutants and bacteria from runoff can be fatal to marine mammals. Low oxygen "dead zones" are spreading due to increasing fertilizer use and growing coastal populations.[vii]

Urban runoff is polluted water from sprinklers, yards and landscaping, from hosing down driveways, sidewalks, cars and parking lots, from washing equipment outside businesses, and from other daily home and business uses that flows - untreated in any way - through county and city drains every day, even in dry weather. All property in every community throughout the county produces runoff, and in dry weather generates a total of 330 million gallons of water every day[viii] – **enough to fill the Rose Bowl four times over**. **This daily runoff carries pollutants** from homes, landscaped areas, businesses and parking lots directly into our creeks, rivers, lakes, beaches, bays and ocean – in most cases without treatment of any kind.



When it rains, the problem is far worse, as the high volumes of stormwater carry huge amounts of trash and pollutants through the county's drainage system very quickly. On rainy days, the flow can increase to 6.5 billion gallons per day.[ix] In an average rainfall year, over 150 billion gallons of stormwater flow through the county's drainage system, without treatment of any kind.[x]

Pollutants in L.A. County's stormwater and daily urban runoff include infection-causing bacteria, toxic metals, pesticides, household and industrial chemicals, trash, oil, oxygen-choking fertilizers and other toxins. High bacteria counts cause serious illnesses and thousands of beach closures in L.A. County every year.[xi] Summer beach closures cost local cities millions of dollars in lost revenue, and these ongoing ocean and beach pollution problems hurt L.A. County's worldwide image as a desirable tourist destination.

The Importance of The Green Solution

Many water quality experts and scientists believe that much of the toxins, bacteria and other contaminants carried by daily urban and stormwater runoff can be permanently addressed by directing these polluted waters to a network of new and well-designed "green" areas: new and restored natural habitat, parks, and recreation lands that allow soil and plants to naturally filter and uptake water and pollutants as well as providing a wide range of open space and other benefits. This would also provide desperately-needed park, recreation and habitat in areas throughout urbanized L.A. County that are starved for these amenities.

As a result of decades of intensive growth and development, much of the county is now heavily urbanized; this extensive development has resulted in a majority of the county's urban areas being paved with concrete, asphalt and other non-porous or impervious substances that do not allow water to penetrate into the soil. This wide-spread imperviousness is one of the biggest causes of L.A. County's polluted runoff problems. Green Solution projects provide one of the most viable and effective means of permanently cleaning up polluted runoff because they restore the natural functions of soil and plants to capture, filter and clean contaminants from runoff before it reaches rivers, bays, beaches and the coast.

Green Solution projects include regional scale projects on large parcels that can clean runoff from surrounding areas and serve a large drainage area, as well as local or on-site projects, which typically clean runoff just from that site, and serve small drainage areas.

These **Green Solution** projects can make urgently-needed and lasting water quality improvements in the county's polluted waters, and can provide many multiple benefits, including:

- reduce infection-causing bacteria
- remove other pollutants
- reduce runoff volumes
- store and recycle water for later use as irrigation
- improve water quality in rivers, at beaches, and in Santa Monica and San Pedro Bays

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Green Solution Projects are proving to be one of the most effective and cost-efficient ways to make lasting water quality improvements consistent with the requirements of the Regional Water Quality Control Board. While providing park and recreation opportunities in heavily urbanized and park-poor areas and restoring important natural habitat, Green Solution Projects can also be effective "water recyclers", and can reduce the effects of drought caused by global warming by catching, storing and re-using stormwater to water parks and landscaping or to sustain natural areas.

Green Solutions effectively utilize natural treatment processes which take advantage of the natural functions of soils and plants. These include biofiltration (filtration of pollutants through vegetation and soil), bio-uptake (biological processes such as the assimilation of pollutants such as nitrogen and phosphorous, which soil and plants can convert for their beneficial use), infiltration, runoff volume reduction through evapotranspiration, and other biological, physical, and biochemical processes that significantly improve water quality. In many cases, natural treatment processes are more effective than other types of more structural and conventional Best Management Practices because they are passive systems, requiring little energy, operations and maintenance – often similar to conventional landscaping maintenance.

The CCI Team's New Methodology & Preliminary Findings

The CCI Team developed a unique methodology to quantify the amount of land potentially necessary for conversion or retrofit to Green Solution projects in order to address polluted runoff and the amount and locations of existing public lands suitable for these projects. The overall approach and analysis posed and responded to the following research questions:

- How much of L.A. County's land actually contributes runoff?
- What pollutants can be cleaned up by Green Solution projects?
- How much land is needed for Green Solutions to clean runoff from contributing areas?
- Which public lands are suitable for Green Solution projects?
- What percent of the Green Solutions need in L.A. County can be met by converting or retrofitting portions of existing publicly-owned lands?

The watersheds evaluated in this study are: Ballona Creek; Dominquez Channel; Upper Los Angeles River; Lower Los Angeles River; Upper San Gabriel River; Lower San Gabriel River; Santa Clara River; Central Santa Monica Bay Coast; North Santa Monica Bay Coast; and South Santa Monica Bay Coast (*see Map of Watersheds following this section*).

The CCI Team evaluated how stormwater and urban runoff moves through each watershed in the county, including both natural flow of water and directed flow within the constructed (man-made) storm drain system. The constructed system drains stormwater and daily urban (dry weather) runoff into over 143,000 individual entry points in gutters and curbs (catch basins) all over the county; these catch basins then empty into an underground network of nearly 5,000 miles of pipes (the storm drains) that flow into the county's streams and river channels, and then out to the beaches, coast and ocean.

The amount of runoff produced in Los Angeles County depends on the extent of imperviousness of lands in each watershed. The team analyzed watersheds within the study area, and determined that there are the equivalent of over 517,000 net acres effectively contributing runoff. This was determined by calculating the percent imperviousness by land use, based on the L.A. County Hydrology Manual and on industry standards for determining runoff. Runoff produced by both impervious and pervious areas was accounted for (90% and 10%, respectively). Figure 1, below, shows each watershed's relative contribution of runoff.

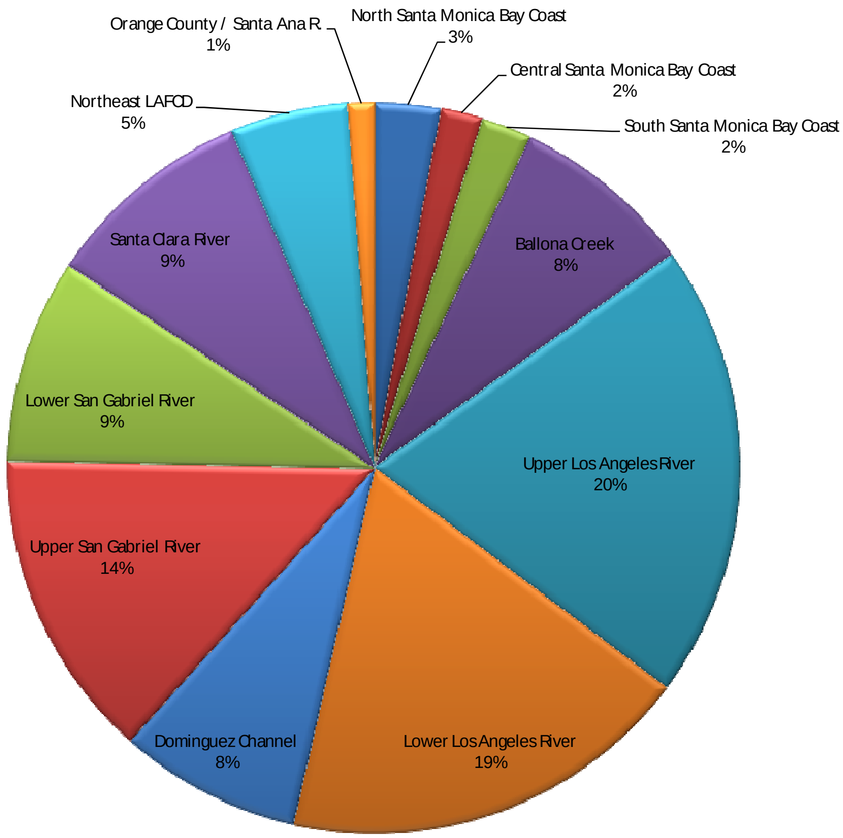

Figure 1. Relative Contribution of Runoff from Los Angeles County Watersheds

Pollutants of concern that were identified as able to be addressed by Green Solution projects are:

- Bacteria
- Excessive nutrients, i.e.; nitrates and other fertilizer-based chemicals
- Heavy metals, including lead and copper
- Oil & grease
- Oxygen-demanding substances
- Sediment
- Trash & debris

Determining which public lands could be suitable for Green Solution projects included an evaluation of location, land use, size, slope, and portion of parcels suitable for either conversion or retrofit. Large parcels (> 100 acres) were evaluated individually; parcels less than ¼ acre were not included. Parcels that had a 20% slope over greater than 50% of their area were excluded. Parcels without significant upstream contributing pollutant loads (e.g., in upper reaches of a natural watershed) were also excluded. Ranges (low to high) were determined in each land use type of the percent of a parcel's area that could be suitable for either conversion of paved, impervious surface to pervious, porous surface or for retrofit of existing pervious

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to more effective catchment, filtration or storage. Depending on the specific land use, percentages of area deemed suitable ranged between 3% to 55%.

The following land uses were identified as being potentially suitable:

- Developed Open Space
- Undeveloped Open Space
- Regional Parks
- Vacant
- Commercial Recreation
- Public Facilities
- Public Office Buildings
- Schools and Colleges
- Residential
- Rights-of-Way
- Powerlines
- Transportation
- Airports
- Waterways

To capture, filter, clean, and reduce pollutants carried by runoff from watersheds throughout the county, the analysis showed that a total of 26,000 to 52,000 acres are needed for conversion or retrofit into Green Solution projects, with an average need of 39,000 acres. Figure 2 shows the acreage needed by watershed.

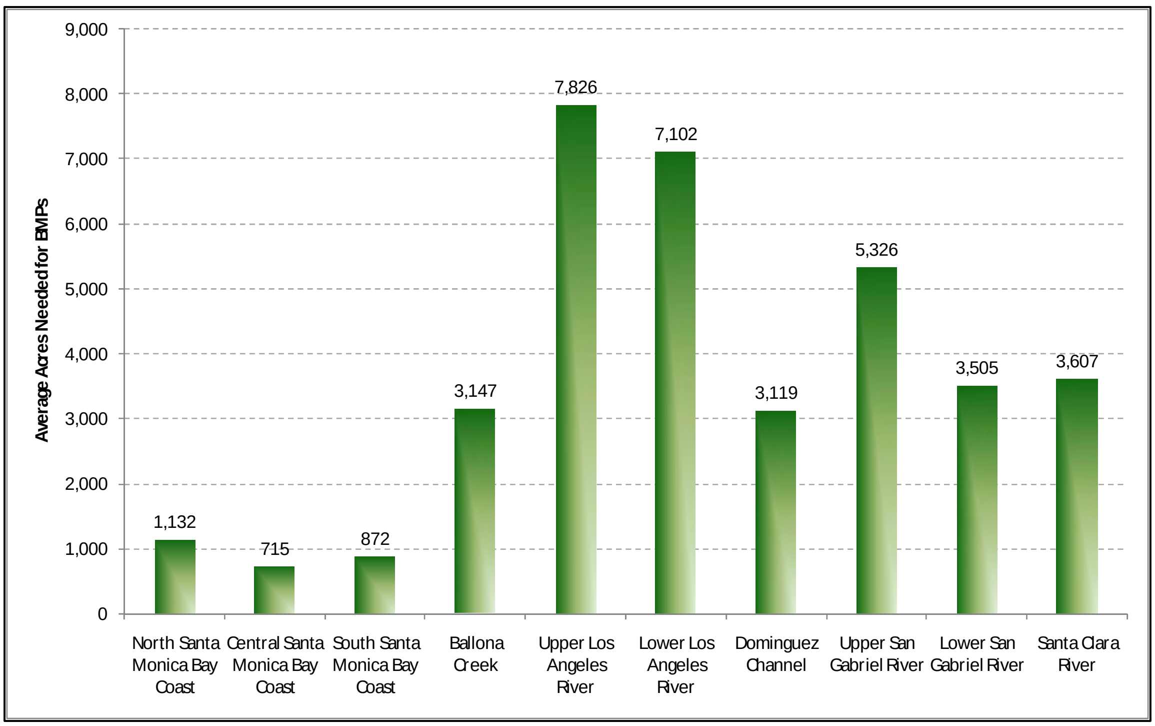


Figure 2. Acres of Land Needed for Green Solution Runoff Treatment, Average by Watershed

There are 10,027 opportunity public parcels – those that passed the rigorous screening and evaluation for suitability – comprising a total land mass of over 71,000 acres. Based on the analysis, which took into account variability within land uses and other factors, these parcels contain a net range of between 9,500 and 20,200 acres of public land that are potentially suitable as Green Solution Projects, with a total average of 15,000 acres in the study area. Figure 3 shows the number of opportunity public parcels, total land acres of those parcels, and both average and total (maximum) acres of public lands suitable for Green Solution Projects by watershed.

Watershed	Total Parcels	Total Acres	Average Suitable Acres	Maximum Suitable Acres
North Santa Monica Bay	120	992	262	351
Central Santa Monica Bay	233	1,037	153	211
South Santa Monica Bay	253	3,862	680	897
Ballona Creek	991	3,831	739	1,009
Upper Los Angeles River	1,893	13,663	2,592	3,490
Lower Los Angeles River	2,812	15,656	3,524	4,948
Dominguez Channel	1,029	6,504	1,356	1,815
Upper San Gabriel River	1,144	11,442	2,017	2,755
Lower San Gabriel River	912	9,202	2,054	2,821
Santa Clara River	264	2,559	586	766
Totals	**9,651**	**68,748**	**13,963**	**19,063**

Figure 3. Opportunity Public Parcels, Total Parcel Acres and Acres Suitable for Green Solution Projects

If Green Solution projects were implemented on the average acres of those public lands deemed suitable, nearly 40% of the Green Solution project need county-wide could be met. Depending on the watershed, between 16% and 78% of each individual watersheds' average runoff clean-up needs that can be addressed through Green Solutions could be met. Figure 4 shows the average need met, by watershed. If these projects were implemented, runoff from approximately 360,000 acres of drainage area could be effectively treated with Green Solution projects.

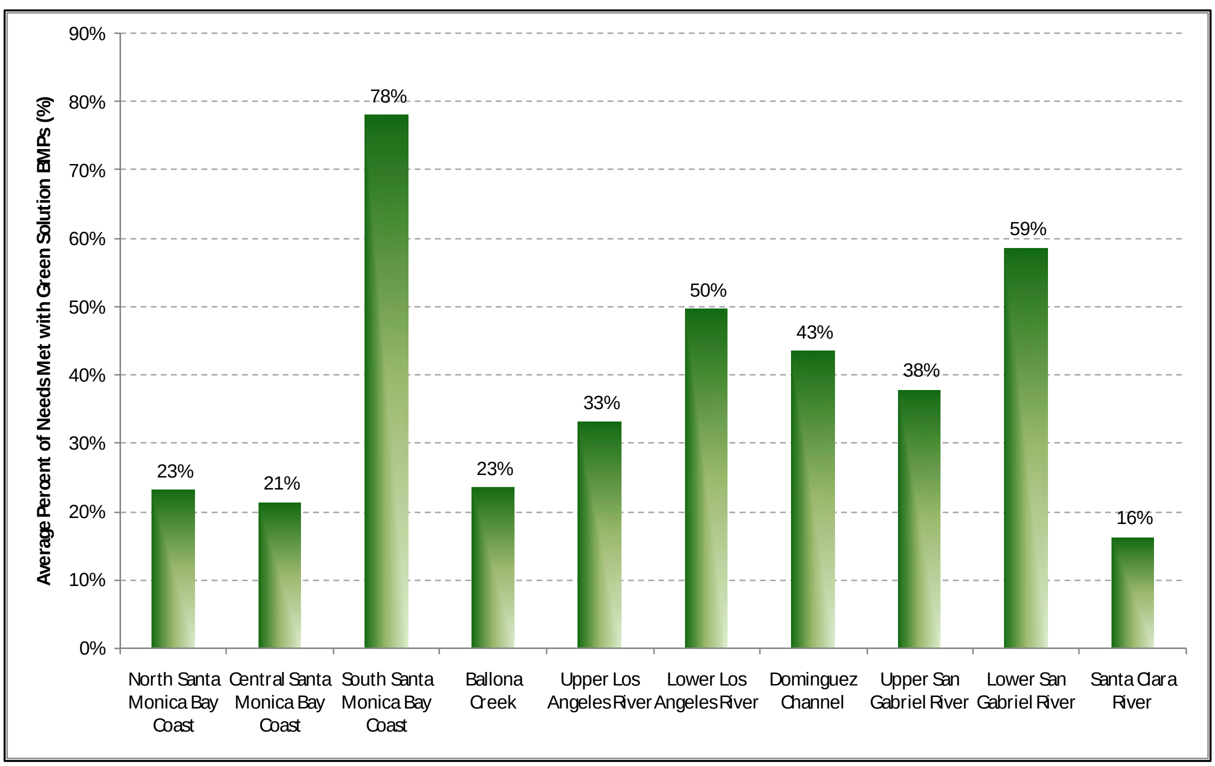


Figure 4. Average percent of Green Solution Project Need Met, per Watershed

Recommendations and Next Steps

This study evaluated an enormous area, encompassing almost 3,000 square miles, multiple watersheds, and tens of thousands of acres of opportunity public lands. The scope and magnitude of the area studied necessitated certain assumptions and summarizing of data.

Next steps should focus on public lands within specific watersheds that are most suitable for **Green Solution projects**. Further studies should develop site-specific concept designs for Green Solution Projects that combine park, habitat and recreation with water quality improvements aimed at naturally cleaning polluted runoff on the highest priority sites that meet strict water quality, land conservation and community needs criteria. Water quality, hydrologic, land conservation, open space and community demographic data must be integrated to carefully analyze, prioritize and rank for project implementation those lands selected as most appropriate for Green Solution projects in each watershed. Top-ranked, specific sites should then be selected for development of Green Solution Project concept designs; these sites should be representative of sites throughout the watershed and should be chosen for maximum replicability to produce the greatest possible benefits to both water quality, natural and human communities.

Water quality, land, conservation and community need and demographic information that should be researched and quantified include the following:

Water Quality Improvement Factors

- Pollutant loading and runoff quantity
- Potential water quality benefit
- Area-specific hydrology
- Proximity to storm drains
- Size of drainage area to be treated
- Other site-specific opportunities

Land Conservation/ Multiple Benefit Factors

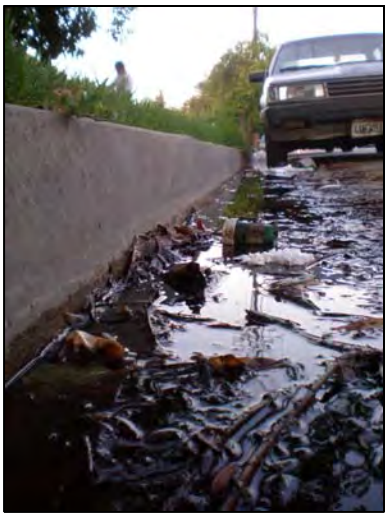
- Nexus with other park & open space uses
- Trail and river connectivity potential
- Potential for trail creation
- Habitat connectivity & need
- Habitat sensitivity
- Habitat restoration potential

Community Need Factors

- Park & open space deficit
- Public access need & potential
- Youth density
- Population density
- Income
- Other demographics

Conclusion

Community Conservancy International's **Green Solution Project Study** demonstrated that significant and wide-spread opportunities exist on public lands in Los Angeles County to address serious polluted runoff problems that harm human health and the environment, while re-greening the heavily-urbanized landscape in the county by creating new networks of park, recreation, habitat and other open space lands. This is the first time that this type of quantitative analysis has been done. Until CCI's Green Solution Project study, the conventional assumption made about the viability of improving water quality using natural "Green Solutions" in L.A. County was that this approach was not really feasible, as very little land was believed available for these types of solutions.



The CCI Team found that there are between 9,500 and 20,200 acres on 10,000 parcels of public lands currently suitable for **Green Solution Projects** in all of the watersheds in L.A. County, and that conversion or retrofit of these publicly-owned lands would address nearly 40% of the polluted runoff problem in the watershed that can be dealt with by Green Solutions – while also creating badly-needed park, habitat and other green open space amenities for surrounding communities.

This new and innovative **Green Solution Project** approach presents a practical way to move forward quickly to protect and improve water quality throughout Los Angeles County and to establish a network of green open space, park, recreation and habitat lands. In addition, the Green Solution Project approach has ramifications throughout the United States. The Green Solution approach can be applied in any area which needs to address pressing water quality problems due to runoff, and which wishes to emphasize the multiple benefits that can be achieved by Green Solution Projects through restoring and creating habitat, park, recreation and other open space lands.

Funders

The Green Solution Project study was funded by the State Coastal Conservancy, Santa Monica Bay Restoration Foundation, Santa Monica Mountains Conservancy, Rivers and Mountains Conservancy, the Trust for Public Land and Community Conservancy International.

About The Community Conservancy International Team

The Green Solution Project Team consisted of Community Conservancy International, Geosyntec Consultants and GreenInfo Network. CCI initiated the project and provided the vision, direction and overall project management, evaluation of all research, data and technical analyses, and production of all project materials. Geosyntec Consultants, a leader in water resources engineering and water quality, and in developing technically sound and innovative green approaches to water quality problems throughout the United States, conducted the technical research and analysis and prepared the attached Technical Report. Geosyntec served as a technical advisor and did not participate in the development of findings or conclusions described in the Executive Summary. GreenInfo Network specializes in complex data analysis and use of integrated Geographic Information Systems mapping technology; GreenInfo Network analyzed and developed all data and prepared all maps.

To quantify the acreage needed and the amount of existing public lands suitable for Green Solution Projects to make effective and lasting water quality improvements in Santa Monica Bay, San Pedro Bay, and the county's numerous watersheds, CCI worked with staff from the State Coastal Conservancy, the Santa Monica Mountains Conservancy, the Rivers and Mountains Conservancy, and the Santa Monica Bay Restoration Commission.

Community Conservancy International

Community Conservancy International (CCI) specializes in tackling complex and challenging problems created by the interaction of people and nature. CCI develops innovative solutions by combining long-range vision with the focused planning needed to transform ideas into reality. By bringing a broad diversity of skills, experience and expertise to each project, CCI is able to implement strategic and practical programs to realize far-reaching visions.

CCI seeks solutions that combine the protection and restoration of natural lands and waters with compatible community uses and permanent public benefits, including cultural, educational, and economic opportunities. CCI works on diverse projects in urban and rural areas that help both natural habitats and people. CCI's projects range from parks and beaches to wilderness and watersheds, and from recreational sites to mixed-use developments. CCI is dedicated to working in areas with exceptional unmet needs: where natural habitats have been degraded; where communities have been neglected; and where recreation, education, cultural and economic opportunities are significantly lacking. For more information, go to www.ccint.org.

Geosyntec Consultants

Geosyntec is a leading national provider of consulting, engineering design and construction management services throughout the U.S. and selectively in other parts of the world. Geosyntec specializes in the earth and environmental sciences and the engineering and construction management disciplines, and is an independent, employee-owned corporation with more than 500 personnel located in 34 offices in the U.S., Canada, Malaysia, and the U.K.

Geosyntec is a leader in the design and development of constructed wetlands for treatment of urban runoff, and is known for its innovative work in stormwater and surface water management, permitting, Best Management Practice (BMP) design, NPDES compliance program management, and monitoring. Geosyntec's business and reputation in stormwater was built on experience in all aspects of water quality science, planning, implementation, infrastructure design, and construction phases. Geosyntec has developed innovative monitoring and planning studies to help public agencies meet water quality objectives, and has implemented the design, construction and monitoring of treatment and source-control BMPs. Geosyntec's projects have been recognized for Outstanding BMP Implementation and Outstanding Research by CASQA, and Geosyntec staff have been recognized locally and nationally by ASCE.

GreenInfo Network

Over the past 10 years, GreenInfo Network (www.greeninfo.org) has provided Geographic Information System (GIS) and related technology support to a wide range of water, land conservation and many other types of projects throughout California and the U.S. A non-profit, GreenInfo Network assists other public interest groups and agencies working at local, regional and national scales, providing them with services including data creation and acquisition, geospatial analyses, geographic modeling, conservation and land use planning, watershed-based planning and modeling, database development, and high quality communications design and cartography. GreenInfo Network's staff is highly skilled in effective, efficient and creative use of information technology to help clients more effectively understand and communicate the relationships between issues, people and places.

For a complete copy of the Green Solution Project report, go to www.ccint.org/greensolution.html

[i] This report deals only with waters within the Los Angeles County Flood Control District, consistent with boundaries established by the Regional Water Quality Control Board for purposes of enforcing the U.S. Clean Water Act. This excludes Palmdale, Lancaster, the high desert, parts of the Angeles National Forest and Avalon.

[ii] Regional Water Quality Control Board, Los Angeles Region

[iii] Suzan Given et al, "Regional Public Health Cost Estimates of Contaminated Coastal Waters: A Case Study of Gastroenteritis at Southern California Beaches," *Environmental Science & Technology,* Vol. 40. No. 16 (2006): 1.

[iv] Heal the Bay's Annual California Beach Report Card for 2005-06

[v] Kenneth R. Weiss and Usha Lee McFarling, "Altered Oceans, A five-part series on the crisis in the seas," *Los Angeles Times*, July-August 2006.

[vi] Los Angeles County Department of Public Works

[vii] Kenneth R. Weiss and Usha Lee McFarling, "Altered Oceans, A five-part series on the crisis in the seas," *Los Angeles Times*, July-August 2006.

[viii] Los Angeles County Department of Public Works

[ix] *ibid*

[x] *ibid*

[xi] Heal the Bay's Annual California Beach Report Card for 2005-06

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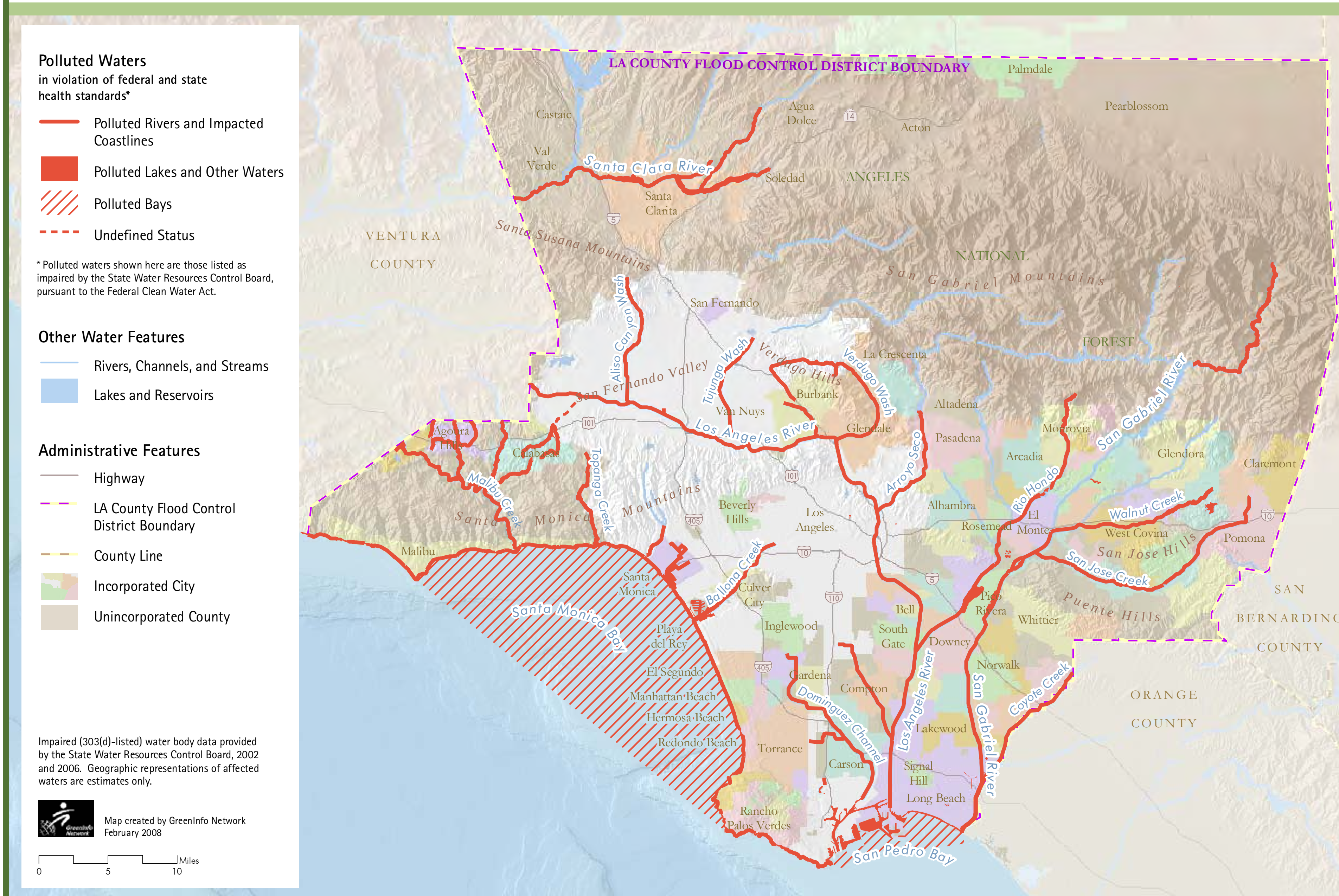
Community Conservancy International

Green Solution Project

Polluted Waters of Cities in Los Angeles County



Community Conservancy International

Green Solution Project

Watersheds and Drain Outlets of Los Angeles County

L.A. County Watershed Summary

- Almost 3,000 square miles
- 85 cities
- 33 distinct watersheds draining to ocean
- 34 urban coastal drainage areas emptying into bays and ocean
- 580 miles of rivers and streams

Urban and Stormwater Runoff Flows

All property in every community throughout the county produces runoff that flows - untreated in any way - to L.A. County's rivers, beaches, bays, and ocean.

Daily Urban Runoff	330 million gallons per day in dry weather
Annual Urban Runoff	over 110 billion gallons
Stormwater Runoff	6.5 billion gallons per day for every half inch of rain
Annual Stormwater Runoff	over 150 billion gallons in an average year

Watershed

A watershed is the entire area that captures all waters that drain into a river and its tributaries.

Urban Runoff

Urban (dry weather) runoff is polluted water from sprinklers, yards and landscaping, hosing down driveways, sidewalks, cars and parking lots, washing equipment outside businesses, and other daily uses that flows through county and city drains every day.

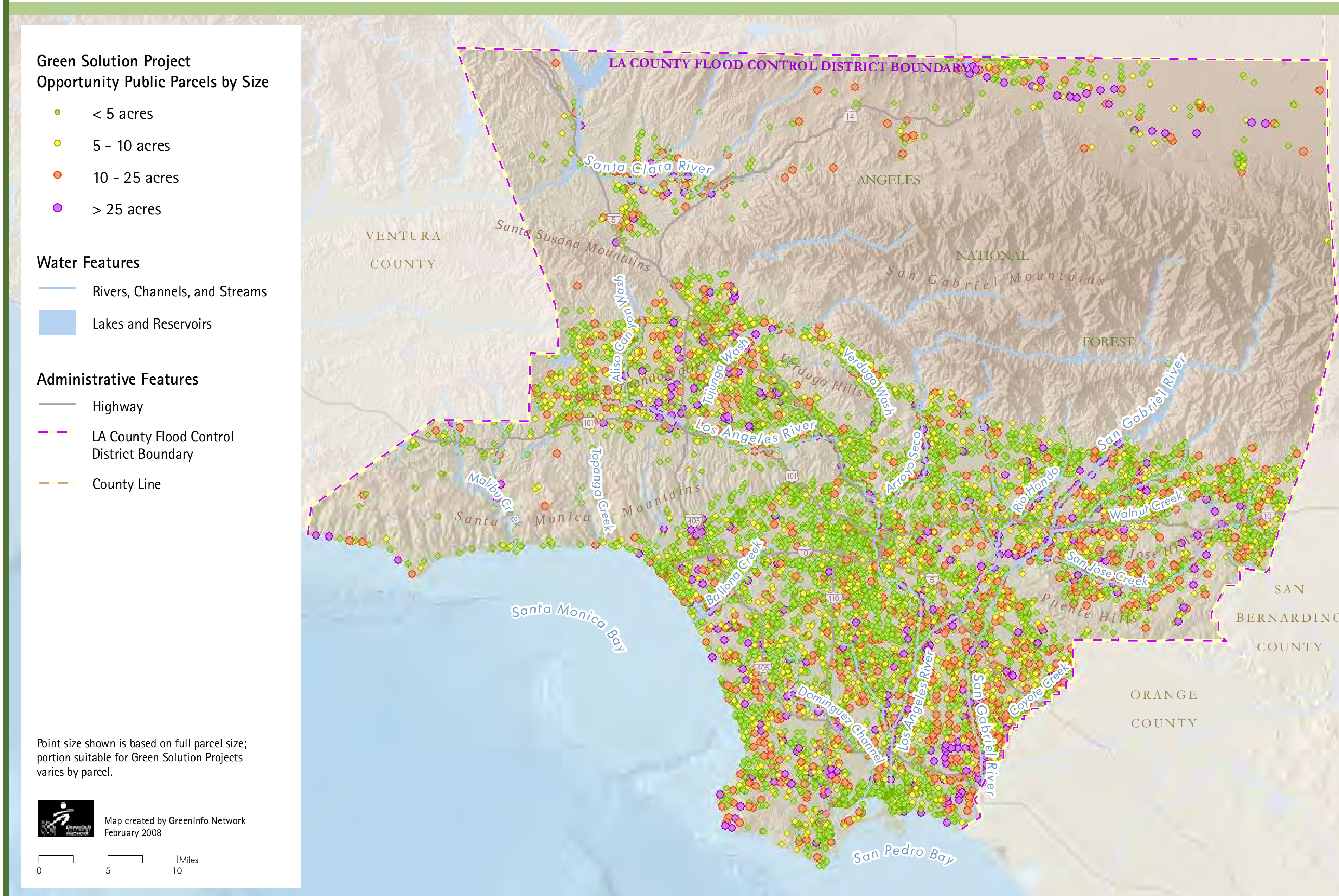
Stormwater Runoff

When it rains, the volume of runoff increases dramatically. High volumes of stormwater carry huge amounts of trash and pollutants through the county drainage system.

Community Conservancy International

Green Solution Project

Opportunity Public Parcels by Size



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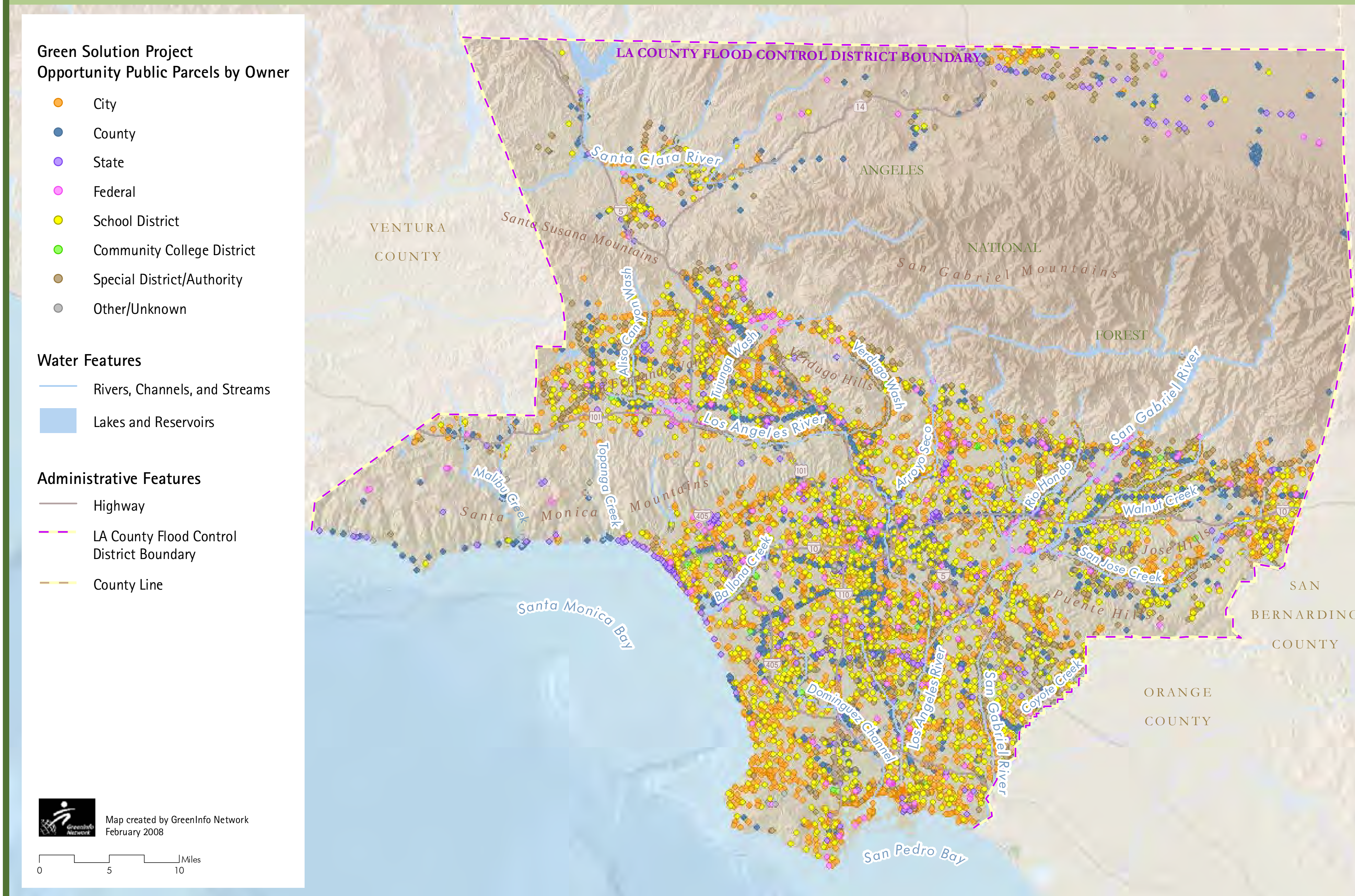
Community Conservancy International

Green Solution Project

Opportunity Public Parcels by Owner



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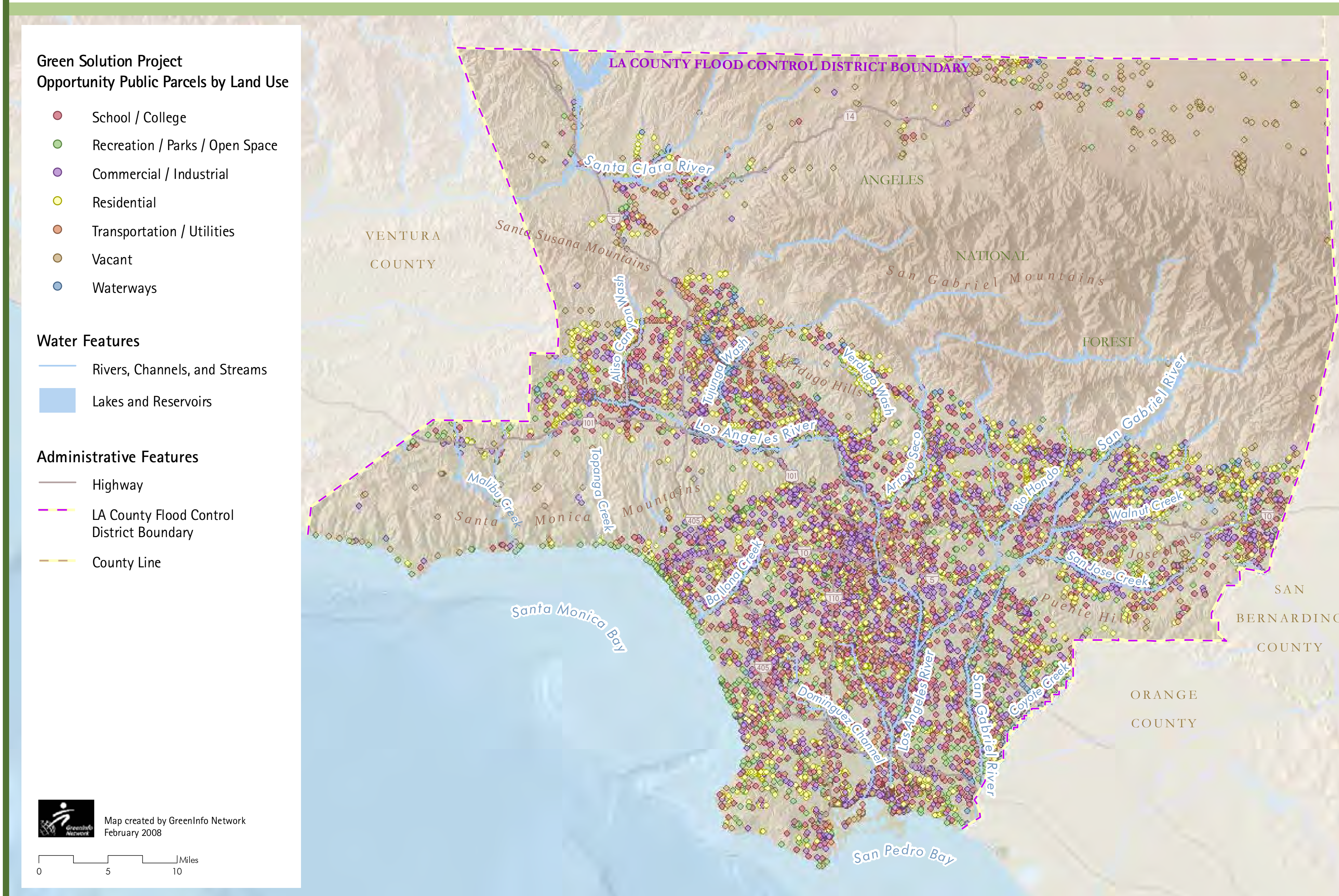
Green Solution Project

Opportunity Public Parcels by Land Use



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Municipal
Regional Permit
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STORMWATER C.3 GUIDEBOOK

Stormwater Quality Requirements for Development Applications

Fifth Edition
October 20, 2010
Visit www.cccleanwater.org for updates.

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Stormwater C.3 Guidebook

Contra Costa Clean Water Program
Tom Dalziel, Interim Program Manager
925-313-2392
tdalz@pw.cccounty.us

This Guidebook is referenced in stormwater ordinances adopted by

Antioch
Phil Hoffmeister
925-779-7035
phoffmeister@ci.antioch.ca.us

Brentwood
Jagtar Dhaliwal
925-516-5128
jdhaliwal@ci.brentwood.ca.us

Clayton
Laura Hoffmeister
925-673-7308
lhoffmeister@ci.clayton.ca.us

Concord
Libbey Bell
925-671-3394
libbey.bell@ci.concord.ca.us

Danville
Chris McCann
925-314-3342
cmccann@ci.danville.ca.us

El Cerrito
Garth Schultz
510-215-4351
gschultz@ci.el-cerrito.ca.us

Hercules
Erwin Blancaflor
510-799-8242
eblancaflor@ci.hercules.ca.us

Lafayette
Donna Feehan
925-934-3908
defeehan@ci.lafayette.ca.us

Martinez
Alex Stroup
925-372-3519
astroup@cityofmartinez.org

Moraga
Jill Mercurio
925-888-7025
jmercurio@moraga.ca.us

Oakley
Frank Kennedy
925-932-7857
fjk@fjkennedy.com

Orinda
Cathleen Terentieff
925-253-4251
cterentieff@ci.orinda.ca.us

Pinole
Dean Allison
510-724-9010
nvoisey@ci.pinole.ca.us

Pittsburg
Jolan Longway
925-252-4803
jburke@ci.pittsburg.ca.us

Pleasant Hill
Rod Wui
925-671-5261
rwui@ci.pleasant-hill.ca.us

Richmond
Lynne Scarpa
510-307-8135
Lynne_Scarpa@ci.richmond.ca.us

San Pablo
Karineh Samkian
510-215-3037
karinehs@ci.san-pablo.ca.us

San Ramon
Steven Spedowfski
925-973-2653
spedowfski@sanramon.ca.gov

Walnut Creek
Rinta Perkins
925-256-3511
perkins@walnut-creek.org

Contra Costa County
Rich Lierly
925-313-2348
rlier@pw.cccounty.us

Contra Costa County Flood Control and Water Conservation District
Paul Detjens
925-313-2394
pdetj@pw.cccounty.us

Prepared with assistance from
Dan Cloak Environmental Consulting

Hydrograph Modification Management Plan consultants: **Philip Williams & Associates and Brown & Caldwell**

5TH EDITION — OCTOBER 20, 2010

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Stormwater Glossary

Best Management Practice (BMP)	Any procedure or device designed to minimize the quantity of pollutants that enter the storm drain system or to control stormwater flow. See Chapter Two.
C.3	Provision in the Municipal Regional Permit. Requires the Permittees to use their planning authorities to include appropriate source control, site design, and stormwater treatment measures in new development and redevelopment projects to address pollutant discharges and prevent increases in runoff flows. Updates C.3 Provisions added to a preceding permit issued by the San Francisco Bay Water Board in February 2003.
C.3 Web Page	http://www.cccleanwater.org/c3.html
California Stormwater Quality Association (CASQA)	Publisher of the California Stormwater Best Management Practices Handbooks, available at www.cabmphandbooks.com.
California BMP Method	A method for determining the required volume of stormwater treatment facilities. Described in Section 5.5.1 of the California Stormwater Best Management Practice Manual (New Development) (CASQA, 2003).
Condition of Approval (COA)	Requirements a municipality may adopt for a project in connection with a discretionary action (e.g., adoption of an EIR or negative declaration or issuance of a use permit). COAs may specify features required to be incorporated into the final plans for the project and may also specify uses, activities, and operational measures that must be observed over the life of the project.
Contra Costa Clean Water Program (CCCWP)	CCCWP is a collaboration established by an agreement among 19 Contra Costa cities and towns, Contra Costa County, and the Contra Costa County Flood and Water Conservation District. CCCWP implements common tasks and assists the member agencies to implement their local stormwater pollution prevention programs.
Design Storm	A hypothetical rainstorm defined by rainfall intensities and durations.
Detention	The practice of holding stormwater runoff in ponds, vaults, within berms, or in depressed areas and letting it discharge slowly to the storm drain system. See definitions of infiltration and retention.
Directly Connected Impervious Area	Any impervious surface which drains into a catch basin, area drain, or other conveyance structure without first allowing flow across pervious areas (e.g. lawns).
Direct Infiltration	Infiltration via methods or devices, such as dry wells or infiltration trenches, designed to bypass unsaturated surface soils and transmit runoff directly to groundwater.

Drawdown time	The time required for a stormwater detention or infiltration facility to drain and return to the dry-weather condition. For detention facilities, drawdown time is a function of basin volume and outlet orifice size. For infiltration facilities, drawdown time is a function of basin volume and infiltration rate.
Flow Control	Control of runoff rates and durations as required by Provision C.3.g. of the Municipal Regional Permit.
Head	In hydraulics, energy represented as a difference in elevation. In slow-flowing open systems, the difference in water surface elevation, e.g., between an inlet and outlet.
Hydrograph	Runoff flow rate plotted as a function of time.
Hydrograph Modification Management Plan (HMP)	A Plan implemented so that post-project runoff from projects creating or replacing an acre or more of impervious area shall not exceed estimated pre-project rates and/or durations, where increased runoff would result in increased potential for erosion or other adverse impacts to beneficial uses. The HMP is available on the CCCWP's C.3 web page. Also see definition for flow control.
Hydrologic Soil Group	Classification of soils by the Natural Resources Conservation Service (NRCS) into A, B, C, and D groups according to infiltration capacity.
Impervious surface	Any material that prevents or substantially reduces infiltration of water into the soil. See discussion of imperviousness in Chapter Two.
Indirect Infiltration	Infiltration via facilities, such as bioretention areas, expressly designed to treat runoff and then allow infiltration to surface soils.
Infiltration	Seepage of runoff through soil to mix with groundwater. See definition of retention.
Infiltration Device	Any structure that is designed to infiltrate stormwater into the subsurface and, as designed, bypasses the natural groundwater protection afforded by surface or near-surface soil. See definition for direct infiltration.
Infiltration Rate	Rate at which water can be added to a soil without creating runoff.
Integrated Management Practice (IMP)	A facility (BMP) that provides small-scale treatment, retention, and/or detention and is integrated into site layout, landscaping and drainage design. See Low Impact Development.
Integrated Pest Management (IPM)	An approach to pest management that relies on information about the life cycles of pests and their interaction with the environment. Pest control methods are applied with the most economical means and with the least possible hazard to people, property, and the environment.

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Lead Agency	The public agency that has the principal responsibility for carrying out or approving a project. (California Environmental Quality Act Guidelines §15367).
Low Impact Development (LID)	A stormwater management strategy aimed at maintaining or restoring the natural hydrologic functions of a site. LID design detains, treats, and infiltrates runoff by minimizing impervious area, using pervious pavements and green roofs, dispersing runoff to landscaped areas, and routing runoff to rain gardens, cisterns, swales, and other small-scale facilities distributed throughout a site.
Maximum Extent Practicable (MEP)	Standard, established by the 1987 amendments to the Clean Water Act, for the reduction of pollutant discharges from municipal storm drains. Also see Chapter Two.
Municipal Regional Permit	A stormwater NPDES permit and Waste Discharge Requirements issued by the San Francisco Bay Regional Water Quality Control Board to 76 cities, towns, and Flood Control Districts on October 14, 2009. Similar requirements are in an permit issued by the Central Valley Water Board to eastern Contra Costa municipalities on September 23, 2010.
Municipal Separate Storm Sewer System (MS4)	A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, diteches, manmade channels, or storm drains) as defined in 40 CFR 122.26(b)(8).
National Pollutant Discharge Elimination System (NPDES)	As part of the 1972 Clean Water Act, Congress established the NPDES permitting system to regulate the discharge of pollutants from municipal sanitary sewers and industries. The NPDES was expanded in 1987 to incorporate permits for stormwater discharges as well.
Numeric Criteria	Sizing requirements for stormwater treatment facilities established in Provision C.3.d. of the Municipal Regional Permit.
Operation and Maintenance (O&M)	Refers to requirements in the Municipal Regional Permit to inspect treatment BMPs and implement preventative and corrective maintenance in perpetuity. See Chapter Six.
Percolation Rate	The rate at which water flows through a soil.
Permeable or Pervious or Porous Pavements	Pavements for roadways, sidewalks, or plazas that are designed to infiltrate runoff, including pervious concrete, pervious asphalt, porous pavers, and granular materials. See the Design Sheet for Pervious Pavements.
Percentile Rainfall Intensity	A method of determining design rainfall intensity. Storms occurring over a long period are ranked by rainfall intensity. The storm corresponding to a given percentile yields the design rainfall intensity.
Permeability	The rate at which water flows through a saturated soil under steady state conditions.

Pre-Project	Conditions that exist on a development site immediately before the project to which municipal approvals apply.
Proprietary Stormwater Treatment Facilities	Products designed and marketed by private businesses for treatment of stormwater. Many of these products do not meet requirements of the Municipal Regional Permit.
Rational Method	A method of calculating runoff flows based on rainfall intensity, tributary area, and a factor representing the proportion of rainfall that runs off.
Regional Water Quality Control Board (Regional Water Board or RWQCB)	California RWQCBs are responsible for implementing pollution control provisions of the Clean Water Act and California Water Code within their jurisdiction. There are nine California RWQCBs. Western and central Contra Costa County are under the jurisdiction of the RWQCB for the San Francisco Bay Region; eastern Contra Costa County is under the jurisdiction of the RWQCB for the Central Valley Region.
Self-retaining area	An area designed to retain runoff. Self-retaining areas may include graded depressions with landscaping or pervious pavements.
Self-treating area	Natural, landscaped, or turf areas that drain overland off-site or to the storm drain system.
Source Control	A facility or procedure to prevent pollutants from entering runoff.
Stormwater Control Plan	A plan specifying and documenting permanent features and facilities to control pollutants and stormwater flows for the life of the project.
Stormwater Control Operation & Maintenance Plan	A plan detailing operation and maintenance requirements for stormwater treatment and flow-control facilities incorporated into a project.
Storm Water Pollution Prevention Plan (SWPPP)	A plan providing for temporary measures to control sediment and other pollutants during construction.
Treatment	Removal of pollutants from runoff, typically by filtration or settling.
WEF Method	A method for determining the minimum design volume of stormwater treatment facilities, recommended by the Water Environment Federation and American Society of Civil Engineers. Described in *Urban Runoff Quality Management* (WEF/ASCE, 1998).
Water Board	See Regional Water Quality Control Board.
Water Quality Volume (WQV)	For stormwater treatment facilities that depend on detention to work, the volume of water that must be detained for a minimum specified drawdown time to achieve pollutant removal.

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Start

How to Use this Guidebook

Read the Overview to get a general understanding of the requirements. Then follow the step-by-step instructions to prepare your Stormwater Control Plan.

THIS *Guidebook* will help you ensure that your project complies with the C.3 requirements in the California Regional Water Quality Control Boards' Municipal Regional Permit. The requirements are complex and technical. Most applicants will require the assistance of a qualified civil engineer, architect, or landscape architect. Because every project is different, you should begin by scheduling a pre-application meeting with municipal planning staff.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

To use the *Guidebook,* start by reviewing Chapter One to find out whether and how Provision C.3 applies to your project. Chapter One also provides an overview of the entire process of planning, design, construction, operation, and maintenance leading to compliance.

If there are terms and issues you find puzzling, look for answers in the glossary or in Chapter Two. Chapter Two provides background on key stormwater concepts and water quality regulations, including design criteria.

Then proceed to Chapter Three and follow the step-by-step guidance to prepare a Stormwater Control Plan for your site. The Stormwater Control Plan is submitted with your application for entitlements and development approvals.

Chapter Four, the Low Impact Development Design Guide, includes instructions for preparing and presenting your design and calculations. The calculations must be included in your Stormwater Control Plan to show compliance with permit requirements.

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As you proceed with design and construction of your project, consult Chapter Five for guidance on preparing construction documents and overseeing construction of Low Impact Development features and facilities.

In Chapter Six you'll find a detailed description of the process for ensuring operation and maintenance of your stormwater facilities over the life of the project. The chapter includes step-by-step instructions for preparing a Stormwater Facilities Operation and Maintenance Plan.

Local Requirements
Cities, towns, or the County may have requirements that differ from, or are in addition to, this county-wide Guidebook. See Appendix A for local requirements.

Throughout each Chapter, you'll find references and resources to help you understand the regulations, complete your Stormwater Control Plan, and design stormwater control measures for your project.

The most recent version of the *Guidebook,* including updates and errata, is on the Contra Costa Clean Water Program website. The on-line *Guidebook* is in Adobe Acrobat format. If you are reading the *Guidebook* on a computer with an internet connection, you can use hyperlinks to navigate the document and to access various references. The hyperlinks are throughout the text, as well as in "References and Resources" sections (marked by the 🕮 icon) and in the Bibliography. Some of these links (URLs) may be outdated. In that case, try entering portions of the title or other keywords into a web search.

Construction-Phase Controls
Your Stormwater Control Plan is a separate document from the Storm Water Pollution Prevention Plan (SWPPP). A SWPPP provides for temporary measures to control sediment and other pollutants during construction at sites that disturb one acre or more. See the CCCWP website for information on requirements for construction-phase controls.

► PLAN AHEAD TO AVOID THE THREE MOST COMMON MISTAKES

The most common (and costly) errors made by applicants for development approvals with respect to C.3 compliance are:

1. Not planning for C.3 compliance early enough. You should think about your strategy for C.3 compliance before completing a conceptual site design or sketching a layout of subdivision lots (Chapter 3).

2. Assuming proprietary stormwater treatment facilities will be adequate for compliance. A complete Low Impact Development design, including reuse, infiltration, evapotranspiration, or bioretention facilities, is now required for nearly all projects (Chapter 2).

3. Not planning for periodic inspections and maintenance of treatment and flow-control facilities. Consider who will own and who will maintain the facilities in perpetuity and how they will obtain access, and identify which arrangements are acceptable to your municipality (Chapter 6).

Chapter 1

Policies and Procedures

Determine if your development project must comply with the Municipal Regional Permit C.3 requirements, and review the steps to compliance.

Thresholds, Effective Dates, and Requirements

Table 1-1 (on following page) summarizes requirements for development projects. Thresholds are based on impervious area created or replaced in connection with a project. Interior remodels and routine maintenance or repair such as roof or exterior surface replacement and pavement resurfacing are excluded.

The 2010-2012 effective dates refer to the date on which a planning application has received final discretionary approval. At the discretion of local municipal staff, projects with applications that are deemed complete and diligently pursued prior to these dates may not have to meet all requirements (requirements in previous *Guidebook* editions may apply).

► THE "50% RULE" FOR PROJECTS ON PREVIOUSLY DEVELOPED SITES

Projects on previously developed sites may also need to retrofit drainage to provide treatment of runoff from all impervious areas of the entire site. For sites creating or replacing a total amount of impervious area greater than the applicable threshold (Table 1-1):

- If the new project results in an alteration of more than 50% of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment measures, then the entire project must be included in the treatment measure design.

- If the new project results in an alteration of less than 50% of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment

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ICON KEY

- ☞ Helpful Tip
- Submittal Requirement
- Terms to Look Up
- References & Resources

measures, then only the new and replaced impervious surface must be included in the treatment system design.

In contrast to the 50% rule for treatment requirements, flow-control requirements use the developed condition of a previously developed site as a baseline when determining if runoff rates or durations will increase as a result of the project.

TABLE 1-1. THRESHOLDS, EFFECTIVE DATES, and Requirements summarized.*

Impervious Area Threshold	Effective Date	Requirement
All projects requiring municipal approvals or permits	May 1, 2010	As encouraged or directed by local staff, preserve or restore open space, riparian areas, and wetlands as project amenities, minimize land disturbance and impervious surfaces (especially parking lots) cluster structures and pavements, include micro-detention in landscaped and other areas, and direct runoff to vegetated areas. Use Bay-friendly landscaping features and techniques. Include Source Controls specified in Appendix D.
Projects between 2,500 and 10,000 square feet requiring approvals or permits	December 1, 2012	Install one or more of the following: Direct roof runoff into cisterns or rain barrels for reuse; direct roof runoff onto vegetated areas; direct runoff from sidewalks, walkways, and/or patios on to vegetated areas; direct runoff from driveways and/or uncovered parking lots on to vegetated areas; construct sidewalks, walkways, and/or patios with permeable surfaces; construct bike lanes, driveways, and uncovered parking lots with permeable surfaces.
Auto service facilities, gas stations, restaurants, and uncovered parking lots over 5,000 square feet	December 1, 2011	Prepare and submit a Stormwater Control Plan as described in Chapter 3, including features and facilities to ensure runoff is treated before leaving the site. Evaluate feasibility of storage for later use. Use the LID Design Guide in Chapter 4, including sizing factors and criteria for "treatment only."
All projects between 10,000 square feet and one acre†	August 15, 2006	
Projects an acre and larger†	October 14, 2006	Select one of four flow-control compliance options in Appendix C. Where required, design project features and facilities for hydrograph modification management (flow-control) as well as stormwater treatment. Prepare and submit a Stormwater Control Plan as described in Chapter 3 and use the LID Design Guide in Chapter 4, including the sizing factors and criteria for "treatment and flow control."

*Summary only. Requirements for any particular project are determined by your municipality.
†Detached single-family homes that are not part of a larger plan of development are specifically excluded.
For road widening projects, count only the impervious area associated with new traffic lanes.

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Compliance Process at a Glance

For the applicant for development project approval, compliance follows these general steps:

1. Discuss C.3 requirements during a pre-application meeting with municipal staff.

2. Review the instructions in this *Guidebook* before you prepare your tentative map, preliminary site plan, drainage plan, and landscaping plan.

3. Prepare a Stormwater Control Plan and submit it with your application for development approvals (entitlements).

4. Following development approval, create your detailed project design, incorporating the features described in your Stormwater Control Plan.

5. In a table on your construction plans, list each stormwater control feature and facility and the plan sheet where it appears.

6. Prepare a draft Stormwater Facility Operation and Maintenance Plan and submit it with your application for building permits. Execute legal documents assigning responsibility for operation and maintenance of stormwater facilities. Some municipalities require legal agreements and financial commitments for operation and maintenance be recorded prior to recordation of a final parcel map.

7. Maintain stormwater facilities during construction and following construction in accordance with required warranties.

8. Following construction, submit a final Stormwater Facility Operation and Maintenance Plan and formally transfer responsibility for maintenance to the owner or permanent occupant.

9. The occupant or owner must periodically verify stormwater facilities are properly maintained.

Local Requirements

Cities, towns, or the County may have requirements that differ from, or are in addition to, this county-wide Guidebook. See Appendix A for local requirements.

Preparation of a complete and detailed Stormwater Control Plan is the key to cost-effective C.3 compliance and expeditious review of your project. Instructions for preparing a Stormwater Control Plan are in Chapter 3.

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Implementing C.3 on Phased Projects

When determining whether Provision C.3 requirements apply, a "project" should be defined consistent with CEQA definitions of "project." That is, the "project" is the whole of an action which has the potential for adding or replacing or resulting in the addition or replacement of roofs, pavement, or other impervious surfaces and thereby resulting in increased flows and stormwater pollutants. "Whole of an action" means the project may not be segmented or piecemealed into small parts if the effect is to reduce the quantity of impervious area for any part to below the C.3 threshold.

Grandfathering. Municipalities may, at their discretion, exempt projects for which applications received final discretionary approval prior to the dates in Table 1-1. However, this "grandfathering" applies only to the specific discretionary approval that was the subject of the original application. Subsequent applications for further approvals constitute a "project" for the purposes of C.3. If those subsequent approvals or entitlements cover specific locations, modes, or designs for addition or replacement of roofs, pavement, or other impervious surfaces, and if the impervious area created or replaced is in excess of the applicable thresholds, then the C.3 requirements will apply to those areas of the project covered by the subsequent approval or entitlement.

CEQA
See the CCCWP's New Development web page for guidance on how to document stormwater impacts and mitigations in Initial Studies and Environmental Impact Reports.

Consider for example an application for a subdivision tentative map which receives final discretionary approval prior to the C.3 start dates. The project may be exempt from Provision C.3; however, if the project proponent later applies for discretionary approval of specific locations, modes, or designs of paving and structures, then C.3 requirements would apply to those improvements.

Applying the "50% rule." Municipal staff will determine case-by-case when and how the "50% rule" applies; in doing so staff may use the original entitlement (discretionary approval) as a guide when calculating the impervious area of the "previously existing development".

Stormwater Control Plan requirements for phased projects. Municipal staff may require, as part of an application for approval of a phased development project, a conceptual or master Stormwater Control Plan which describes and illustrates, in broad outline, how the drainage for the project will comply with the Provision C.3 requirements. The level of detail in the conceptual or master Stormwater Control Plan should be consistent with the scope and level of detail of the development approval being considered. The conceptual or master Stormwater Control Plan should

Local Requirements
Cities, towns, or the County may have requirements that differ from, or are in addition to, this countywide Guidebook. See Appendix A and check with local planning and community development staff.

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specify that a more detailed Stormwater Control Plan for each later phase or portion of the project will be submitted with subsequent applications for discretionary approvals.

Applying C.3 to New Subdivisions

If a tentative map approval would potentially entitle future owners of individual parcels to construct new or replaced impervious area which, in aggregate, could exceed the thresholds in Table 1-1, then the applicant must take steps to ensure C.3 requirements can and will be implemented as the subdivision is built out.

If the tentative map application does not include plans for site improvements, the applicant should nevertheless identify the type, size, location, and final ownership of stormwater treatment and flow-control facilities adequate to serve new roadways and any common areas, and to also manage runoff from an expected reasonable estimate of the square footage of future roofs, driveways, and other impervious surfaces on each individual lot. The municipality may condition approval of the map on implementation of stormwater treatment measures in compliance with Provision C.3 when construction occurs on the individual lots. This condition may be enforced by a grant deed of development rights or by a development agreement.

If a municipality deems it necessary, the future impervious area of one or more lots may be limited by a deed restriction. This might be necessary when a project is exempted from one or all C.3 provisions because the total impervious area is below a threshold, or to ensure runoff from impervious areas added after the project is approved does not overload a stormwater treatment and flow-control facility.

Subdivision maps should dedicate an "open space easement, as defined by Government Code Section 51075," to suitably restrict the future building of structures at each stormwater facility location.

In general, it is recommended **stormwater treatment facilities not be located on individual single-family residential lots**, particularly when those facilities manage runoff from other lots, from streets, or from common areas. However, local requirements vary. A better alternative may be to locate stormwater facilities on one or more separate, jointly owned parcels.

See the *Policy for C.3 Compliance for Subdivisions* on the Contra Costa Clean Water Program's C.3 web page.

After consulting with local planning staff, applicants for subdivision approvals will propose one of the following four options, depending on project characteristics and local policies:

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1. Show the sum of future impervious areas to be created or replaced on all parcels could not exceed the applicable C.3 thresholds shown in Table 1-1.

2. Show that, for each and every lot, the intended use can be achieved with a design which disperses runoff from roofs, driveways, streets, and other impervious areas to self-retaining pervious areas, using the criteria in Chapter 4 of this *Guidebook*.

3. Prepare improvement plans showing drainage to treatment and/or flow-control facilities designed in accordance with this *Guidebook,* and commit to constructing the facilities prior to transferring the lots.

4. Prepare improvement plans showing drainage to treatment and/or flow-control facilities designed in accordance with this *Guidebook*, and provide appropriate legal instruments to ensure the proposed facilities will be constructed and maintained by subsequent owners.

For the option selected, municipal staff will determine the appropriate conditions of approval, easements, deed restrictions, or other legal instruments necessary to assure future compliance. In general, when new streets and common areas are constructed, facilities to treat runoff from those new impervious areas must be constructed concurrently, and agreements for the operation and maintenance of those facilities must be executed timely.

Compliance with Flow-Control Requirements

As shown in Table 1-1, in addition to incorporating treatment controls, projects creating or replacing an acre or more of impervious area must also provide flow control so post-project runoff does not exceed estimated pre-project rates and durations. Projects subject to flow-control requirements have four options for demonstrating compliance. The options are summarized in Table 1-2. Detailed requirements are in Appendix C.

Depending on location and existing site conditions, a project proponent may wish to consider the feasibility of these options in the following order:

- For projects on previously developed sites, it may be possible to show the project will not increase the existing quantity of impervious area and will not facilitate the efficiency of drainage collection and conveyance (Option 1).

- Depending on project location, the project proponent may be able show all downstream channels between the project site and the Bay/Delta are enclosed pipes, are engineered hardened channels, are subject to tidal action, or are aggrading (Option 4a).

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- Proponents may use the LID Design Guide in Chapter 4 to meet both treatment and flow-control requirements (Option 2).
- Proponents of larger developments, particularly those with complex or extensive drainage, might consider creating a continuous hydrologic simulation model, using the criteria in Appendix C, to demonstrate that, after incorporation of flow-control measures, post-project runoff will not exceed pre-project rates or durations (Option 3).

TABLE 1-2. Options for compliance with flow-control requirements*

What must be demonstrated	*How applicants can comply*	*Stormwater Control Plan submittal requirements*
Option 1: No increase in impervious area	Compare the project design to the pre-project condition and show the project will not increase impervious area and also will not increase efficiency of drainage collection and conveyance.	Inventory and accounting of existing and proposed impervious areas, measures used to reduce imperviousness, and a qualitiative comparison of pre- and post-project drainage efficiency.
Option 2: Integrated Management Practices	Use the design procedure and design criteria in this *Guidebook*, and the Program's sizing tool, to select and size IMPs for flow control (also meets treatment requirements).	Stormwater Control Plan and sizing tool output (Chapter 3).
Option 3: Post-project runoff does not exceed pre-project rates and durations	Use a continuous-simulation model and 30 years or more of hourly rainfall data to simulate pre-project and post-project runoff, including the effect of proposed control facilities.	Model parameters and modeling techniques are specified in Appendix C.
Option 4a: All downstream reaches are at "low risk" of erosion	Show all downstream channels between the project site and the Bay/Delta are enclosed pipes, are engineered hardened channels, are subject to tidal action, or are aggrading.	Report or letter report by an engineer or qualified environmental professional documenting drainage between the project site and the Bay or Delta.
Options 4b and 4c: Erosion risks are mitigated by in-stream restoration projects	Propose and implement appropriate in-stream restoration projects to fully mitigate potential risk.	Requires additional regulatory approvals. See Appendix C.

*Summary only. Applicability to and requirements for any particular project are determined by your municipality.

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- Under Options 4b and 4c, proponents may propose and implement an appropriate in-stream restoration project to fully mitigate the potential risk of increased downstream erosion created by their proposed development.

Runoff treatment is required regardless of the flow-control compliance option chosen.

Alternative Compliance Options

In lieu of incorporating facilities to treat runoff from impervious areas at the development project site, an applicant may propose a secondary project that will treat runoff from an equivalent amount of impervious area at another location within the same watershed.

To be considered, the secondary project must include construction, operation, and maintenance of facilities meeting the criteria in Chapter 4. Those facilities must treat runoff from an amount of impervious surface equivalent to, or greater than, the impervious surface that would be subject to requirements at the project location.

An applicant may propose to combine on-site and off-site facilities to add up to the equivalent amount of impervious area as would be required for only on-site treatment. An applicant may also propose to share in a larger project and be credited for a proportional amount of the impervious area for which runoff is treated by that project.

Consideration or acceptance of such proposals is at the discretion of the local municipality.

Experience has shown implementation of LID facilities, as described in Chapter 4, is feasible on nearly all development sites with sufficient advance planning.

References and Resources:

- Appendix C—Flow Control
- CCCWP Policy for C.3 Compliance for Subdivisions
- CCCWP Web Page for Construction Activities
- CCCWP Hydrograph Modification Management Plan
- MRP Provision C.3.g. and Attachment C (Hydrograph Modification Management)
- MRP Provision C.3.e. (Alternative or In-Lieu Compliance)

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Chapter

2

Concepts and Criteria

Technical background and explanations of policies and design requirements

The Regional Water Board first issued a municipal stormwater NPDES permit to Contra Costa County, its cities and towns, and the Contra Costa Flood Control and Water Conservation District in 1993. The permit mandates a comprehensive program to prevent stormwater pollution. That program now includes measures to prevent pollution from municipal facilities and operations, identification and elimination of illicit discharges to storm drains, business inspections, public outreach, construction site inspections, monitoring and studies of stream health, and control of runoff pollutants from new developments and redevelopments.

The Regional Water Board added Provision C.3 in 2003, and the permittees began implementing the provision in 2005. The Regional Water Board added hydrograph modification management (flow control) requirements in 2006.

In October 2009, the Regional Water Board included Contra Costa municipalities in its first Municipal Regional Permit (MRP). The MRP applies to 77 municipal Bay Area permittees and supersedes the countywide stormwater NPDES permits.

The MRP mandates a Low Impact Development (LID) approach similar to that developed by the CCCWP from 2003 through 2009. This chapter explains the technical background of the LID approach and how it was derived.

Water-Quality Regulations

MRP Provision C.3 requires municipalities to condition development approvals with incorporation of specified stormwater controls. The municipalities' annual report to the Regional Water Board includes a list of development projects approved during the year and the specific stormwater controls required for each project. In the annual report, the municipalities also document their program to verify stormwater treatment and flow-control facilities are being adequately

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maintained. The municipalities—not the Regional Board or its staff—are charged with ensuring development projects comply with the C.3 requirements. (Regional Water Board staff sometimes reviews stormwater controls in connection with applications for Clean Water Act Section 401 water-quality certification, which is required for projects that involve work in streams, including dredging and filling.)

In a nutshell, MRP Provision C.3 requires that applicable new developments and redevelopments:

- Design the site to minimize imperviousness, detain runoff, and infiltrate, reuse or evapotranspirate runoff where feasible
- Cover or control sources of stormwater pollutants
- Treat runoff prior to discharge from the site
- Ensure runoff does not exceed pre-project peaks and durations
- Maintain treatment and flow-control facilities

► MAXIMUM EXTENT PRACTICABLE

Clean Water Act Section 402(p)(3)(iii) sets the standard for control of stormwater pollutants as "maximum extent practicable," but doesn't define that term. As implemented, "maximum extent practicable" is ever-changing and varies with conditions.

Many stormwater controls, including LID, have proven to be practicable in most development projects. To achieve fair and effective implementation, criteria and guidance for those controls must be detailed and specific—while also offering the right amount of flexibility or exceptions for special cases. The MRP includes various standards, including hydrologic criteria, which have been found to provide "maximum extent practicable" control. CCCWP's C.3 guidance is continuously improved and refined based on the experience of municipal planners and engineers, with input from land developers and development professionals.

► BEST MANAGEMENT PRACTICES

Clean Water Act Section 402(p) and USEPA regulations (40 CFR 122.26) specify a municipal program of "management practices" to control stormwater pollutants. Best Management Practice (BMP) refers to any kind of procedure or device designed to minimize the quantity of pollutants that enter the Municipal Separate Storm Sewer System (MS4).

To minimize confusion, this guidebook refers to "facilities," "features," "controls," and Integrated Management Practices (IMPs) to be incorporated into development projects. All of these are BMPs.

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Hydrology for NPDES Compliance

► IMPERVIOUSNESS

Schueler (1995) proposed imperviousness as a "unifying theme" for the efforts of planners, engineers, landscape architects, scientists, and local officials concerned with urban watershed protection. Schueler argued (1) that imperviousness is a useful indicator linking urban land development to the degradation of aquatic ecosystems, and (2) imperviousness can be quantified, managed, and controlled during land development.

Imperviousness has long been understood as the key variable in urban hydrology. Peak runoff flow and total runoff volume from small urban catchments is usually calculated as a function of the ratio of impervious area to total area (rational method). The ratio correlates to the composite runoff factor, usually designated "C". Increased flows resulting from urban development tend to increase the frequency of small-scale flooding downstream.

Imperviousness links urban land development to degradation of aquatic ecosystems in two ways.

First, the combination of paved surfaces and piped runoff efficiently collects urban pollutants and transports them, in suspended or dissolved form, to surface waters. These pollutants may originate as airborne dust, be washed from the atmosphere during rains, or may be generated by automobiles and outdoor work activities.

Second, increased peak flows and runoff durations can cause erosion of stream banks and beds, transport of fine sediments, and disruption of aquatic habitat. Measures taken to control stream erosion, such as hardening banks with riprap or concrete, may permanently eliminate habitat. By reducing infiltration to groundwater, imperviousness may also reduce dry-weather stream flows.

Imperviousness has two major components: rooftops and transportation (including streets, highways, and parking areas). The transportation component is usually larger and is more likely to be directly connected to the storm drain system.

The effects of imperviousness can be mitigated by disconnecting impervious areas from the drainage system and by making drainage less efficient—that is, by encouraging detention and retention of runoff near the point where it is generated. Detention and retention reduce peak flows and volumes and allow pollutants to settle out or adhere to soils before they can be transported downstream.

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► SIZING REQUIREMENTS FOR STORMWATER TREATMENT FACILITIES

MRP permit criteria for sizing stormwater treatment facilities and flow-control facilities are based on simulation of runoff from a long-term (30-year or more) rainfall record. This is different from the "event-based" or "design storm" hydrology typically used to size drainage and flood-control facilities.

The CCCWP's LID design guidance (Chapter 4) was crafted to ensure LID facilities comply with the NPDES permit's hydraulic sizing requirements for stormwater treatment facilities and flow-control facilities, as well as meeting the LID mandate in MRP Provision C.3.c. The technical background follows.

Most runoff is produced by frequent storms of small or moderate intensity and duration. Treatment facilities are designed to treat smaller storms and the first flush of larger storms—approximately 80% of average annual runoff.

MRP Provision C.3.d. identifies two sets of criteria for sizing stormwater treatment facilities—volume-based and flow-based.

For **volume-based** treatment facilities, MRP Provision C.3.d. references two alternative methods, the **WEF method** and the **California BMP method**. As described in Chapter 4, local rainfall data and the California BMP method are used for sizing detention basins in Contra Costa County. Both the WEF and California BMP methods are based on continuous simulation of runoff from a hypothetical one-acre area entering a basin designed to draw down in 48 hours. The simulation is iterated to find the unit basin size that detains about 80% of the total runoff during the simulation period. The unit basin storage size is expressed as a depth which varies from about 0.45" to 0.85" in Contra Costa County.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

For **flow-based** facilities, the NPDES permit specifies the rational method be used to determine flow. The rational method uses the equation

$Q = CiA$, where

Q = flow

C = weighted runoff factor between 0 and 1

i = rainfall intensity

A = area

The permit identifies three alternatives for calculating rainfall intensity:

1. the intensity-duration-frequency method, with a hydrograph corresponding to a 50-year storm,

2. the 85th percentile rainfall intensity times two, and

3. 0.2 inches per hour.

An analysis conducted for the CCCWP determined all three methods yielded similar results. The 0.2 inches per hour rainfall intensity is used for sizing flow-based treatment facilities in Contra Costa County. This intensity corresponds to storms producing approximately 0.6 inches precipitation.

The CCCWP used the 0.2 inches per hour criterion to develop a consistent countywide sizing factor for bioretention facilities when used for stormwater treatment only (i.e., not for flow control). The factor is based on a design maximum surface loading rate of 5 inches per hour (now mandated by MRP Provision C.3.c.i.(2)(b)(iv)). The sizing factor is the ratio of the design intensity of rainfall on tributary impervious surfaces (0.2 inches/hour) to the design percolation rate in the facility (5 inches/hour), or 0.04 (dimensionless).

► FLOW-CONTROL (HYDROGRAPH MODIFICATION MANAGEMENT)

MRP Provision C.3.g. specifies for applicable projects:

> "Increases in runoff flow and volume shall be managed so that post-project runoff shall not exceed estimated post-project runoff peaks and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force."

Contra Costa applicants for development approvals may select among four options for compliance. See Table 1-2. The first three options allow an applicant to demonstrate—by showing there will be no net increase in impervious area, by using Integrated Management Practice designs and sizing factors developed by the CCCWP, or by constructing a site-specific hydrologic model—that runoff will not exceed pre-project rates and durations.* Applicants may use the fourth option to demonstrate that, even though runoff will increase, it will not cause erosion or other significant effects on beneficial uses. This may be done by showing downstream channels are not susceptible to erosion (Option 4a) or that a

* For sites that are already partially developed, see the Technical Memorandum, "Guidance on Flow Control For Development Projects on Sites that are Already Partially Developed," on the CCCWP's C.3 web pages.

restoration project will mitigate any impacts from increased flows (Options 4b and 4c).

Details on compliance requirements are in Appendix C. Technical background is in the Hydrograph Modification Management Plan, which is available on the CCCWP's website.

Selection of Stormwater Treatment Facilities

The MRP mandates an LID approach similar to the approach developed by Contra Costa municipalities and incorporated in earlier editions of this *Stormwater C.3 Guidebook*.

► HARVESTING, USE, INFILTRATION, AND EVAPOTRANSPIRATION

MRP Provision C.3.c.i.(2)(b) requires applicable projects to treat 100% of the amount of runoff identified in Provision C.3.d. using LID facilities, which are defined as follows:

- LID treatment measures are harvesting and re-use, infiltration, evapotranspiration, or biotreatment.
- A properly engineered and maintained biotreatment system may be considered only if it is infeasible to implement harvesting and re-use, infiltration, or evapotranspiration at a project site.
- Infeasibility to implement harvesting and re-use, infiltration, or evapotranspiration at a project site may result from conditions including the following:
    - Locations where seasonal high groundwater would be within 10 feet of the LID treatment measure.
    - Locations within 100 feet of a groundwater well used for drinking water.
    - Development sites where pollutant mobilization in the soil or groundwater is a documented concern.
    - Locations with potential geotechnical hazards.
    - Smart growth and infill or development sites where the density and nature of the project would create significant difficulty for compliance with the onsite volume retention requirement.

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- Locations with tight clay soils that significantly limit the infiltration of stormwater.

Here is how these requirements are implemented in Contra Costa municipalities:

The LID Design Guide directs the applicant to first consider incorporating into the proposed project design LID features that minimize runoff. These features include:

- Minimized disturbance of natural drainage
- Minimized amount of roofs and paving
- Permeable pavements and green roofs
- Dispersing runoff to landscape

Remaining runoff from impervious surfaces must be directed to LID facilities designed to the hydraulic sizing criteria in Provision C.3.d.

The LID Design Guide then directs the applicant to assess the feasibility of meeting the permit's treatment and flow-control requirements—for each specific sub-drainage area within the site—by storing runoff for later use.

There are two options identified.

The first option is to store runoff for two days or less, which requires a consistent, reliable demand for a non-potable use other than irrigation. For this option, the applicant is directed to calculate the required storage and 48-hour drawdown rate for 80% capture. This calculation uses the methodology specified in CASQA Handbook and local rainfall data as specified in MRP Provision C.3.d.i.(1)(b). It is presumed storage of this quantity of runoff is feasible, and the applicant is directed to evaluate whether a reliable, accessible, implementable non-potable demand exists for this supply during the rainy season.

The second option is to accumulate runoff throughout the rainy season for use during the irrigation season. The required storage volume is calculated using the mean annual precipitation falling on the impervious surface times a factor of 0.6, which accounts for estimated losses to evaporation (less than 10%), the 80% capture of runoff, and runoff produced and used during the irrigation season (May – October). The applicant is directed to evaluate whether (1) there is sufficient landscape within or near the project to ensure demand for this quantity of water each year, and (2) whether annual storage of this quantity of water is feasible.

For projects located at sites with Hydrologic Soil Group "A" or "B" soils, the LID Design Guide requires remaining runoff be routed to one of the following types of facilities:

- Dry well
- Bioretention
- Cistern + Bioretention
- Bioretention + Vault

All of these facilities are designed to infiltrate at least the flow of runoff specified in Provision C.3.d. when sized and configured for "treatment only" and a greater volume when sized and configured for "treatment and flow control."

For projects located at sites with "tight clay soils that significantly limit the infiltration of stormwater" (Hydrologic Soil Group "C" and "D" soils), the LID Design Guide requires remaining runoff be routed to one of the following facilities:

- Bioretention
- Cistern + Bioretention
- Bioretention + Vault

In these soil conditions, the amount of infiltration and evapotranspiration achieved by a bioretention facility is subject to unpredictable variation based on location-specific soil, slopes, and subsurface drainage patterns. Bioretention facilities are designed to facilitate infiltration and evapotranspiration to the extent feasible given conditions at the location.

Flow-through planters may be used where facilities are located on upper-story plazas, adjacent to building foundations, where mobilization of pollutants in soil or groundwater is a concern, and where potential geotechnical hazards are associated with infiltration. Flow-through planters facilitate evapotranspiration and, like bioretention facilities, reuse runoff to promote growth of plants within the facility.

Pending Actions

MRP Provision C.3.c.iii.(1) requires the municipal permitees to submit proposed feasibility and infeasibility criteria for runoff storage/reuse and infiltration to the Water Board by May 1, 2011.

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► NON-LID TREATMENT FACILITIES

MRP Provision C.3.e.ii.(1) states:

> When considered at the watershed scale, certain types of smart growth, high density and transit-oriented development can either reduce existing impervious surfaces, or create less "accessory" impervious areas and automobile-related pollutant impacts. Incentive LID treatment reduction credits approved by the Water Board may be applied to these types of Special Projects.

Pending Actions
MRP Provision C.3.e.ii.(2) requires the municipal permitees to submit types of projects proposed for consideration of "LID treatment reduction credits" to the Water Board by December 1, 2010.

Through experience, Contra Costa municipalities have determined the LID facilities in Chapter 4 can be implemented on most "smart growth, high-density, and transit-oriented development," and have decided LID facilities should be incorporated on those projects. Contra Costa municipalities have set an overall goal of incorporating LID treatment for runoff from at least 95% of impervious area created or replaced, and incorporating non-LID treatment for runoff from the remaining 5% of impervious area created or replaced.

Projects where LID may not always be feasible generally fall into one of the following two categories:

- Portions of sites which are not being developed or redeveloped, but which must be retrofit to meet treatment requirements in accordance with the "50% rule."
- Sites smaller than one acre approved for lot-line to lot-line development or redevelopment as part of a municipality's stated objective to preserve or enhance a pedestrian-oriented "smart-growth" type of urban design.

In these special situations, municipal staff may—based on evidence that 100% LID treatment is infeasible—allow non-LID treatment to be used to treat runoff from some or all impervious surfaces. The non-LID treatment must include media filtration.

Regional Water Board staff has found oil/water separators ("water quality inlets") and storm drain inlet filters do not meet the "maximum extent practicable" standard.* When used as a sole method of stormwater treatment, hydrodynamic separators, including vortex separators and continuous deflection separators ("CDS units"), do not meet the "maximum extent practicable" requirement, although they may be used in series with other facilities.†

Criteria for Infiltration Devices

MRP Provision C.3.d.iv. restricts the design and location of "infiltration devices" that, as designed, may bypass filtration through surface soils before reaching groundwater. These devices include dry wells, infiltration basins, and infiltration trenches, but do not include bioretention facilities or other facilities that treat runoff before allowing it to infiltrate.

Infiltration devices may not be used in areas of industrial or light industrial activity; areas subject to high vehicular traffic (25,000 or greater average daily traffic on main roadway or 15,000 or more average daily traffic on any intersecting roadway); automotive repair shops; car washes; fleet storage areas (bus, truck, etc.); nurseries, or other areas with pollutant sources that could pose a high threat to water quality, as determined by municipal staff.

The vertical distance from the base of any infiltration device to the seasonal high groundwater mark shall be at least 10 feet. Infiltration devices shall be located a minimum of 100 feet horizontally from any known water supply wells.

In addition, infiltration devices are not recommended where:

- The infiltration device would receive drainage from areas where chemicals are used or stored, where vehicles or equipment are washed, or where refuse or wastes are handled.
- Surface soils or groundwater are polluted.
- The facility could receive sediment-laden runoff from disturbed areas or unstable slopes.
- Increased soil moisture could affect the stability of slopes of foundations.

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* "Use of Storm Drain Inlet Filters and Oil/Water Separators to Meet the Requirements of NPDES Municipal Stormwater Permits," letter from Regional Water Board Executive Officer Bruce Wolfe to Bay Area Stormwater Management Agencies Association managers, August 5, 2004

† *Policy on the Use of Hydrodynamic Separators to Achieve Compliance with NPDES Provision C.3*, November 16, 2005

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- Soils are insufficiently permeable to allow the device to drain within 72 hours.

► MOST LID FEATURES AND FACILITIES ARE NOT INFILTRATION DEVICES

Self-treating and self-retaining areas, pervious pavements, bioretention facilities, and flow-through planters are not considered to be infiltration devices because they do not bypass filtration through surface soils before reaching groundwater.

Bioretention facilities work by percolating runoff through 18 inches or more of engineered soil. This removes most pollutants before the runoff is allowed to seep into native soils below or discharge through the outlet. Further pollutant removal typically occurs in the unsaturated (vadose) zone before moisture reaches groundwater. Self-treating and self-retaining areas allow removal of pollutants in surface soils before runoff mixes with groundwater.

Where there is concern about the effects of increased soil moisture on slopes or foundations, an impermeable barrier may be added so the facility is "flow through" and all treated runoff is underdrained away from the facility. See the design sheets for Bioretention Facilities and Flow-Through Planters in Chapter 4.

Environmental Benefit Perspective

The diverse natural geography of Contra Costa County includes tidal and freshwater wetlands, alluvial plains, and mountain slopes. Average annual rainfall varies from 12.5 inches in Brentwood to 30 inches in Orinda.

The climate, soils, slope, and vegetation give each Contra Costa stream a characteristic structure of riffles, pools, terraces, floodplains, and wetlands. In relatively undisturbed stream reaches, this geomorphic structure supports trees and other riparian vegetation. Trees provide shade (cooling stream temperatures), create root wads and undercut banks (refuge for fish) and produce falling leaves and detritus (the bottom of a food web). Fish, frogs, and other animals have evolved to thrive in riparian habitats. Because Contra Costa habitats are diverse and complex, some species are specialized, have limited ranges, and may be rare.

Contra Costa's landscape, like that of all the San Francisco Bay Area, has been repeatedly transformed since the Spanish arrived in the 1770s. Even before the area was developed, European grasses, weeds, and other plants replaced much of the native vegetation. Creek flows were diverted to irrigate farms, and wetlands were diked or filled for farmland.

Suburbs and former farm towns developed rapidly during and after the Second World War. In many places, to make flood-prone land suitable for development, creeks were channelized or confined within levees. Buildings, streets, and pavement now cover much of the land, and storm drains pipe runoff from urban

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neighborhoods directly into the creeks. Urbanization has changed the timing and intensity of stream flows and has set off a chain of unanticipated consequences. These consequences include more frequent flooding, destabilized stream banks, armoring of streambanks with riprap and concrete, loss of streamside trees and vegetation, and the destruction of stream habitat.

The remaining habitat, even where it has been disturbed and reduced to remnants, is an important refuge for various species. The U.S. and California have listed some of these species, including steelhead (*Oncorhyncus mykiss),* as endangered. Other species are listed as threatened, rare, or having other special status.

Once altered, natural streams and their ecosystems cannot be fully restored. However, it is possible to stop, and partially reverse, the trend of declining habitat and preserve and enhance some ecosystem values for the benefit of future generations.

This is an enormous, long-term effort. Managing runoff from a single development site may seem inconsequential, but by changing the way most sites are developed (and redeveloped), we may be able to preserve and enhance existing stream ecosystems in urban and urbanizing areas.

References and Resources

- *The Importance of Imperviousness* (Tom Scheuler, 1995)
  Site Planning for Urban Stream Protection, available from the Center for Watershed Protection)
- California Stormwater BMP Handbooks
- *Urban Runoff Quality Management,* Water Environment Federation and American Society of Civil Engineers, 1998. ISBN 1-57278-039-8 ISBN 0-7844-0174-8.
- *Policy on Selection of Stormwater Treatment Facilities for Maximum Extent Practicable Effectiveness in Compliance with NPDES Provision C.3* (CCCWP, 2007)
- Use of Storm Drain Inlet Filters and Oil/Water Separators to Meet the Requirements of NPDES Municipal Stormwater Permits," letter from Regional Water Board Executive Officer Bruce Wolfe to Bay Area Stormwater Management Agencies Association managers, August 5, 2004
- *Stormwater Infiltration,* Bruce K. Ferguson, 1994. ISBN 0-87371-987-5
- Municipal Regional Permit Provisions C.3.c., C.3.d., C.3.e.
- RWQCB Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan)
- RWQCB Water Quality Control Plan for the Central Valley Region (Basin Plan)
- Clean Water Act Section 402(p)
- 40 CFR 122.26(d)(2)(iv)(A)(2) – Stormwater Regulations for New Development
- *Restoring Streams in Cities* (Riley, 1998)
- *Stream Restoration: Principles, Processes, and Practices*
  (Federal Interagency Stream Restoration Working Group, 1998, revised 2001)
- *Contra Costa County Watershed Atlas* (Contra Costa County, 2003

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Chapter

3

Preparing Your Stormwater Control Plan

Step-by-step assistance to document compliance.

Your Stormwater Control Plan will demonstrate your project complies with all applicable requirements in the stormwater NPDES permit—to minimize imperviousness, retain or detain stormwater, slow runoff rates, incorporate required source controls, treat stormwater prior to discharge from the site, control runoff rates and durations if required, and provide for operation and maintenance of treatment and flow-control facilities.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

The Plan must be submitted with your application for discretionary approvals and must have sufficient detail to ensure the stormwater design, site plan, and landscaping plan are congruent.

A complete and thorough Stormwater Control Plan will facilitate quicker review and fewer cycles of review. Every Contra Costa municipality requires a Stormwater Control Plan for every applicable project.

Your Stormwater Control Plan will consist of a report and an exhibit.

Municipal staff will use the checklist on the following page to evaluate your Plan:

STORMWATER CONTROL PLAN CHECKLIST

CONTENTS OF EXHIBIT

Show all of the following on drawings:

- ❒ Existing natural hydrologic features (depressions, watercourses, relatively undisturbed areas) and significant natural resources. (Step 1 in the following step-by-step instructions)
- ❒ Existing and proposed site drainage network and connections to drainage off-site. (Step 3)
- ❒ Layout of buildings, pavement, and landscaped areas. (Step 3)
- ❒ Impervious areas proposed (roof, plaza/sidewalk, and streets/parking) and area of each. (Step 3)
- ❒ Entire site divided into separate Drainage Management Areas, with each DMA identified as self-treating, self-retaining (zero-discharge), draining to a self-retaining area, or draining to an IMP. Each DMA has one surface type (roof, paving, or landscape), is labeled, and square footage noted. (Step 3)
- ❒ Locations and sizes of proposed treatment and flow-control facilities. (Step 3)
- ❒ Potential pollutant source areas, including refuse areas, outdoor work and storage areas, etc. listed in Appendix D and corresponding required source controls. (Step 4)

CONTENTS OF REPORT

Include all of the following in a report:

- ❒ Narrative analysis or description of site features and conditions that constrain, or provide opportunities for, stormwater control. Include soil types (including Hydrologic Soil Group), slopes, and depth to groundwater (Step 2)
- ❒ Narrative description of site design characteristics that protect natural resources. (Step 3)
- ❒ Narrative description and/or tabulation of site design characteristics, building features, and pavement selections that minimize imperviousness of the site. (Step 3)
- ❒ Evaluation of the feasibility of storage and use, infiltration, and evapotranspiration (Step 3).
- ❒ Tabulation of DMAs, including self-treating areas, self-retaining areas, areas draining to self-retaining areas, and areas tributary to Integrated Management Practices (IMPs), in the format shown in Chapter 4. Output from the IMP Sizing Calculator may be used. (Step 3)
- ❒ Sketches and/or descriptions showing there is sufficient hydraulic head to route runoff into, through, and from each IMP to an approved discharge point. (Step 3)
- ❒ A table of identified pollutant sources and for each source, the source control measure(s) used to reduce pollutants to the maximum extent practicable. See worksheet in Appendix D. (Step 4)
- ❒ General maintenance requirements for infiltration, treatment, and flow-control facilities. (Step 5)
- ❒ Means by which facility maintenance will be financed and implemented in perpetuity. (Step 5)
- ❒ Statement accepting responsibility for interim operation & maintenance of facilities. (Step 5)
- ❒ Identification of any conflicts with codes or requirements or other anticipated obstacles to implementing the Stormwater Control Plan. (Step 6)
- ❒ Construction Plan C.3 Checklist. (Step 6)
- ❒ Certification by a civil engineer, architect, and landscape architect. (Step 6)
- ❒ Appendix: Compliance with flow-control requirements (if using an HMP compliance option other than Option 2, Integrated Management Practices).

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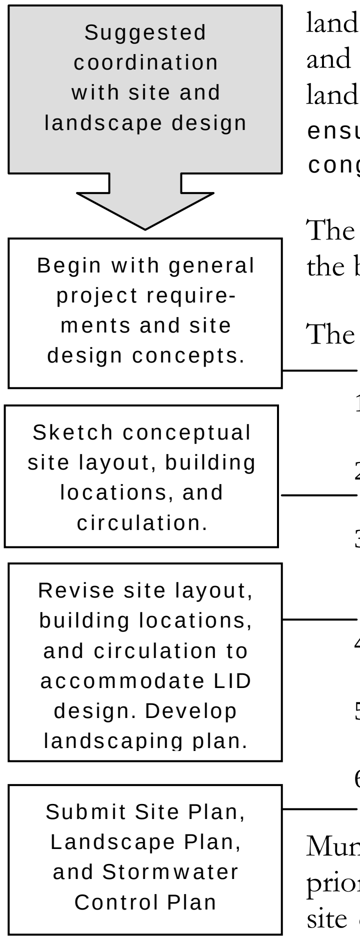
Step by Step



Plan and design your stormwater controls integrally with the site planning and landscaping for your project. It's best to start with general project requirements and preliminary site design concepts; then prepare the detailed site design, landscape design, and Stormwater Control Plan simultaneously. This will help ensure that your site plan, landscape plan, and Stormwater Control Plan are congruent.

The following step-by-step procedure should optimize your design by identifying the best opportunities for stormwater controls early in the design process.

The recommended steps are:

1. Assemble needed information.
2. Identify site opportunities and constraints.
3. Follow the LID design guidance in Chapter 4 to analyze your project for LID and to develop and document your drainage design.
4. Specify source controls using the table in Appendix D.
5. Plan for ongoing maintenance of treatment and flow-control facilities.
6. Complete the Stormwater Control Plan.

Municipal staff may recommend you prepare and submit a preliminary site design prior to formally applying for planning and zoning approvals. Your preliminary site design should incorporate a conceptual plan for site drainage, including self-treating and self-retaining areas and the location and approximate sizes of any treatment and flow-control facilities. This additional up-front design effort will save time and avoid potential delays later in the review process.

Step 1: Assemble Needed Information

To select types and locations of treatment and flow-control facilities, the designer needs to know the following site characteristics:

- Existing natural hydrologic features and natural resources, including any contiguous natural areas, wetlands, watercourses, seeps, or springs.
- Existing site topography, including contours of any slopes of 4% or steeper, general direction of surface drainage, local high or low points or depressions, any outcrops or other significant geologic features.

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- Zoning, including requirements for setbacks and open space.
- Soil types (including hydrologic soil groups) and depth to groundwater, which may determine whether infiltration is a feasible option for managing site runoff. Depending on site location and characteristics, and on the selection of treatment and flow-control facilities, site-specific information (e.g. from boring logs or geotechnical studies) may be required.
- Existing site drainage. For undeveloped sites, this should be obtained by inspecting the site and examining topographic maps and survey data. For previously developed sites, site drainage and connection to the municipal storm drain system can be located from site inspection, municipal storm drain maps, and plans for previous development.
- Existing vegetative cover and impervious areas, if any.

Step 2: Identify Constraints & Opportunities

Review the information collected in Step 1. Identify the principal constraints on site design and selection of treatment and flow-control facilities as well as opportunities to reduce imperviousness and incorporate facilities into the site and landscape design. For example, constraints might include impermeable soils, high groundwater, groundwater pollution or contaminated soils, steep slopes, geotechnical instability, high-intensity land use, heavy pedestrian or vehicular traffic, utility locations, or safety concerns. Opportunities might include existing natural areas, low areas, oddly configured or otherwise unbuildable parcels, easements and landscape amenities including open space and buffers (which can double as locations for bioretention facilities), and differences in elevation (which can provide hydraulic head).

Prepare a brief narrative describing site opportunities and constraints. This narrative will help you as you proceed with LID design and explain your design decisions to others.

Step 3: Prepare and Document Your LID Design

Use the Low Impact Development Design Guide (Chapter 4) to analyze your project for LID, design and document drainage, and specify preliminary design details for integrated management practices.

Chapter 4 includes calculation procedures and formats for presenting your calculations.

As shown in the checklist (page 24), your Exhibit must show:

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- The entire site divided into separate Drainage Management Areas (DMAs), with each area identified as self-treating, self-retaining, draining to a self-retaining area, or draining to an IMP. Each area should be clearly marked with a unique identifier.
- For each drainage area, the types of impervious area proposed, and the area of each.
- Proposed locations and sizes of treatment and flow-control facilities. Each facility should be clearly marked with a unique identifier.

Your Stormwater Control Plan report must include:

- An assessment of the feasibility of storing runoff and using it for irrigation or other non-potable use as a means of achieving criteria for treatment or treatment-and-flow-control. Use the equations and questions in Chapter 4.
- Tabulation of proposed self-treating areas, self-retaining areas, areas draining to self-retaining areas, and areas draining to IMPs, and the corresponding IMPs identified on the Exhibit.
- Calculations, in the format shown in Chapter 4, showing the minimum square footage required and proposed square footage for each IMP. If flow-control requirements apply, the required storage volume or volumes must also be shown.
- Preliminary designs for each IMP. The design sheets and accompanying drawings in Chapter 4 may be used or adapted for this purpose.

Also include in your Stormwater Control Plan report:

- A narrative overview of your design and how your design decisions optimize the site layout, use pervious surfaces, disperse runoff from impervious surfaces, and drain impervious surfaces to engineered IMPs. See Chapter 4.
- A narrative briefly describing each DMA, its drainage, and where drainage will be directed.
- A narrative briefly describing each IMP. Include any special characteristics or features distinct from the design sheets in Chapter 4.

Group and consolidate descriptions, or provide additional detail, as necessary to help the reviewer understand your drainage design.

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References and Resources

- Chapter 4
- *Start at the Source* (BASMAA, 1999).
- Your municipality's *General Plan*
- Your municipality's Zoning Ordinance and Development Codes
- *Low Impact Development Manual* (Prince George's County, Maryland, 1999).
- *Bioretention Manual* (Prince George's County, Maryland, rev. 2002)
- *Low Impact Development Technical Guidance Manual for Puget Sound* (Puget Sound Action Team, 2005)
- *LID for Big Box Retailers* (Low Impact Development Center, 2006)

Step 4. Specify Source Control BMPs

Some everyday activities – such as trash recycling/disposal and washing vehicles and equipment – generate pollutants that tend to find their way into storm drains. These pollutants can be minimized by applying **source control BMPs.**

Source control BMPs include **permanent**, structural features that may be required in your project plans—such as roofs over and berms around trash and recycling areas—and **operational** BMPs, such as regular sweeping and "housekeeping," that must be implemented by the site's occupant or user. The maximum extent practicable standard typically requires both types of BMPs. In general, operational BMPs cannot be substituted for a feasible and effective permanent BMP.

Use the following procedure to specify source control BMPs for your site:

► IDENTIFY POLLUTANT SOURCES

Review the first column in the **Pollutant Sources/Source Control Checklist** (Appendix D). Check off the potential sources of pollutants that apply to your site.

► NOTE LOCATIONS ON STORMWATER CONTROL PLAN EXHIBIT

Note the corresponding requirements listed in Column 2 of the Pollutant Sources/Source Control Checklist (Appendix D). Show the location of each pollutant source and each permanent source control BMP in your Stormwater Control Plan Exhibit.

► PREPARE A TABLE AND NARRATIVE

Check off the corresponding requirements listed in Column 3 in the Pollutant Sources/Source Control Checklist (Appendix D). Now, create a table using the format in Table 3-1. In the left column, list each potential source on your site (from Appendix E, Column 1). In the middle column, list the corresponding permanent, structural BMPs (from Columns 2 and 3, Appendix D) used to prevent pollutants from entering runoff. Accompany this table with a narrative that explains any special features, materials, or methods of construction that will be used to implement these permanent, structural BMPs.

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TABLE 3-1. Format for table of permanent and operational source control measures.

Potential source of runoff pollutants	*Permanent source control BMPs*	*Operational source control BMPs*

► IDENTIFY OPERATIONAL SOURCE CONTROL BMPS

To complete your table, refer once again to the Pollutant Sources/Source Control Checklist (Appendix D, Column 4). List in the right column of your table the operational BMPs that should be implemented as long as the anticipated activities continue at the site. The local stormwater ordinance requires that these BMPs be implemented; the same BMPs may also be required as a condition of a use permit or other revocable discretionary approval for use of the site.

References and Resources

- Appendix D, Stormwater Pollutant Sources/Source Control Checklist
- Municipal Regional Permit Provision C.3.c.
- *Start at the Source*, Section 6.7: Details, Outdoor Work Areas
- *California Stormwater Industrial/Commercial Best Management Practice Handbook*
- *Urban Runoff Quality Management* (WEF/ASCE, 1998) Chapter 4: Source Controls

Step 5: Stormwater Facility Maintenance

As required by MRP Provision C.3.h, your local municipality will periodically verify that treatment and flow-control facilities on your site are maintained and continue to operate as designed.

To make this possible, your municipality will require that you include in your Stormwater Control Plan:

1. A means to finance and implement facility maintenance in perpetuity.

2. Acceptance of responsibility for maintenance from the time the facilities are constructed until responsibility for operation and maintenance is legally transferred. A warranty covering a period following construction may also be required.

3. An outline of general maintenance requirements for the treatment and flow-control facilities you have selected.

Your local municipality will also require that you prepare and submit a detailed Stormwater Facilities Operation and Maintenance Plan that sets forth a maintenance schedule for each of the treatment and flow-control facilities built on your site. An agreement assigning responsibility for maintenance and providing for inspections and certification may also be required.

Details of these requirements, and instructions for preparing a Stormwater Facilities Operation and Maintenance Plan, are in Chapter 6.

References and Resources

- *Chapter 6*
- *Model Stormwater Ordinance (CCCWP, 2005)*
- Operation, Maintenance, and Management of Stormwater Management Systems (Watershed Management Institute, 1997)

Step 6: Stormwater Control Plan Exhibit & Report

Your Stormwater Control Plan should document the information gathered and decisions made in Steps 1-5. A clear, complete, well-organized Plan will make it possible to confirm your design meets the minimum requirements of the Municipal Regional Permit, the municipal stormwater pollution prevention ordinance, and this *Guidebook*.

► COORDINATION WITH SITE, ARCHITECTURAL, AND LANDSCAPING PLANS

Before completing your Stormwater Control Plan exhibit and report, ensure your stormwater control design is fully coordinated with the site plan, grading plan, and landscaping plan being proposed for the site.

Information submitted and presentations to design review committees, planning commissions, and other decision-making bodies must incorporate relevant aspects of the stormwater design. In particular, ensure:

- Curb elevations, elevations, grade breaks, and other features of the drainage design are consistent with the delineation of DMAs.
- The top edge (overflow) of each bioretention facility is level all around its perimeter—this is particularly important in parking lot medians.
- The resulting grading and drainage design is consistent with the design for parking and circulation.
- Bioretention facilities and other IMPs do not create conflicts with pedestrian access between parking and building entrances.

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- Vaults and utility boxes will be accommodated outside bioretention facilities and will not be placed within bioretention facilities.

- The visual impact of stormwater facilities, including planter boxes at building foundations and any terracing or retaining walls required for the stormwater control design, is shown in renderings and other architectural drawings.

- Landscaping plans, including planting plans, show locations of bioretention facilities, and the plant requirements are consistent with the engineered soils and conditions in the bioretention facilities.

- Renderings and representation of street views incorporate any stormwater facilities located in street-side buffers and setbacks.

- Any potential conflicts with local development standards have been identified and resolved.

Review Chapter 5, IMP Construction, to anticipate additional requirements for construction of IMPs.

► CONSTRUCTION PLAN C.3 CHECKLIST

When you submit construction plans for City review and approval, the plan checker will compare that submittal with your Stormwater Control Plan. By creating a Construction Plan C.3 Checklist for your project, you will facilitate the plan checker's comparison and speed review of your project.

TABLE 3-2. Format for Construction Plan C.3 Checklist.

Stormwater Control Plan Page #	*BMP Description*	*See Plan Sheet #s*

Here's how:

1. Create a table similar to Table 3-2. Number and list each measure or BMP you have specified in your Stormwater Control Plan in Columns 1 and 2 of the table. Leave Column 3 blank. Incorporate the table into your Stormwater Control Plan.

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2. When you submit construction plans, **duplicate the table** (by photocopy or electronically). Now fill in Column 3, identifying the plan sheets where the BMPs are shown. List all plan sheets on which the BMP appears. Submit the updated table with your construction plans.

Note that the updated table—or Construction Plan C.3 Checklist—is **only a reference tool** to facilitate comparison of the construction plans to your Stormwater Control Plan. Local municipal staff can advise you regarding the process required to propose changes to the approved Stormwater Control Plan.

See Chapter 5 for details of IMP construction to be included in construction plans.

► CERTIFICATION

Your local municipality may require that your Stormwater Control Plan be certified by an architect, landscape architect, or civil engineer. See Appendix A.

Your certification should state: "The selection, sizing, and preliminary design of stormwater treatment and other control measures in this plan meet the requirements of Regional Water Quality Control Board Order R2-2009-0074 and subsequent amendments."

► STORMWATER CONTROL PLAN REPORT SAMPLE OUTLINE AND CONTENTS

I. Project Setting

   A. Project Name, Location, Description

   B. Existing site features and conditions

   C. Opportunities and constraints for stormwater control

II. Low Impact Development Design Strategies

   A. Optimization of site layout

      (1) Limitation of development envelope

      (2) Preservation of natural drainage features

      (3) Setbacks from creeks, wetlands, and riparian habitats

      (4) Minimization of imperviousness

      (5) Using drainage as a design element

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B. Use of permeable pavements

C. Dispersal of runoff to pervious areas

D. Assessment of the feasibility of short-term and seasonal storage and reuse to meet treatment and flow-control requirements.

(1) Identification of impervious areas where runoff might be feasibly captured and stored.

(2) Calculation of minimum required storage and use rates for non-irrigation and irrigation uses for each such area.

(3) Storage for non-irrigation uses –Is there within the project site a reliable, accessible, implementable on-site non-potable demand to fully and reliably use the calculated supply during the rainy season?

(4) Storage for irrigation uses – Is there sufficient landscape within or near the project to ensure demand to the calculated quantity of water each year, and if so, is annual storage of this quantity of water feasible?

E. Use of Integrated Management Practices

III. Documentation of Drainage Design

A. Drainage Management Areas

(1) Tabulation

(2) Descriptions

B. Integrated Management Practices

(1) Tabulation and Sizing Calculations

(2) Descriptions

IV. Source Control Measures

A. Description of site activities and potential sources of pollutants

B. Table showing sources, permanent source controls, and operational source controls

V. Facility Maintenance Requirements

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A. Ownership and responsibility for maintenance in perpetuity.

(1) Commitment to execute any necessary agreements and/or annex into a fee mechanism, per local requirements.

(2) Statement accepting responsibility for operation and maintenance of facilities until that responsibility is formally transferred.

B. Summary of maintenance requirements for each stormwater facility.

VI. Construction Plan C.3 Checklist

VII. Certifications

Attachment: Stormwater Control Plan Exhibit

Appendix: Compliance with Flow-Control (Hydrograph Modification Management) requirements (if IMPs are not used).

► STORMWATER CONTROL PLAN TEMPLATE

A template with the above format and headings is available on the CCCWP website.

► EXAMPLE STORMWATER CONTROL PLANS

Example Stormwater Control Plans can be accessed via the CCCWP's website. Because of the pace at which the Regional Water Board has issued new requirements, some of these plans may have been prepared under requirements that have now been superseded. Your Stormwater Control Plan will reflect the unique character of your own project and should meet the requirements identified in this *Guidebook*. Municipal staff can assist you to determine how specific requirements apply to your project.

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Chapter
4

Low Impact Development Design Guide

Guidance for designing and documenting your LID site drainage, stormwater treatment facilities, and flow-control facilities, including feasibility of storage for later use

Your Stormwater Control Plan—to be submitted with your application for planning and zoning approvals (entitlements)—must show how your project will comply with the applicable Low Impact Development, stormwater treatment, and flow-control (hydrograph modification management) standards in the Municipal Regional Permit (MRP).

This will require careful documentation of:

- Pervious and impervious areas in the planned project.
- Drainage from each of these areas.
- Locations, sizes, and types of proposed LID, stormwater treatment, and flow-control facilities.

Your Stormwater Control Plan must include calculations showing the site drainage and proposed treatment and flow-control facilities meet the criteria in this Guidebook.

This Low Impact Development Design Guide will help you:

- Analyze your project and identify and select options for meeting LID requirements and runoff treatment requirements—and flow-control requirements, if they apply.

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- **Design and document drainage** for the whole site and document how that design meets this Guidebook's stormwater treatment and flow-control criteria.

- **Specify preliminary design details** and integrate your LID drainage design with your paving and landscaping design.

For most projects, you will need to iterate these three steps to converge on a workable design that complements site conditions and project objectives. Non-LID facilities are discussed in the final section of this chapter.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

Before beginning your LID design, determine whether flow-control requirements apply to your site. See Table 1.1 in Chapter 1. If flow-control requirements apply, review Appendix C to understand your options for meeting those requirements. The calculation procedures in this Design Guide enable you to comply with flow-control requirements using "Option 2" in Appendix C. If flow-control requirements do not apply, or if you are using another option to meet flow-control requirements, then you may use the treatment-only factors to size your facilities.

Analyze Your Project for LID

Conceptually, there are five LID strategies for managing runoff from buildings and paving:

1. **Optimize the site layout** by preserving natural drainage features and designing buildings and circulation to minimize the amount of roofs and paving.

2. **Use pervious surfaces** such as turf, gravel, or pervious pavement—or use surfaces that retain rainfall, such as "green roofs."

3. **Disperse runoff** from impervious surfaces on to adjacent pervious surfaces (e.g., direct a roof downspout to disperse runoff onto a lawn).

4. **Store runoff and use it later** for irrigation or other non-potable use.

5. Drain impervious surfaces to engineered **Integrated Management Practices** (IMPs), such as bioretention facilities, flow-through planters, or dry wells. IMPs evapotranspirate some runoff, infiltrate

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runoff to groundwater, and/or percolate runoff through engineered soil and allow it to drain away slowly.

A combination of two or more strategies may work best for your project. Table 4-1 includes ideas for applying LID strategies to site conditions and types of development. It may be useful as a starting point for thinking through application of the five strategies.

With forethought in design, the five LID strategies can provide multiple, complementary benefits to your development. Pervious surfaces reduce heat island effects and temperature extremes. Landscaping improves air quality, creates a better place to live or work, and upgrades value for rental or sale. Retaining natural hydrology helps preserve and enhance the natural character of the area. LID drainage design can also conserve water and reduce the need for drainage infrastructure.

TABLE 4-1. Ideas for Runoff Management

Site Features/Issues	*Pervious Pavement*	*Green Roof*	*Disperse Runoff to Landscape*	*Storage for Later Use*	*Bioretention Facility*	*Flow-through Planter*	*Dry Well*	*Cistern + bioretention*	*Bioretention + Vault*
Clayey native soils		✓	✓	✓	✓	✓		✓	✓
Permeable native soils	✓	✓	✓	✓	✓	✓	✓		
Very steep slopes		✓		✓		✓			
Shallow depth to groundwater		✓		✓		✓			
Roof drainage			✓	✓	✓	✓	✓	✓	
Parking lots	✓		✓	✓	✓		✓		✓
Extensive landscaping			✓	✓	✓				
Densely developed sites with limited space/landscape	✓	✓		✓		✓	✓	✓	✓

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► OPTIMIZE THE SITE LAYOUT

To minimize stormwater-related impacts, apply the following design principles to the layout of newly developed and redeveloped sites:

- Define the development envelope and protected areas, identifying areas that are most suitable for development and areas that should be left undisturbed.
- Set back development from creeks, wetlands, and riparian habitats.
- Preserve significant trees.

Where possible, conform the site layout along natural landforms, avoid excessive grading and disturbance of vegetation and soils, and replicate the site's natural drainage patterns.

Concentrate development on portions of the site with less permeable soils, and preserve areas that can promote infiltration.

Coordination
Chapter One includes a presentation of how review of your project's site design and landscape design is coordinated with review for compliance with Provision C.3.

For all types of development, **limit overall coverage** of paving and roofs. This can be accomplished by designing compact, taller structures, narrower and shorter streets and sidewalks, smaller parking lots (fewer stalls, smaller stalls, and more efficient lanes), and indoor or underground parking. Examine site layout and circulation patterns and identify areas where landscaping can be substituted for pavement.

Detain and retain runoff throughout the site. On flatter sites, it typically works best to intersperse landscaped areas and IMPs among the buildings and paving. On hillside sites, drainage from upper areas may be collected in conventional catch basins and piped to landscaped areas and IMPs in lower areas. Or use low retaining walls to create terraces that can accommodate IMPs. Wherever possible, direct drainage from landscaped slopes offsite and not to IMPs.

Use drainage as a design element. Use depressed landscape areas, vegetated buffers, and bioretention areas as amenities and focal points within the site and landscape design. Bioretention areas can be almost any shape and should be located at low points.

► USE PERVIOUS SURFACES

Consider a green roof. Green roofs are growing (in popularity), and many have been built in the Bay Area in the last few years. Benefits include longer roof life, lower heating and cooling costs, and better sound insulation, in addition to air quality and water quality benefits.

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However, initial costs are higher than for conventional roofs, and green roofs may add to the complexity of permitting, financing, and insuring new buildings. For C.3 compliance purposes, green roofs are considered not to produce increased runoff or runoff pollutants (i.e., any runoff from a green roof requires no further treatment or detention).

Pending Actions
MRP Provision C.3.c.i.(2)(b)(vii) requires the municipal permitees to submit proposed minimum specifications for green roofs to the Water Board by December 1, 2010.

Green roof designs with growing media 4 inches or deeper are encouraged but not required. Where possible, drainage from green roofs should be routed to landscaping rather than being tied directly into storm drains. This is because drain water may be high in organics due to extended contact with soils and plant roots.

Consider permeable pavements and surface treatments. Inventory paved areas on your preliminary site plan. Identify where permeable pavements, such as crushed aggregate, turf block, unit pavers, pervious concrete, or pervious asphalt could be substituted for impervious concrete or asphalt paving.

► DISPERSE RUNOFF TO ADJACENT PERVIOUS AREAS

Look for opportunities to direct runoff from impervious areas to adjacent landscaping. The design, including slopes and soils, must reflect a reasonable expectation that an inch of rainfall will soak into the soil and produce no runoff. For example, a lawn or garden depressed 3-4" below surrounding walkways or driveways provides a simple but functional landscape design element.

For sites subject to stormwater treatment requirements only, a 2:1 maximum ratio of impervious to pervious area is acceptable. If flow-control requirements apply, the impervious-to-pervious ratio must be limited to 1:1. Be sure soils will drain adequately.

Under some circumstances, it may be allowable to direct runoff from impervious areas to pervious pavement (for example, from roof downspouts to a parking lot paved with crushed aggregate or turf block). The pore volume of pavement and base course must be enough to retain an inch of rainfall, including runoff from the tributary area. The slopes and soils must be compatible with infiltrating that volume without producing runoff. This solution is most practical on flat sites with permeable soils.

► STORE RUNOFF FOR LATER USE

Use the following instructions and equations for a preliminary screening of the potential for storing runoff for later use on the site. As noted in Chapter 3, this determination of feasibility must be included in your Stormwater Control Plan.

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First, identify all specific impervious areas (for example, a roof or portion of a roof) from which runoff might be feasibly captured and stored. Consider direction of drainage and potential locations for runoff storage. Calculate the square footage of each area.

Pending Actions
MRP Provision C.3.c.iii.(1) requires the municipal permittees to submit proposed feasibility and infeasibility criteria for runoff storage/reuse and infiltration to the Water Board by May 1, 2011.

Then use the isohyetal diagram (County Public Works Drawing B-166) to estimate the Mean Annual Precipitation (MAP) at the project location.

Apply the following analysis for each specific impervious area identified. You will need to identify the Hydrologic Soil Group (A, B, C, or D) of the native soil underlying each specific impervious area.

Storing for a later use other than irrigation. If treatment-only requirements apply to your project (Table 1-1), use the following regression equation to estimate the storage volume for 80% capture:

Required volume (ft^3) = Impervious area (ft^2) × (0.0032 × MAP (in) + 0.0058)
(Eq 4-1)

This volume must be used (i.e., storage must be fully drained) each 48 hours.

If flow-control requirements also apply, use Equation 4-5, p. 51, to calculate the required storage volume. Referring to Table 4-8, use the factor for the upstream volume V of a "cistern + bioretention" facility. Then use the appropriate equation for the site soil group (Equation 4-17, 4-12, 4-10, or 4-11 from Table 4-9 on p. 51) to calculate the required use rate.

Given the calculated use rate, answer the following question and include the answer in your Stormwater Control Plan:

Is there within or near the project site a reliable, accessible, implementable on-site non-potable demand to fully use this supply during the rainy season?

Consider opportunities to use stored runoff for:

- Toilet flushing.
- Industrial use.
- Washing.
- Other uses.

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Storing for irrigation use. To be sure of diverting 80% of runoff for irrigation, it is necessary to store runoff during periods when there is little to no irrigation demand (approximately November through April) so that it may be used during the dry season. If treatment-only requirements apply, use the following equation to estimate the required storage:

Required volume (ft^3) = Impervious area (ft^2) × MAP (in)/12 × 0.6) *(Eq 4-2)*

Answer the following questions and include the answers in your Stormwater Control Plan: (1) Is there sufficient landscape within or near the project to ensure demand for this quantity of water each year? (2) If yes, is annual storage of this quantity of water feasible?

If flow-control requirements also apply, seasonal storage is not likely to be a feasible solution and need not be evaluated. Flow-control facilities are designed to store and release runoff flows which occur more rarely than once per year, and the facilities must be drained between storms.

If short-term or seasonal use of runoff from a specific impervious area is feasible, identify that area as a self-retaining drainage management area (DMA), as described on page 45.

Storage of a smaller volume of runoff for later use. Runoff storage that is less than the minimum calculated by Equations 4-1 and 4-2 is encouraged for water conservation. However, facilities for treatment and flow control must be sized independently of and in addition to storage for later use.

References and Resources

- *Municipal Handbook, Rainwater Harvesting Policies* (USEPA, 2008)
- *Green Roofs for Stormwater Runoff Control* (USEPA, 2009a)
- *Porous Pavements* (Ferguson, 2005)
- Municipal Regional Permit Provision C.3.c.

► DIRECT RUNOFF TO INTEGRATED MANAGEMENT PRACTICES

The CCCWP has developed design criteria for the following IMPs:

- Bioretention facilities, which can be configured as swales, free-form areas, or planters to integrate with your landscape design.
- Flow-through planters, which can be used near building foundations and other locations where infiltration to native soils is not desired.

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- Cistern + bioretention facilities, which use an upstream storage volume and metered flow to reduce the required square footage of a bioretention facility or flow-through planter.

- Bioretention + vault facilities, which capture a volume downstream of bioretention and meter outflows.

- Dry wells and other infiltration facilities, which can be used only where soils are permeable. See restrictions on page 20.

See the design sheets at the end of this chapter.

Finding the right location for treatment and flow-control facilities on your site involves a careful and creative integration of several factors:

- To make the most efficient use of the site and to maximize aesthetic value, integrate IMPs with site landscaping. Many local zoning codes may require landscape setbacks or buffers, or may specify that a minimum portion of the site be landscaped. It may be possible to locate some or all of your site's treatment and flow-control facilities within this same area, or within utility easements or other non-buildable areas.

- Planter boxes and bioretention facilities must be level or nearly level all the way around. Linear bioretention facilities (swales) may be gently sloped end to end, but opposite sides must be at the same elevation. Facilities on steeper slopes must be terraced or provided with check dams.

- For effective, low-maintenance operation, locate facilities so drainage into and out of the device is by gravity flow. Pumped systems are feasible, but are expensive, require more maintenance, are prone to untimely failure, and can cause mosquito control problems. Most IMPs require 3 feet or more of head.

- Bioretention facilities and other IMPs require excavations three or more feet deep, which can conflict with underground utilities.

- If the property is being subdivided now or in the future, the facility should be in a common, accessible area. In particular, avoid locating facilities on private residential lots. Even if the facility will serve only one site owner or operator, make sure the facility is located for ready access by inspectors from the local municipality and the Contra Costa Mosquito and Vector Control District.

- The facility must be accessible to equipment needed for its maintenance. Access requirements for maintenance will vary with

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the type of facility selected. Bioretention facilities will typically need access for the same types of equipment used for landscape maintenance.

To complete your analysis, include in your Stormwater Control Plan a brief narrative documenting the site layout and site design decisions you made. This will provide background and context for how your design meets the quantitative LID design criteria.

Develop and Document Your Drainage Design

The CCCWP's design documentation procedure begins with careful delineation of pervious areas and impervious areas (including roofs) throughout the site. The procedure accounts for how runoff from each delineated area is managed. For areas draining to IMPs, the procedure ensures each IMP is appropriately sized.

The procedure results in a space-efficient, cost-efficient LID design for meeting C.3 requirements on most residential and commercial/industrial developments. The procedure arranges documentation of drainage design and IMP sizing in a consistent format for presentation and review.

This procedure is intended to facilitate, not substitute for, creative interplay among site design, landscape design, and drainage design. Several iterations may be needed to optimize your drainage design as well as aesthetics, circulation, and use of available area for your site.

You should be able to complete the needed calculations using only the project's site development plan, hydrologic soil group (A, B, C, or D) and mean annual precipitation. Mean annual precipitation at locations in Contra Costa County can be determined using isohyetal maps accessible from the CCCWP's C.3 web page.

The CCCWP has created an IMP Sizing Calculator to facilitate the iterative calculations needed to create an optimal site design. The calculator is a stand-alone application and is available, along with instructions for its use, on the CCCWP's C.3 web pages. In addition to performing calculations, the IMP Sizing Calculator formats calculation results into a summary report. The summary report can be attached to your Stormwater Control Plan submittal.

Should you decide to use the calculator, be sure to read through the following instructions, as they include key information you will need for design.

The following formulas and procedures can be used without the sizing calculator to complete calculations and prepare a report suitable for submittal with your Stormwater Control Plan. The same formulas and procedures should be used to check and verify calculations made with the IMP Sizing Calculator.

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► STEP 1: DELINEATE DRAINAGE MANAGEMENT AREAS

This is the key first step. You must divide the entire project area into individual, discrete Drainage Management Areas (DMAs). Typically, lines delineating DMAs follow grade breaks and roof ridge lines. The Exhibit, tables, text, and calculations in your Stormwater Control Plan will illustrate, describe, and account for runoff from each of these areas.

Use separate DMAs for each surface type (e.g., landscaping, pervious paving, or roofs). Each DMA must be assigned a single hydrologic soil group. Assign each DMA an identification number and determine its size in square feet.

► STEP 2: CLASSIFY DMAS AND DETERMINE RUNOFF FACTORS

Next, determine how drainage from each DMA will be handled. Each DMA will be one of the following four types:

1. Self-treating areas.
2. Self-retaining areas (also called "zero-discharge" areas).
3. Areas that drain to self-retaining areas.
4. Areas that drain to IMPs.

Self-treating areas are landscaped or turf areas that do not drain to IMPs, but rather drain directly off site or to the storm drain system. Examples include upslope undeveloped areas which are ditched and drained around a development and grassed slopes that drain off-site to an existing public street or storm drain. In general, self-treating areas include no impervious areas, unless the impervious area is very small (5% or less) in relationship to the receiving pervious area and slopes are gentle enough to ensure runoff from impervious areas will be absorbed into the vegetation and soil.

Rationale

Pollutants in rainfall and windblown dust will tend to become entrained in the vegetation and soils of landscaped areas, so no additional treatment is needed. It is assumed the self-treating landscaped areas will produce runoff less than or equal to the pre-project site condition.

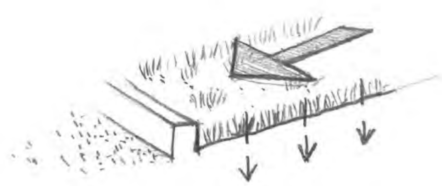

FIGURE 4-1. SELF-TREATING AREAS are entirely pervious and drain directly off-site or to the storm drain system.

Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. The technique works best on flat, heavily landscaped sites. It may be used on mild slopes if there is a reasonable expectation that a one-inch rainfall event would produce no runoff.

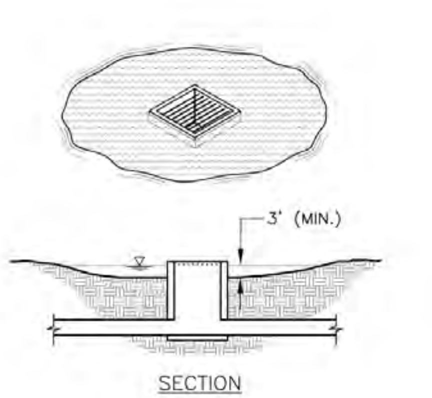

FIGURE 4-2. SELF-RETAINING AREAS. Berm or depress the grade to retain at least an inch of rainfall and set inlets of any area drains at least 3 inches above low point to allow ponding.

To create self-retaining turf and landscape areas in flat areas or on terraced slopes, berm the area or depress the grade into a concave cross-section so that these areas will retain the first inch of rainfall. Grade slopes, if any, toward the center of the pervious area. Inlets of area drains, if any, should be set 3 inches above the low point to allow ponding.

Under some circumstances, pervious pavement (e.g., crushed stone, pervious asphalt, or pervious concrete) can be self-retaining. Adjacent roofs or impervious pavement may drain on to the pervious pavement in the same maximum ratios as described below. A gravel base course four or more inches deep will ensure an adequate proportion of rainfall is infiltrated into native soils (including clay soils) rather than producing runoff. Consult with a qualified engineer regarding infiltration rates, pavement stability, and suitability for the intended traffic.

Drainage from green roofs is considered to be self-retained. An emergency overflow should be provided for extreme events. Areas draining to storage for later use may be considered "self-retained" if facilities with the required storage volumes and release rates are provided and reliable demand is documented in the Stormwater Control Plan.

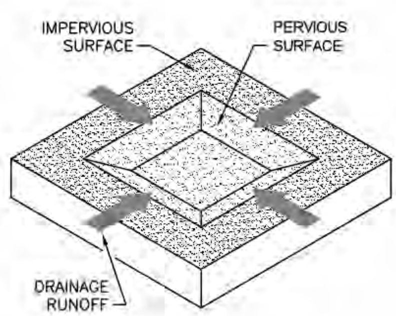

FIGURE 4-3. RELATIONSHIP OF IMPERVIOUS TO PERVIOUS area for self-retaining areas.
Where flow-control requirements apply: ***pervious ≥ impervious***
Where only treatment requirements apply : ***pervious ≥ ½ impervious***

Areas draining to self-retaining areas. Runoff from impervious or partially pervious areas can be managed by routing it to self-retaining pervious areas. For example, roof downspouts can be directed to lawns, and driveways can be sloped toward landscaped areas. The maximum ratio is 2 parts impervious area for every 1 part pervious area if only treatment requirements apply to the development project. If flow-control requirements also apply, the maximum ratio is 1 part impervious area for every 1 part pervious area.

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The drainage from the impervious area must be directed to and dispersed within the pervious area, and the entire area must be designed to retain an inch of rainfall without flowing off-site. For example, if the maximum ratio of 2 parts impervious area into 1 part pervious area is used, then the pervious area must absorb 3 inches of water over its surface before overflowing to an off-site drain.

A partially pervious area may be drained to a self-retaining area. For example, a driveway composed of unit pavers may drain to an adjacent lawn. In this case, the maximum ratios are, for treatment-only sites:

Derivation of Criteria

A computer model was used to continuously simulate rainfall, infiltration, and runoff at an hourly time-step over 30 years. Results indicate drainage areas using the 1:1 ratio will not exceed pre-project peaks and durations.

(Runoff factor) x (tributary area) $\leq$ 2 x (self-retaining area) *Equation 4-3*

For sites subject to flow-control requirements:

(Runoff factor) x (tributary area) $\leq$ 1 x (self-retaining area) *Equation 4-4*

Use the runoff factors in Table 4-2.

TABLE 4-2. RUNOFF FACTORS for evaluating drainage to self-retaining areas and for sizing IMPs.

Surface	Treatment and Flow Control	Treatment only
Roofs	1.0	1.0
Concrete or Asphalt	1.0	1.0
Pervious Concrete	0.1	0.1
Porous Asphalt	0.1	0.1
Grouted Unit Pavers	1.0	1.0
Solid Unit Pavers Set in Sand	0.5	0.2
Open and Porous Pavers	0.1	0.1
Crushed Aggregate	0.1	0.1
Turfblock	0.1	0.1
Landscape, Group A Soil	0.1	0.1
Landscape, Group B Soil	0.3	0.1
Landscape, Group C Soil	0.5	0.1
Landscape, Group D Soil	0.7	0.1

Prolonged ponding is a potential problem at higher impervious/pervious ratios. In your design, ensure that the pervious area soils can handle the additional run-on and are sufficiently well-drained.

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Runoff from self-treating and self-retaining areas does not require any further treatment or flow control. Further, there is no requirement for operation and maintenance inspections (see Chapter 6).

Areas draining to IMPs are used to calculate the required size of the IMP. On most densely developed sites—such as commercial and mixed-use developments and small-lot residential subdivisions—most DMAs will drain to IMPs.

The CCCWP has developed sizing factors (ratios of IMP area to impervious DMA area). For each IMP design, factors are provided for:

- Treatment-only.
- Treatment-plus-flow-control.

Treatment-only IMPs are smaller and in some cases are simpler in design.

More than one drainage management area can drain to the same IMP. However, because the minimum IMP sizes are determined by ratio to drainage area size, one drainage area may not drain to more than one IMP. See Figures 4-4 and 4-5.

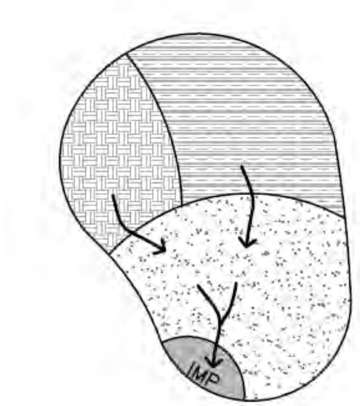

FIGURE 4-4. MORE THAN ONE
Drainage Management Area can drain to a single IMP.

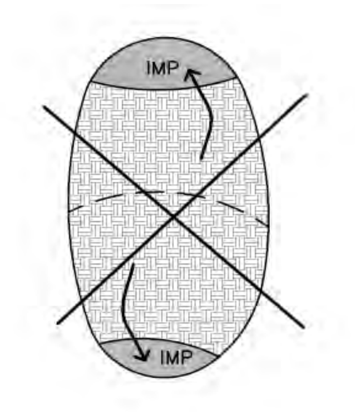

FIGURE 4-5. ONE DRAINAGE
Management Area cannot rain to more than one IMP. Use a grade break to divide the DMA.

Where possible, design site drainage so only impervious roofs and pavement drain to IMPs. This yields a simpler, more efficient design and also helps protect IMPs from becoming clogged by sediment.

If it is necessary to include turf, landscaping, or pervious pavements within the area draining to an IMP, list each surface as a separate DMA. A runoff factor (similar to a "C" factor used in the rational method) is applied to account for the reduction in the quantity of runoff. For example, when a turf or landscaped drainage management area drains to an IMP, the resulting increment in IMP size is:

(pervious area) × (runoff factor) × (sizing factor).

Use the runoff factors in Table 4-2.

► STEP 3: TABULATE DRAINAGE MANAGEMENT AREAS

- Tabulate self-treating areas in the format shown in Table 4-3.
- Tabulate self-retaining areas in the format shown in Table 4-4.
- Tabulate areas draining to self-retaining areas in the format shown in Table 4-5. Check to be sure the total amount of (square feet of tributary area × runoff factor) for all DMAs draining to a receiving self-retaining area is no greater than a 1:1 ratio to the square footage of the receiving self-retaining area itself. A 2:1 ratio may be used on sites not subject to flow-control requirements.

Compile a list of DMAs draining to IMPs. Proceed to Step 4 to check the sizing of the IMPs.

TABLE 4-3. FORMAT FOR TABULATING Self-Treating Areas

DMA Name	*Area (square feet)*

TABLE 4-4. FORMAT FOR TABULATING Self-Retaining Areas

DMA Name	*Area (square feet)*

TABLE 4-5. FORMAT FOR TABULATING Areas Draining to Self-Retaining Areas

DMA Name	*Area (square feet)*	*Post-project surface type*	*Runoff factor*	*Product (Area × runoff factor)[A]*	*Receiving self-retaining DMA*	*Receiving self-retaining DMA Area (square feet) [B]*	*Ratio [A]/[B]*

► STEP 4: SELECT AND LAY OUT IMPS ON SITE PLAN

Select from the IMPs in Table 4-6.

TABLE 4-6. IMP SELECTION

	Treatment Only				Treatment + Flow Control			
Hydrologic Soil Group	A	B	C	D	A	B	C	D
Bioretention	✓	✓	✓	✓	✓	✓	✓	✓
Flow-through Planter	✓	✓	✓	✓			✓	✓
Dry Well	✓	✓			✓	✓		
Cistern + Bioretention					✓	✓	✓	✓
Bioretention + Vault					✓	✓	✓	✓

Descriptions, illustrations, designs, and design criteria for the IMPs are in the design sheets at the end of this chapter. Once you have laid out the IMPs, calculate the square footage you have set aside on your site plan for each IMP.

► STEP 5: CALCULATE MINIMUM IMP AREA AND VOLUMES

For **treatment only**, the minimum IMP areas and volumes are determined by summing up the contributions of each tributary DMA and multiplying times the factors shown in Table 4-7. Criteria for IMPs, including surface reservoir depths, underdrain bedding requirements, and depths and characteristics of planting soils, are in design sheets in this chapter.

TABLE 4-7. MINIMUM IMP AREAS AND VOLUMES for treatment only

Hydrologic Soil Group	A	B	C	D
Bioretention Facility A	0.04	0.04	0.04	0.04
Flow-through Planter A	0.04	0.04	0.04	0.04
Dry Well (treatment only) A V	0.02 0.068	0.04 0.136	N/A N/A	N/A N/A
A = ft^2 of IMP footprint per ft^2 of tributary area (unitless) V = ft^3 per ft^2 of tributary area (ft.) Apply runoff factors from Table 4-2 for landscape or other pervious surfaces.				

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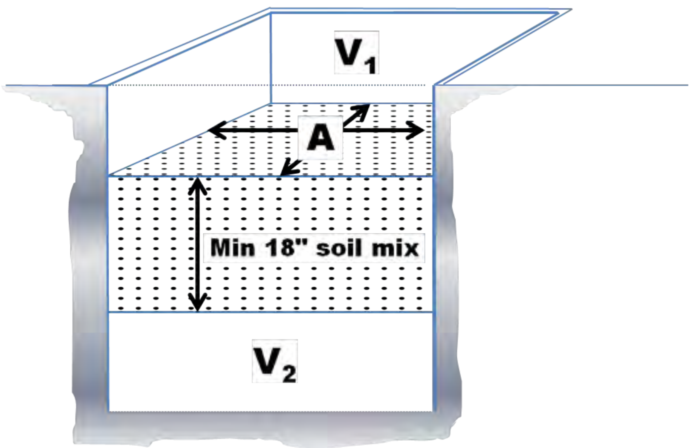
For treatment-and-flow-control, the minimum area and minimum storage volumes are found by summing up the contributions of each tributary DMA and applying sizing factors and equations. The configuration of area (A), surface reservoir volume (V_1) and subsurface reservoir volume (V_2) for bioretention facilities and flow-through planters is shown in Figure 4-6.

FIGURE 4-6. A, V_1, and V_2.



Note: V_2 is the free volume. For gravel, multiply by an assumed porosity of 0.4.

V_1 is the floodable volume above the soil layer (that is, the total volume of surface storage when the facility just begins to overflow). V_2 is the storage volume below the soil layer. If gravel fill is used to provide subsurface volume, only the free pore volume is considered and is calculated by multiplying the volume of gravel by an assumed porosity of 0.4.

Sizing factors for treatment-only IMPs do not require any adjustment for differing rainfall patterns. Both area (A) and volume (V_1, V_2) sizing factors for treatment-plus-flow-control IMPs, however, must be adjusted to account for the effects of differing rainfall patterns on pre-project and post-project runoff. Cisterns and dry wells have a single storage volume.

Note these volumes can be configured in a variety of practical combinations of depth and area to best fit into your landscape design. For example, if a bioretention facility were designed with double the minimum value of A, then the depth of the surface reservoir and the depth of the subsurface reservoir could both be halved. Some other strategies to achieve the required minimum values of V1 and V2 are described in the design sheets in this chapter.

The minimum values of A, V_1, and V_2 are calculated by Equation 4-5.

Equation 4-5

$$Min.IMP\ Area\ or\ Volume = \sum \begin{pmatrix} DMA & & DMA \\ Square & \times & Runoff \\ Footage & & Factor \end{pmatrix} \times \begin{pmatrix} IMP \\ Sizing \\ Factor \end{pmatrix} \times \begin{pmatrix} Rain \\ Adjustment \\ Factor \end{pmatrix}$$

IMP Sizing Factors and equations for calculating Rain Adjustment Factors are in Tables 4-8 and 4-9.

TABLE 4-8. FACTORS FOR CALCULATING IMP Area and Storage Volumes (Treatment-and-flow-control)

Facility Design	Soil Group	Area (ft^2/ft^2)	Volume V_1 (ft^3/ft^2)	Volume V_2 (ft^3/ft^2)	Rainfall Adjustment for Surface Area	Rainfall Adjustment for Storage Volume	Maximum Release Rate
Bioretention Facility	A	0.07	0.058	No min.	Eq. 4-6	Eq. 4-6	No orifice
	B	0.11	0.092	No min.	Eq. 4-7	Eq. 4-7	No orifice
	C	0.06	0.050	0.066	Eq. 4-8	Eq. 4-8	Eq. 4-10
	D	0.05	0.042	0.055	Eq. 4-9*	Eq. 4-9	Eq. 4-11
Flow-through Planter	A	Not permitted in "A" soils					
	B	Not permitted in "B" soils					
	C	0.06	0.050	0.066	Eq. 4-8	Eq. 4-8	Eq. 4-10
	D	0.05	0.042	0.055	Eq. 4-9*	Eq. 4-9	Eq. 4-11
Dry Well	A	0.05	0.130	N/A	Eq. 4-6	Eq. 4-6	No release
	B	0.06	0.204	N/A	Eq. 4-7	Eq. 4-7	No release
	C	Not permitted in "C" soils					
	D	Not permitted in "D" soils					
Cistern + Bioretention	A	0.020	0.193	N/A	Eq. 4-13	Eq. 4-6	Eq. 4-17
	B	0.009	0.210	N/A	Eq. 4-14	Eq. 4-7	Eq. 4-12
	C	0.013	0.105	N/A	Eq. 4-15	Eq. 4-8	Eq. 4-10
	D	0.017	0.063	N/A	Eq. 4-16	Eq. 4-9	Eq. 4-11
Bioretention + Vault	A	0.04	N/A	0.096	N/A	Eq. 4-6	No release
	B	0.04	N/A	0.220	N/A	Eq. 4-7	Eq. 4-12
	C	0.04	N/A	0.152	N/A	Eq. 4-8	Eq. 4-10
	D	0.04	N/A	0.064	N/A	Eq. 4-9	Eq. 4-11

A = ft^2 of IMP footprint per ft^2 of tributary impervious area (unitless)
V_1, V_2 = ft^3 per ft^2 of equivalent tributary impervious area (ft.) Cisterns, dry wells, and vaults have only one volume.
*If MAP is 25 inches or greater, this equation will yield a rainfall adjustment less than 0.8 and a bioretention facility area less than 0.04 times the tributary area. In that case, use 0.04 times the tributary area to calculate the minimum allowable bioretention facility area. Equation 4-9 may still be used to adjust minimum required storage volumes.

TABLE 4-9. EQUATIONS TO BE USED in calculating IMP sizes and outflow rates.

Eq. 4-6	$Rain\ Adjustment = \frac{0.0009 \times (MAP_{project\ site} - 20.2) + 0.07}{0.07}$
Eq. 4-7	$Rain\ Adjustment = \frac{-0.0005 \times (MAP_{project\ site} - 20.2) + 0.11}{0.11}$
Eq. 4-8	$Rain\ Adjustment = \frac{-0.0022 \times (MAP_{project\ site} - 20.2) + 0.06}{0.06}$
Eq. 4-9	$Rain\ Adjustment = \frac{-0.0022 \times (MAP_{project\ site} - 20.2) + 0.05}{0.05}$
Eq. 4-10	$Flow\ (cfs\ per\ ft^2) = \frac{0.093 \times (MAP_{project\ site} - 20.2) + 1.42}{10^6}$
Eq. 4-11	$Flow\ (cfs\ per\ ft^2) = \frac{0.122 \times (MAP_{project\ site} - 20.2) + 1.85}{10^6}$
Eq. 4-12	$Flow\ (cfs\ per\ ft^2) = \frac{0.071 \times (MAP_{project\ site} - 20.2) + 0.91}{10^6}$
Eq. 4-13	$Area\ Ratio = \frac{0.151 \times (MAP_{project\ site} - 20.2) + 2.30}{2.30}$
Eq. 4-14	$Area\ Ratio = \frac{0.071 \times (MAP_{project\ site} - 20.2) + 0.91}{0.91}$
Eq. 4-15	$Area\ Ratio = \frac{0.093 \times (MAP_{project\ site} - 20.2) + 1.42}{1.42}$
Eq. 4-16	$Area\ Ratio = \frac{0.122 \times (MAP_{project\ site} - 20.2) + 1.85}{1.85}$
Eq. 4-17	$Flow\ (cfs\ per\ ft^2) = \frac{0.151 \times (MAP_{project\ site} - 20.2) + 2.30}{10^6}$

MAP = Mean Annual Precipitations, determined from Contra Costa County Public Works Figure B-166.

Use the format of Table 4-10 to present the calculations of the required minimum area and volumes of the receiving IMP.

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TABLE 4-10. FORMAT FOR PRESENTING CALCULATIONS of minimum IMP Areas and Volumes

DMA Name	*DMA Area (square feet)*	*Post-project surface type*	*DMA Runoff factor*	*DMA Area × runoff factor*
			Total	

Soil Type:	*IMP Name*			
IMP Sizing factor	*Rain Adjust-ment Factor*	*Minimum Area or Volume*	*Proposed Area or Volume*	
				IMP Area
				V or V1
				V2
			Orifice Size:	

► STEP 6: DETERMINE IF IMP AREA AND VOLUME ARE ADEQUATE

Sizing and configuring IMPs may be an iterative process. After computing the minimum IMP area using Steps 1–6, review the site plan to determine if the reserved IMP area is sufficient.

If so, the planned IMPs will meet the Provision C.3 sizing requirements. If not, revise the plan accordingly. Revisions may include:

- Reducing the overall imperviousness of the project site.
- Changing the grading and drainage to redirect some runoff toward other IMPs which may have excess capacity.
- Making tributary landscaped DMAs self-treating or self-retaining (may require changes to grading).
- Expanding IMP surface area.

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- Using a different IMP—the cistern + bioretention and bioretention + vault options were created to achieve flow control in a smaller footprint than bioretention alone. Note these options are more costly and complex to build and operate.

Note revisions to square footage of an IMP typically require a corresponding revision to the square footage of the surrounding or adjacent DMA area.

Once a design with adequate area is achieved, review the IMP configuration to confirm the required minimum volumes are met. If not, revisions to V_1 may include adjusting depth or side slopes and extending the floodable storage area to include adjacent paved or landscaped areas. Revisions to V_2 may include adjusting width or depth, or incorporating buried pipes or arches in the gravel layer.

► STEP 7: COMPUTE MAXIMUM ORIFICE FLOW RATE

This step applies only to treatment-and-flow-control bioretention facilities and flow-through planters built on native Group C and Group D soils, cistern + bioretention-facilities built in all soils, and bioretention + vault facilities built on Group B, Group C, and Group D native soils. See Table 4-6.

Treatment-only bioretention facilities and flow-through planters in Group C and Group D soils are equipped with underdrains, but there is no restriction on the rate of outflow.

For treatment-and-flow-control IMPs, the underdrain has a flow control orifice sized to ensure rates and durations of flows do not exceed pre-project conditions.

For a cistern + bioretention-facility, the flow-control orifice is placed on the outlet from the cistern where it discharges to the bioretention facility. The bioretention facility must have an underdrain in B, C, and D soils, but no flow-control orifice is required on the underdrain.

For a bioretention + vault facility, the flow-control orifice is placed on the discharge from the vault.

Find the appropriate equation in Tables 4-8 and 4-9 to determine the maximum underdrain flow. Sum the total area draining to an IMP (including all tributary DMAs; do not use runoff factors. Compute the maximum orifice release rate, and then apply the orifice equation (Eq. 4-18) to determine the required orifice area. Then use Eq. 4-19 to determine the diameter of the flow control orifice.

Equation 4-18

$$Orifice\ Area\ (in\ \ feet) = \frac{UnderdrainMaxFlow}{c \times \sqrt{64.4 \times H}}$$

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where c is the orifice coefficient, which may be approximated as 0.6. H is the height of the storage above the orifice.

Equation 4-19

$$Orifice\ Diameter\ (in\ inches) = 12 \times \sqrt{\frac{4 \times Orifice\ Area}{\pi}}$$

STEP 8: COMPLETE YOUR SUMMARY REPORT

Present your IMP sizing calculations in tabular form. Adapt the following format as appropriate to your project. (Note: the IMP Sizing Calculator produces this output for you.) Coordinate your presentation of DMAs and calculation of minimum IMP sizes with the Stormwater Control Plan exhibit (labeled to show delineation of DMAs and locations of IMPs) and with your Stormwater Control Plan report, which should incorporate a brief description of each DMA and each IMP.

Tabulate and sum the total area of all DMAs and IMPs listed and show it is equal to the total project area. This step may include adjusting the square footage of some DMAs to account for area used for IMPs.

Format:

Project Name:

Project Location:

APN or Subdivision Number:

Total Project Area (square feet):

Mean Annual Precipitation at Project Site:

IMPs designed for (treatment only or treatment-and-flow-control):

I. Self-treating areas:

DMA Name	*Area (square feet)*

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II. Self-retaining areas:

DMA Name	*Area (square feet)*

III. Areas draining to self-retaining areas:

DMA Name	*Area (square feet)*	*Post-project surface type*	*Runoff factor*	*Product (Area × runoff factor)[A]*	*Receiving self-retaining DMA*	*Receiving self-retaining DMA Area (square feet) [B]*	*Ratio [A]/[B]*

IV. Areas draining to IMPs (repeat for each IMP):

DMA Name	*DMA Area (square feet)*	*Post-project surface type*	*DMA Runoff factor*	*DMA Area × runoff factor*
			Total	

Soil Type:	*IMP Name*

IMP Sizing factor	*Rain Adjustment Factor*	*Minimum Area or Volume*	*Proposed Area or Volume*	
				IMP Area
				V or V1
				V2
			Orifice Size:	

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Specify Preliminary Design Details

In your Stormwater Control Plan, describe your features and facilities in sufficient detail to demonstrate the area, volume, and other criteria of each can be met within the constraints of the site.

Ensure these details are consistent with preliminary site plans, landscaping plans, and architectural plans submitted with your application for planning and zoning approvals.

Following are design sheets for:

- Self-treating and self-retaining areas
- Pervious pavements
- Bioretention
- Flow-through planter
- Dry well
- Cistern + bioretention
- Bioretention + vault

These design sheets include recommended configurations and details, and example applications, for these features and facilities. **The information in these design sheets must be adapted and applied to the conditions specific to the development project**. Local planning, building, and public works officials have final review and approval authority over the project design.

Keep in mind that proper and functional design of features and facilities is the responsibility of the applicant. Effective operation of facilities throughout the project's lifetime will be the responsibility of the property owner.

Alternatives to LID Design

LID has been found to be feasible for nearly all development sites. If you believe LID design may be infeasible for your development site, review the criteria for the selection of stormwater treatment facilities on page 16. If flow-control requirements apply, also review the options for compliance in Appendix C. Then consult with municipal staff before preparing an alternative design for stormwater treatment or flow-control.

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Pending Actions
MRP Provision C.3.e.ii.(2) requires the municipal permitees to submit types of projects proposed for consideration of "LID treatment reduction credits" to the Water Board by December

For all alternative designs, the applicant must submit a complete Stormwater Control Plan, including an exhibit showing the entire site divided into discrete Drainage Management Areas, text and tables showing how drainage is routed from each DMA to a treatment facility, and calculations demonstrating the design achieves the applicable design criteria for each facility.

► TREATMENT CONTROL ALTERNATIVES

Here are criteria and design considerations for alternatives that may be used under the conditions allowed by the permit and by the municipality:

Sand Filters. To ensure effectiveness is not compromised by compacting or clogging of the filter surface, sand filters must be maintained frequently.

The following criteria apply to sand filters:

- Calculate the design flow using the rational method with an intensity of 0.2"/hour and the runoff factors for treatment only from Table 4-2.
- To determine the required filter surface area, divide the design flow by an allowable maximum design surface loading rate of 5"/hour.
- The minimum depth of filter media is 18". The media should be washed sand, with gradation similar to that specified for fine aggregate in ASTM C-33.
- The entire filter area must be accessible for easy maintenance without the need to enter a confined space.

A typical filter design includes a gravel drain layer and a perforated pipe underdrain. Filter fabric may be used to prevent the filter media from entering the gravel layer.

The design should not include any permanent pool or other standing water. Instead of including a pretreatment basin, consider the following features in the area tributary to the filter to reduce the potential for filter clogging:

- Limit the size of the Drainage Management Area.
- Include only impervious areas in the DMA.
- Stabilize slopes and eliminate sources of sediment in the DMA.
- Provide screens for trash and leaves at storm drain inlets.

For additional design considerations and details, see *Design of Stormwater Filtering Systems* by Richard A. Claytor and Thomas R. Schueler, The Center for Watershed Protection, 1996, and *California Stormwater BMP Handbooks* Fact Sheet TC-40, Media Filter.

"Wet" Detention Ponds and Constructed Wetlands. The required detention volume is determined using the "Unit Basin Storage Size for 80% Capture" chart available on the CCCWP's website and the mean annual precipitation determined from Contra Costa County Public Works Drawing B-166. . Before proceeding with design, contact the Contra Costa Mosquito and Vector Control District to coordinate the design and plan ongoing inspection and maintenance of the facility for mosquito control. For design considerations and details, see the *California Stormwater Best Management Practices Handbooks*, Fact Sheet TC-20, "Wet Ponds," and Fact Sheet TC-21, "Constructed Wetlands."

Higher-rate surface filters and vault-based filters. As described on page 16, these facilities may be used only in specific types of projects where other alternatives have proven infeasible. For surface filters, the grading and drainage design should minimize the area draining to each unit and maximize the number of discrete drainage areas and units. Proprietary facilities should be installed and maintained consistent with the manufacturer's instructions.

► TREATMENT AND FLOW CONTROL ALTERNATIVES

By using the CCCWP's design procedure, including LID IMPs, your project will meet requirements to minimize imperviousness, treat runoff, and control runoff peaks and durations. If the use of LID IMPs is not feasible, compliance with each of these requirements must be demonstrated individually. Separate facilities may be needed for treatment and for flow control.

If flow-control compliance is achieved by Options #1 or #4 in Appendix C, treatment compliance may be achieved by use of LID IMPs sized using treatment-only criteria.

Cistern with sand filter. Treatment and flow-control requirements can be met by using the cistern, including the volume calculated using Equation 4-5 and the discharge rate calculated using Equation 4-5 and Equation 4-17, 4-12, 4-10 or 4-11, and a sand filter sized to achieve a maximum surface loading rate of 5"/hour based on the calculated maximum discharge of the cistern orifice.*

* This option would not occur under the Program's current policy. All development projects subject to HMP requirements are also subject to LID requirements. It is retained here for information pending further Water Board action.

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Treatment-and-flow-control detention basin, wet pond, or wetland. A detention basin may be sized and configured to achieve treatment and flow control:

- The facility must contain a volume calculated using the "Unit Basin Storage Size for 80% capture" chart which has a drawdown time of 48 hours. To achieve maximum treatment effectiveness, this volume and discharge rate should be as close to the criteria as possible, neither oversized nor undersized.

- The facility must also match pre-project peak flows and durations as must be shown using the modeling procedure described under Option #3 in Appendix C.

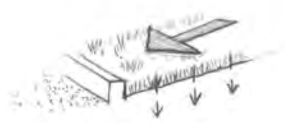
Applicants considering this option should consult with municipal staff and with the Contra Costa Mosquito and Vector Control District before proceeding with design.*

* This option would not occur under current policy. Detention basins and wetlands are suitable for drainage management areas larger than an acre; projects creating or replacing an acre or more of impervious area are always subject to LID requirements.

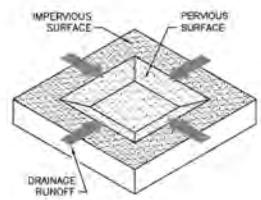
RB-AR32873

Self-Treating and Self-Retaining Areas

► CRITERIA



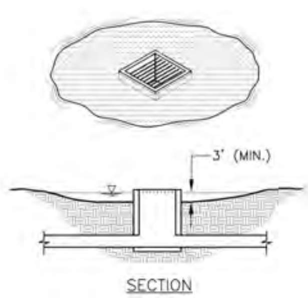
Rainfall on self-treating areas infiltrates or—during intense storms— drains directly off-site or to the storm drain system.



Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. During intense storms, runoff may drain off-site, to the storm drain system, or to IMPs.

LID design seeks to manage runoff from roofs and paving so effects on water quality and hydrology are minimized. Runoff from landscaping, however, does not need to be managed the same way. Runoff from landscaping can be managed by creating self-treating and self-retaining areas.

Self-treating areas are natural, landscaped, or turf areas that drain directly off site or to the storm drain system. Examples include upslope undeveloped areas from which runoff is piped or ditched and drained around a development and grassed slopes that drain offsite to a street or storm drain. Self-treating areas may not drain on to adjacent paved areas within the project.



Set overflows and area drain inlets (if any) high enough to ensure ponding (3" deep) over the surface of the self-retaining area.

Where a landscaped area is upslope from or surrounded by paved areas, a self-retaining area (also called a zero-discharge area) may be created. Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. The technique works best on flat, heavily landscaped sites. It may be used on mild slopes if there is a reasonable expectation that the first inch of rainfall would produce no runoff.

Best Uses

- Sites with extensive landscaping

Advantages

- No maintenance verification requirement
- Complements site landscaping

Limitations

- Requires substantial square footage
- Grading requirements must be coordinated with landscape design

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Areas draining to self retaining areas. Drainage from roofs and paving can be directed to self-retaining areas and allowed to infiltrate into the soil. The maximum ratios are:

Site requirement	Maximum allowable ratio
Treatment only	2 parts impervious: 1 pervious
Treatment and flow-control	1 part impervious: 1 pervious

The self-retaining area must be bermed or depressed to retain an inch of rainfall including the flow from the tributary impervious area.

► DETAILS

Drainage from self-treating areas must flow to off-site streets or storm drains without flowing on to paved areas within the project.

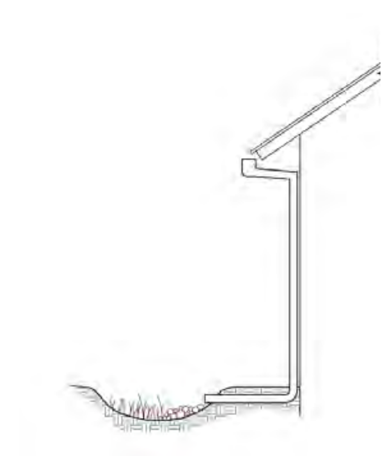
To create self-retaining turf and landscape areas in flat areas or on terraced slopes, berm the area or depress the grade into a concave cross-section so that these areas will retain the first inch of rainfall. Inlets of area drains, if any, should be set 3 inches above the low point to allow ponding.

Pavement within a self-treating area cannot exceed 5% of the total area.

In self-retaining areas, overflows and area drain inlets should be set high enough to ensure ponding over the entire surface of the self-retaining area.

Self-retaining areas should be designed to promote even distribution of ponded runoff over the area.

Leave enough reveal (elevation difference) to accommodate buildup of turf or mulch.



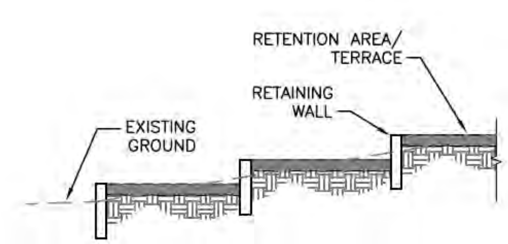
Connecting a roof leader to a self-retaining area. The head from the eave height makes it possible to route roof drainage some distance away from the building.

► APPLICATIONS

Lawn or landscaped areas adjacent to streets can be considered self-treating areas.

Self-retaining areas can be created by depressing lawn and landscape below surrounding sidewalks and plazas.

Runoff from walkways or driveways in parks and park-like areas can sheet-flow to self-retaining areas.



Mild slopes can be terraced to create self-retaining areas.

Roof leaders can be connected to self-retaining areas by piping beneath plazas and walkways. If necessary, a "bubble-up" can be used.

Self-retaining areas can be created by terracing mild slopes. The elevation difference promotes subsurface drainage.

► DESIGN CHECKLIST FOR SELF-TREATING AREAS

- ❒ The self-treating area is at least 95% lawn or landscaping (not more than 5% impervious).
- ❒ Re-graded or re-landscaped areas have amended soils, vegetation, and irrigation as may be required to maintain soil stability and permeability.
- ❒ Runoff from the self-treating area does not enter an IMP or another drainage management area, but goes directly offsite or to the storm drain system.

► DESIGN CHECKLIST FOR SELF-RETAINING AREAS

- ❒ Area is bermed all the way around or graded concave.
- ❒ Slopes do not exceed 4%.
- ❒ Entire area is lawn, landscaping, or pervious pavement (see criteria in Chapter 4).
- ❒ Area has amended soils, vegetation, and irrigation as may be required to maintain soil stability and permeability.
- ❒ Any area drain inlets are at least 3 inches above surrounding grade.

► DESIGN CHECKLIST FOR AREAS DRAINING TO SELF-RETAINING AREAS

- ❒ Ratio of tributary impervious area to self-retaining area is not greater than 2:1 (1:1 if flow-control requirements apply).
- ❒ Roof leaders collect runoff and route it to the self-retaining area.
- ❒ Paved areas are sloped so drainage is routed to the self-retaining area.
- ❒ Inlets are designed to protect against erosion and distribute runoff across the area.

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Pervious Pavements

► CRITERIA

Impervious roadways, driveways, and parking lots account for much of the hydrologic impact of land development. In contrast, pervious pavements allow rainfall to collect in a gravel or sand base course and infiltrate into native soil.

Pervious pavements are designed to transmit rainfall through the surface to storage in a base course. For example, a 4-inch-deep base course provides approximately 1.6 inches of storage. Runoff stored in the base course infiltrates to native soils over time. Except in the case of solid pavers, the surface course provides additional storage.

When configured to drain directly off-site, areas with the following pervious pavements may be regarded as "self-treating" and require no additional treatment or flow control.

- Pervious concrete
- Porous asphalt
- Porous pavers
- Crushed aggregate (gravel)
- Open pavers with grass or plantings
- Open pavers with gravel
- Artificial turf

Areas with pervious pavements can be self-retaining areas receiving runoff from impervious areas if they are bermed or

Best Uses

- Flat areas
- Areas with permeable native soils
- Low-traffic areas
- Where aesthetic quality can justify higher cost

Advantages

- No maintenance verification requirement
- Variety of surface treatments can complement landscape design

Limitations

- Initial cost
- Placement requires specially trained crews
- Geotechnical concerns, especially in clay soils
- Concerns about pavement strength and surface integrity

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depressed to retain the first one inch of rainfall, including runoff from any tributary impervious areas.

Solid unit pavers—such as bricks, stone blocks, or precast concrete shapes—are considered to reduce runoff compared to impervious pavement, when the unit pavers are set in sand or gravel with $\frac{3}{8}$" gaps between the pavers. Joints must be filled with an open-graded aggregate free of fines.

Use the runoff factors in Table 4-2.

► DETAILS

Permeable pavements can be used in clay soils; however, special design considerations, including an increased depth of base course, typically apply and will increase the cost of this option. Geotechnical fabric between the base course and underlying clay soil is recommended.

Permeable pavements are best used on grades from flat to approximately 2%. Installations on steeper grades, particularly on clay soils, require cut-off trenches lateral to the slope to intercept, store, and infiltrate drainage from the base course.

Pavement strength and durability typically determines the required depth of base course. If underdrains are used, the outlet elevation must be a minimum of 3 inches above the bottom elevation of the base course.

Pervious concrete and porous asphalt must be installed by crews with special training and tools. Industry associations maintain lists of qualified contractors.

Parking lots with crushed aggregate or unit pavers may require signs or bollards to organize parking.

▶ DESIGN CHECKLIST FOR PERVIOUS PAVEMENTS

- ❒ No erodible areas drain on to pavement.
- ❒ Subgrade is uniform. Compaction is minimal.
- ❒ Reservoir base course is of open-graded crushed stone. Base depth is adequate to retain rainfall and support design loads.
- ❒ If a subdrain is provided, outlet elevation is a minimum of 3 inches above bottom of base course.
- ❒ Subgrade is uniform and slopes are not so steep that subgrade is prone to erosion.
- ❒ Rigid edge is provided to retain granular pavements and unit pavers.
- ❒ Solid unit pavers are set in sand or gravel with minimum $\frac{3}{8}$" gaps between the pavers. Joints are filled with an open-graded aggregate free of fines.
- ❒ Permeable pavements are installed by industry-certified professionals according to vendor's recommendations.
- ❒ Selection and location of pavements incorporates Americans with Disabilities Act requirements, site aesthetics, and uses.

▶ RESOURCES

Concrete Promotion Council of Northern California www.concreteresources.net.

California Asphalt Pavement Association
http://www.californiapavements.org/stormwater.html

Interlocking Concrete Pavement Institute
http://www.icpi.org/

Start at the Source Design Manual for Water Quality Protection, pp. 47-53.

Porous Pavements, by Bruce K. Ferguson. 2005. ISBN 0-8493-2670-2.

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Bioretention Facilities

Bioretention facilities can rectangular, linear, or nearly any shape.
Photo by Scott Wikstrom

Bioretention detains runoff in a surface reservoir, filters it through plant roots and a biologically active soil mix, and then infiltrates it into the ground. Where native soils are less permeable, an underdrain conveys treated runoff that does not infiltrate to a storm drain or to surface drainage.

Bioretention facilities can be configured as in-ground or above-ground planter boxes, with the bottom open to allow infiltration to native soils underneath. *If infiltration cannot be allowed, use the sizing factors and criteria for the Flow-Through Planter.*

▶ CRITERIA

For development projects subject only to runoff treatment requirements, the following criteria apply:

Parameter	Criterion
Soil mix depth	18 inches minimum
Soil mix requirements	See Appendix B
Soil mix surface area	0.04 times tributary impervious area (or equivalent)
Surface reservoir depth	6 inches minimum; may be sloped to 4 inches where adjoining walkways.
Underdrain	Required in Group "C" and "D" soils. Perforated pipe (PVC SDR 35 or approved equivalent) embedded in gravel ("Class 2 permeable" recommended), connected to storm drain or other accepted discharge point.

Best Uses

- Commercial areas
- Residential subdivisions
- Industrial developments
- Roadways
- Parking lots
- Fit in setbacks, medians, and other landscaped areas

Advantages

- Can be any shape
- Low maintenance
- Can be landscaped

Limitations

- Require 4%-15% of tributary impervious square footage
- Require 3-4 feet of head
- Irrigation may be required

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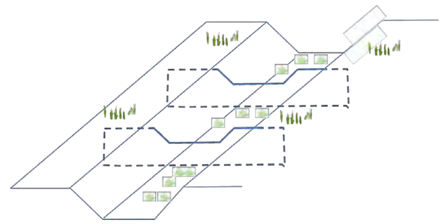
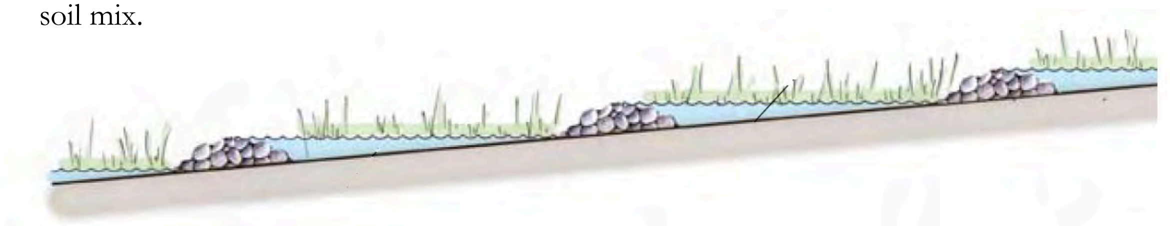
Where flow-control requirements also apply, the bioretention facility mutt be designed to meet the minimum surface area (A), surface volume (V_1), and subsurface volume (V_2) using the sizing factors and equations in Tables 4-8 and 4-9.



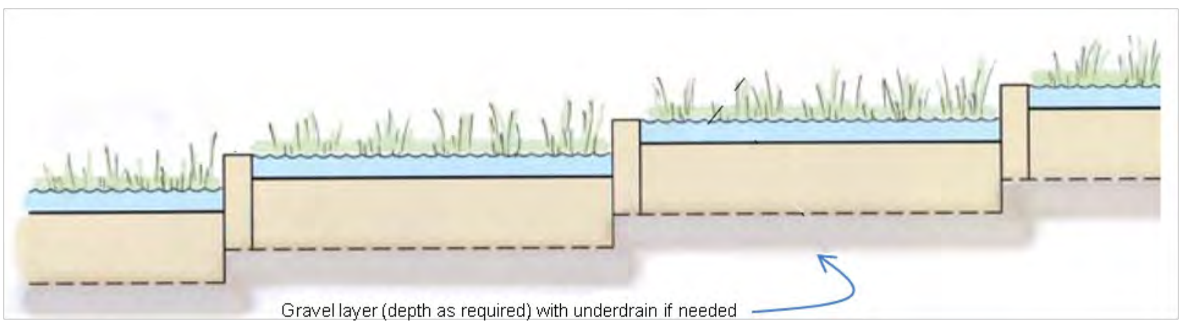
Key check dams into bottom and side slopes.

▶ DETAILS

Plan and Profile. On the surface, a bioretention facility should be one level, shallow basin—or a series of basins. As runoff enters each basin, it should flood and fill throughout before runoff overflows to the outlet or to the next downstream basin. This will help prevent movement of surface mulch and soil mix.

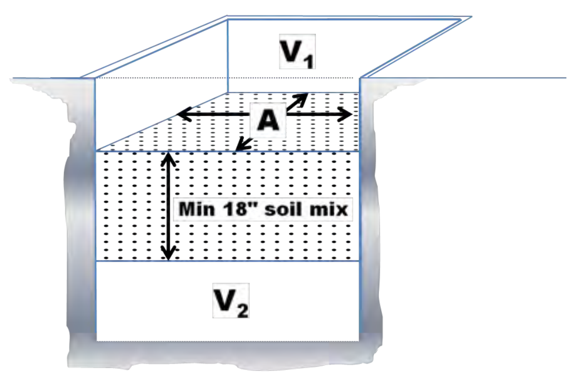


Swale with check dams. Provides limited storage; not suitable for slopes 6% and greater.



Planter on slope provides more storage. Check dams should be keyed into planter sides. (USEPA 2009b)

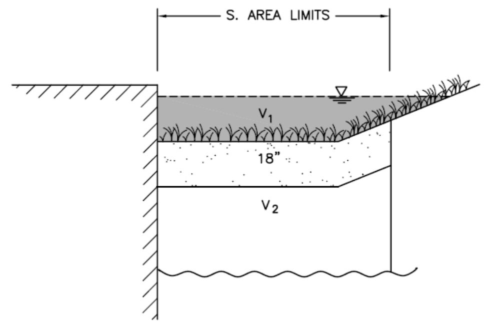
In a linear swale, check dams should be placed for every 4 to 6 inches of elevation change and so that the lip of each dam is at least as high as the toe of the next upstream dam. A similar principle applies to bioretention facilities built as terraced roadway shoulders.



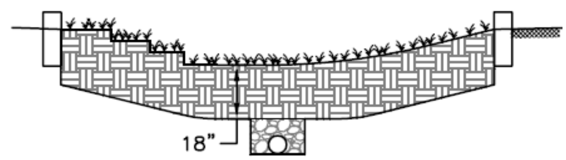
(a) A, V_1 and V_2

Minimum Surface Volume. For a treatment-and-flow-control facility, the sizing factor V_1 is equivalent to the sizing factor A flooded to a 12" depth (10" overflow plus 2" freeboard). Surrounding the facility with a 12" vertical wall minimizes the required surface area as shown in (a). However, alternatives include:

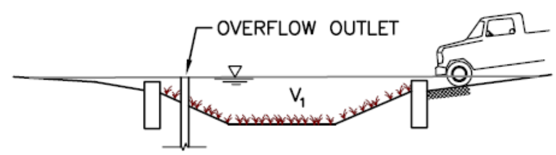
- Increasing the facility area and reducing the surface depth accordingly.
- Sloping the soil mix surface to be deeper than 12" at the middle, but less deep at the edges, so the average 12" depth is achieved (works best on larger facilities).
- Sloping or stepping back the wall as shown in (b) and (c) (requires additional area).
- Allowing shallow flooding on a portion of adjacent landscape or paving when the facility is at peak capacity as shown in (d) (rare and relatively brief events).



(b) Sloped side wall



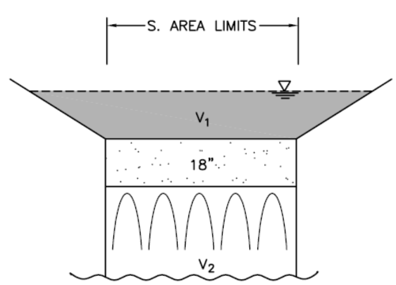
(c) Stepped back side wall



(d) allowing occasional flooding of adjacent landscaping and pavement.

Soil mix. The required soil mix is similar to a loamy sand. It must maintain a minimum percolation rate of 5" per hour throughout the life of the facility, and it must be suitable for maintaining plant life with a minimum of fertilizer use. Typically, on-site soils will not be suitable due to clay content. See Appendix B and check with local staff for further guidance.

Storage and drainage layer. "Class 2 permeable," Caltrans specification 68-1.025, is preferred. Open-graded crushed rock, washed, may be used, but requires 4"-6" washed pea gravel be substituted at the top of the crushed rock gravel layers. Do not use filter fabric to separate the soil mix from the gravel drainage layer or the gravel drainage layer from the native soil.

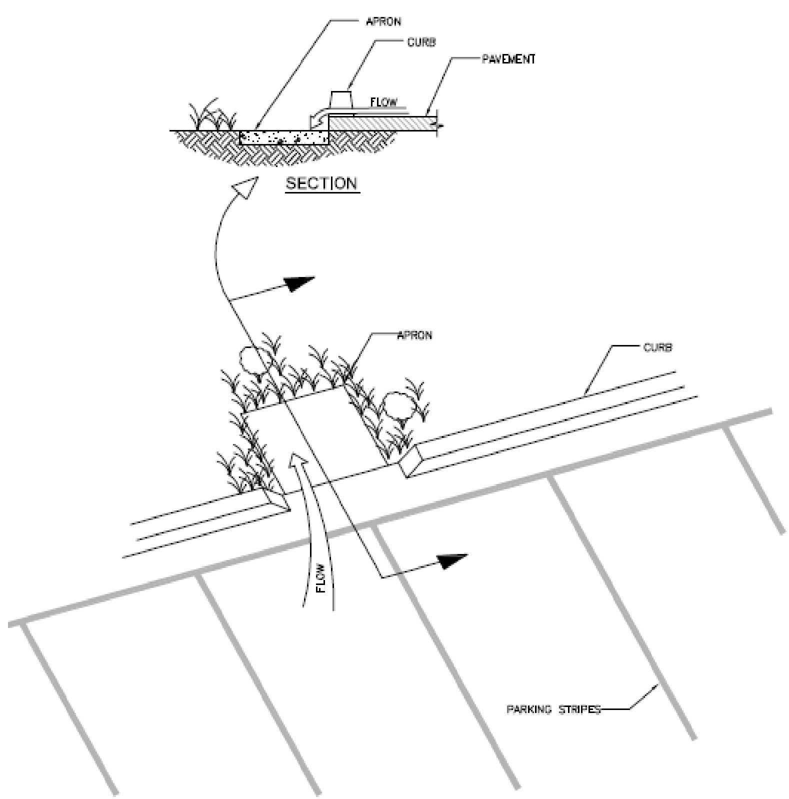


Buried pipes or arches may be used to achieve the required subsurface volume V_2

Minimum subsurface volume. No minimum subsurface volume is required for treatment-only facilities. The gravel layer must be extensive enough and deep enough to ensure the soil mix is well-drained. For treatment-a nd-flow-control facilities where the native soils are Hydrologic Soil Group C or D, the minimum subsurface volume V_2 specified in Table 4-8 is equivalent to the minimum area times a 30" deep layer of gravel of 40% porosity (V_2 is the void space, not the entire volume of gravel.) Note that if the facility area is increased, the required depth is correspondingly decreased. If desired, voids created by buried structures such as pipes or arches may be substituted, as long as the voids are hydraulically interconnected and the minimum subsurface volume calculated by Equation 4-5 is achieved.

Inlets. Paved areas draining to the facility should be graded, and inlets should be placed, so that runoff remains as sheet flow or as dispersed as possible. Curb cuts should be wide (12" is recommended) to avoid clogging with leaves or debris. Allow for a minimum reveal of 4"-6" between the inlet and soil mix elevations to ensure turf or mulch buildup does not block the inlet. In addition, place an apron of stone or concrete, a foot square or larger, inside each inlet to prevent vegetation from growing up and blocking the inlet.

Where runoff is collected in pipes or gutters and conveyed to the facility, protect the landscaping from high-velocity flows with energy-dissipating rocks. In larger installations, provide cobble-lined channels to better distribute flows throughout the facility.



Recommended design details for bioretention facility inlets (see text).

"Bubble ups" can be used to dissipate energy when runoff is piped from roofs and upgradient paved areas.

Underdrains. In locations where native soils beneath the facility are Hydrologic Soil Group A or B, underdrains are optional but municipal reviewers may require them as a preventative against poor drainage. For treatment-only facilities where native soils are Group C or D, a perforated pipe must be bedded in the gravel layer and must terminate at a storm drain or other approved discharge point. Underdrains must be constructed of rigid pipe and provided with a cleanout.

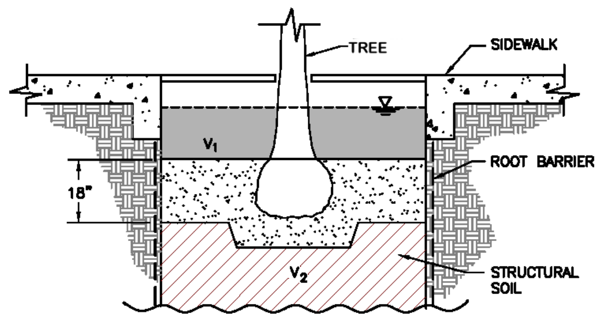
Flow-control orifice. For treatment-and-flow-control facilities, the underdrain must be routed through a device designed to limit flows to that specified in Equation 4-10 or 4-11. Details of combined outlet-and-underdrain facilities are shown on page 76.

Overflow outlets. In treatment-only facilities, overflow outlets must be set high enough to ensure the surface reservoir fills and the entire surface area of soil mix is flooded before the outlet elevation is reached. In swales, this can be achieved with appropriately placed check dams.

In treatment-and-flow-control facilities, the outlet elevation must be set to achieve the minimum surface storage volume calculated using Equation 4-5 and the V_1 sizing factor.

The outlet should be designed to exclude floating mulch and debris.

Vaults, utility boxes and light standards. It is best to locate utilities outside the bioretention facility—in adjacent walkways or in a separate area set aside for this purpose. If utility structures are to be placed within the facility, the locations should be anticipated and adjustments made to ensure the minimum bioretention surface area and volumes are achieved. Leaving the final locations to each individual utility can produce a haphazard, unaesthetic appearance and make the bioretention facility more difficult to maintain.

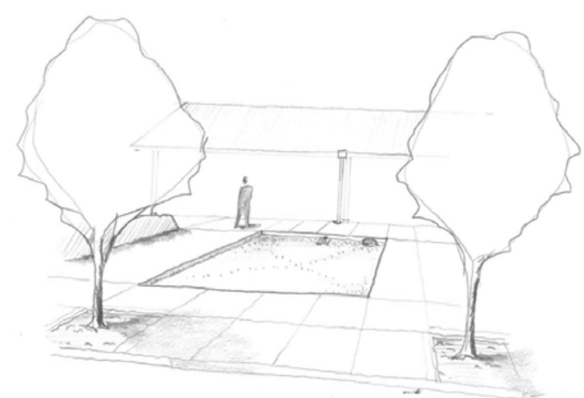


Bioretention facility configured as a tree well.
The root barrier is optional.

Emergency overflow. The site grading plan should anticipate extreme events and potential clogging of the overflow and route emergency overflows safely.

Trees. Bioretention areas can accommodate small or large trees within the minimum areas and volumes calculated by Equation 4-5. Tree canopies intercept rain, and extensive tree roots maintain soil permeability and help retain runoff. Normal maintenance of a bioretention facility should not affect tree lifespan.

The bioretention facility can be integrated with a tree pit of the required depth and filled with structural soil. If a root barrier is used, it can be located to allow tree roots to spread throughout the bioretention facility while protecting adjacent pavement. Locations and planting elevations should be selected to avoid blocking the facility's inlets and outlets as trees mature.



Bioretention facility configured as a recessed decorative lawn with hardscaped edge.

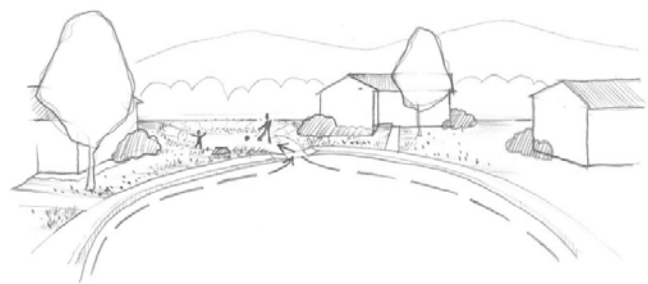
► APPLICATIONS

Multi-purpose landscaped areas. Bioretention facilities are easily adapted to serve multiple purposes. The loamy sand soil mix will support turf or a plant palette suitable to the location and a well-drained soil. See Appendix B for additional guidance on soil, plant selection, and irrigation.

Example landscape treatments:

- Lawn with sloped transition to adjacent landscaping.
- Swale in setback area
- Swale in parking median
- Lawn with hardscaped edge treatment
- Decorative garden with formal or informal plantings
- Traffic island with low-maintenance landscaping
- Raised planter with seating
- Bioretention on a terraced slope

Residential subdivisions. In the design of many subdivisions, it has proven easiest and most effective to drain roofs and driveways to the streets (in the conventional manner) and then drain the streets to bioretention areas, with one bioretention area for each 1 to 6 lots, depending on subdivision layout and topography.



Bioretention facility configured and planted as a lawn/ play area.

Bioretention areas can be placed on one or more separate, dedicated parcels with joint ownership.

Sloped sites. Bioretention facilities must be constructed as a basin or series of basins, with the circumference of each basin level. It may be necessary to add curbs or low retaining walls during final grading if elevations have not been determined with sufficient precision during design.

Design Checklist for Bioretention

- ❒ Volume or depth of surface reservoir meets or exceeds minimum.
- ❒ 18" depth "loamy sand" soil mix with minimum long-term percolation rate of 5"/hour. See Appendix B.
- ❒ Area of soil mix meets or exceeds minimum.
- ❒ Perforated pipe (PVC SDR 35 or approved equivalent) underdrain bedded in "Class 2 perm" with holes facing downward. Connection and sufficient head to storm drain or approved discharge point (except in "A" or "B" soils).
- ❒ No filter fabric.
- ❒ Underdrain has a clean-out port consisting of a vertical, rigid, non-perforated PVC pipe, with a minimum diameter of 4 inches and a watertight cap.
- ❒ Location and footprint of facility are shown on site plan, landscaping plan, and grading plan.
- ❒ Bioretention area is designed as a basin (level edges) or a series of basins, and grading plan is consistent with these elevations. If facility is designed as a swale, check dams are set so the lip or weir of each dam is at least as high as the toe of the next upstream dam.
- ❒ Curb inlets are 12" wide, have 4"-6" reveal and an apron or other provision to prevent blockage when vegetation grows in, and energy dissipation as needed.
- ❒ Overflow connected to a downstream storm drain or approved discharge point.
- ❒ Emergency spillage will be safely conveyed overland.
- ❒ Plantings are suitable to the climate, exposure, and a well-drained soil, and occasional inundation during large storm events.
- ❒ Irrigation system with connection to water supply, on a separate zone.
- ❒ Vaults, utility boxes, and light standards are located outside the minimum soil mix surface area.
- ❒ When excavating, avoid smearing of the soils on bottom and side slopes. Minimize compaction of native soils and "rip" soils if clayey and/or compacted. Protect the area from construction site runoff.

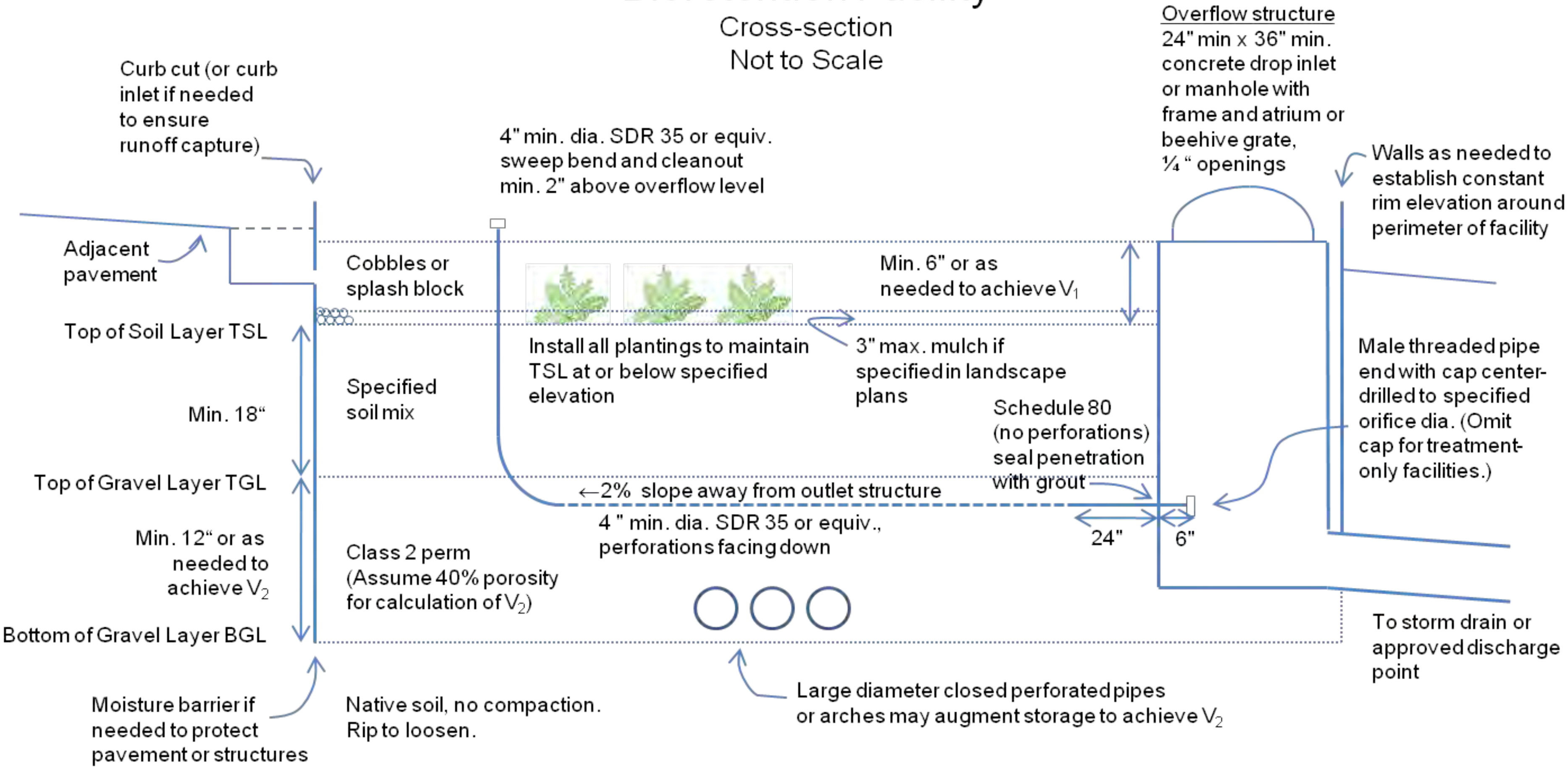
For treatment-and-flow-control facilities only

- ❒ Volume of subsurface storage meets or exceeds minimum.
- ❒ In "C" and "D" native soils, underdrain is connected to discharge through an appropriately sized orifice or other flow-limiting device.

RB-AR32888

Bioretention Facility

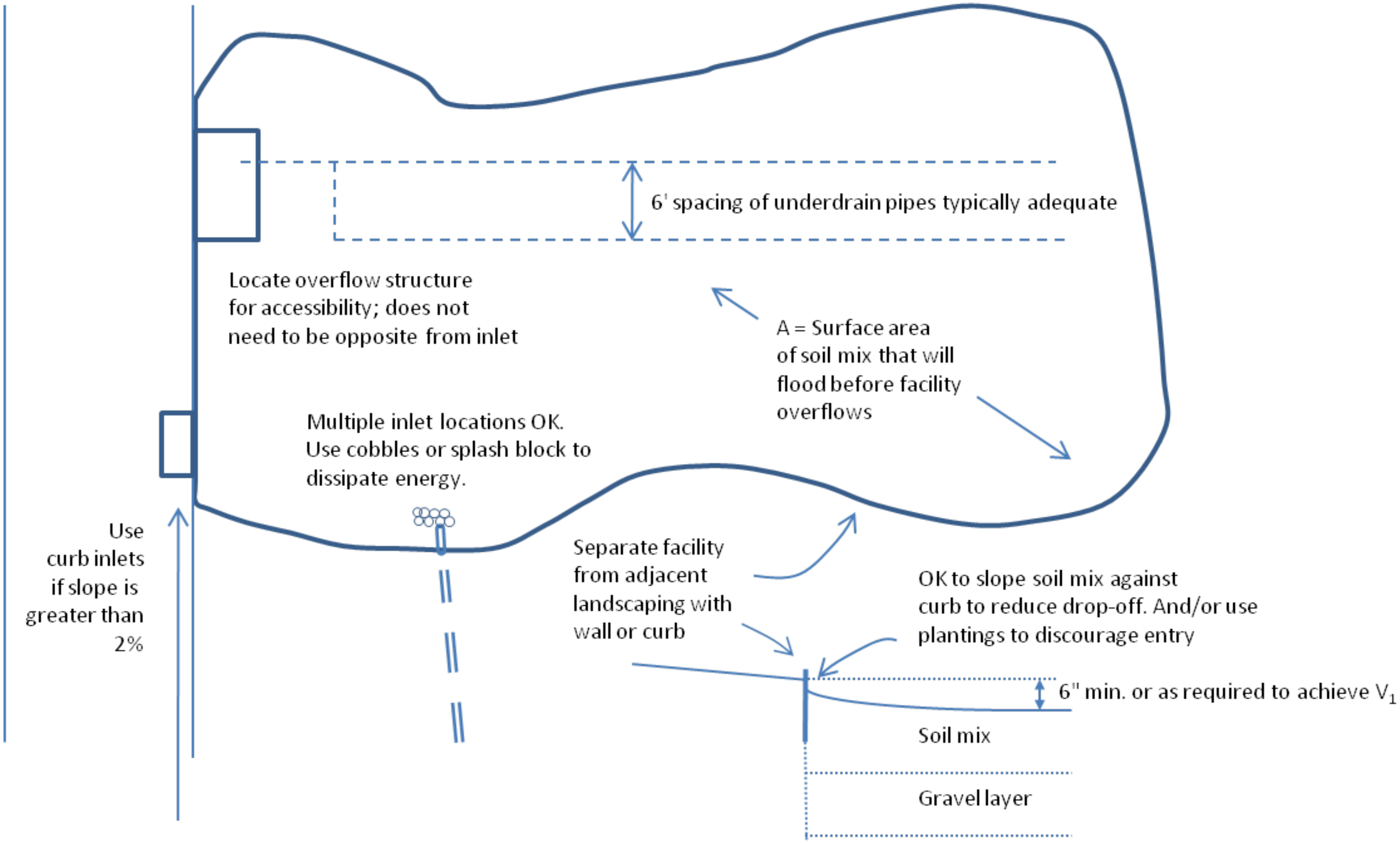
Cross-section
Not to Scale



Notes:
- No liner, no filter fabric, no landscape cloth.
- Maintain BGL. TGL, TSL throughout facility area at elevations to be specified in plan.
- Class 2 perm layer may extend below and underneath drop inlet.
- Preferred elevation of perforated pipe underdrain is near top of gravel layer.
- See Appendix B for soil mix specification, planting and irrigation guidance.
- See Chapter 4 for factors and equations used to calculate V_1, V_2 and orifice diameter.

Bioretention Facility

Plan (Not to Scale)



Note: Call out elevations of curb, pavement, inlet, top of soil layer (TSL), bottom of soil layer (BSL), and bottom of gravel layer (BGL) at all inlets and outlets and at key points along edge of facility.

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Flow-through Planter


Planter prior to planting

Flow-through planters treat and detain runoff without allowing seepage into the underlying soil. They can be used next to buildings and on slopes where stability might be affected by adding soil moisture.

Flow-through planters typically receive runoff via downspouts leading from the roofs of adjacent buildings. However, they can also be set in-ground or fit into terraces and receive sheet flow from adjacent paved areas.

Flow-through planters may be used where facilities are located on upper-story plazas, adjacent to building foundations, where seasonal high groundwater would be within 10 feet of the facility, where mobilization of pollutants in soil or groundwater is a concern, and where potential geotechnical hazards are associated with infiltration.

5th Edition

The restriction on where flow-through planters may be used applies to sites subject to treatment-only requirements as well as those subject to treatment-plus-flow-control requirements.

Pollutants are removed as runoff passes through the soil layer and is collected in an underlying layer of gravel or drain rock. A perforated-pipe underdrain must be connected to a storm drain or other discharge point. An overflow outlet conveys flows which exceed the capacity of the planter.

► CRITERIA

Treatment only. For development projects subject only to runoff treatment requirements, the following criteria apply:

Best Uses

- Management of roof runoff
- Next to buildings or on building plazas
- Dense urban areas
- Where infiltration is not desired

Advantages

- Can be used on or next to structures and on slopes
- Versatile
- Can be any shape
- Low maintenance

Limitations

- Can be used only on sites with "C" and "D" soils
- Requires underdrain
- Requires 3-4 feet of head

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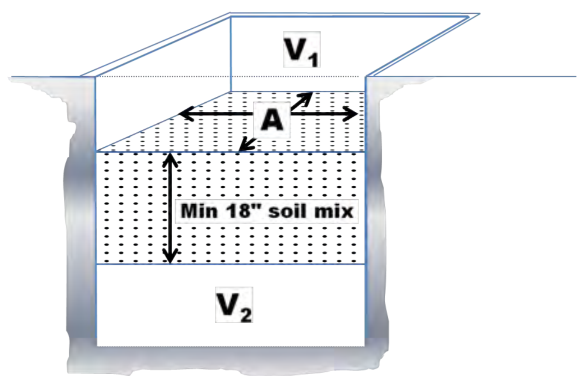
Parameter	**Criterion**
Soil mix depth	18 inches minimum
Soil mix	See Appendix B
Soil mix surface area	0.04 times tributary impervious area (or equivalent)
Surface reservoir depth	6" minimum; may be sloped to 4" where adjoining walkways.
Underdrain	Required. Perforated pipe (PVC SDR 35 or approved equivalent) embedded in gravel ("Class 2 permeable" recommended), connected to storm drain or other accepted discharge point.

Treatment and flow control. In addition to the treatment requirements above, the flow-through planter must be designed to meet the minimum surface area (A), surface volume (V_1), and subsurface volume (V_2) calculated using the sizing factors and Equation 4-5. In addition, the planter underdrain must be equipped with an orifice or other device to limit flow to that calculated by Equation 4-10 or 4-11. A suggested outlet design is on page 83.

► DETAILS

Configuration. In a vertical-sided box-like planter for treatment-and-flow-control with the minimum surface area A, the minimum surface volume V_1 can be achieved with an overflow height of 10" (12" total height of walls with 2" of freeboard). The minimum subsurface volume V_2 can be achieved with a gravel (Class 2 permeable) depth of 30". This combination results in a planter approximately 5' high. The planter height can be reduced by incorporating void-creating structures into a shallower Class 2 permeable layer or by increasing the planter area so that the minimum V_2 is achieved.



Parameters for flow-through planters for treatment and flow-control: A, V1, and V2.

The planter must be level. To avoid standing water in the subsurface layer, set the perforated pipe underdrain and orifice as nearly flush with the planter bottom as possible.

Inlets. Protect plantings from high-velocity flows by adding rocks or other energy-dissipating structures at downspouts and other inlets.

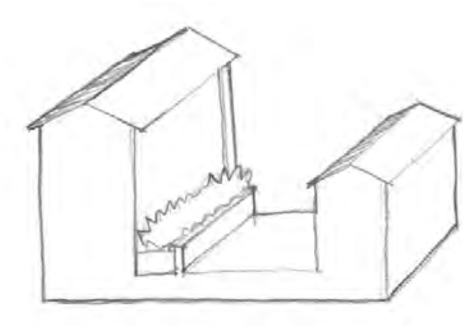
Soil mix. The required soil mix is similar to a loamy sand. It must maintain a minimum percolation rate of 5" per hour throughout the life of the facility, and it must be suitable for maintaining plant life. Typically, on-site soils will not be suitable due to clay content. Various local suppliers have identified mixes which meet these criteria. Check with local staff regarding acceptable soil mixes. See Appendix B for further guidance.

Gravel storage and drainage layer. "Class 2 permeable," Caltrans specification 68-1.025, is recommended. Open-graded crushed rock, washed, may be used, but requires 4"-6" of washed pea gravel be substituted at the top of the crushed rock layer. Do not use filter fabric to separate the soil mix from the gravel drainage layer.

Emergency overflow. The planter design and installation should anticipate extreme events and potential clogging of the overflow and route emergency overflows safely.

► APPLICATIONS

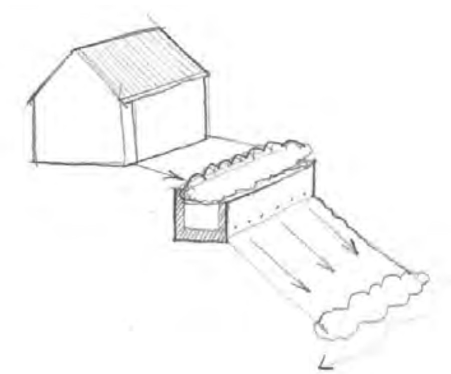
Adjacent to buildings. Flow-through planters may be located adjacent to buildings, where the planter vegetation can soften the visual effect of the building wall. A setback with a raised planter box may be appropriate even in some neo-traditional pedestrian-oriented urban streetscapes.



Flow-through planter on the plaza level of a podium-style development.

At plaza level. Flow-through planters have been successfully incorporated into podium-style developments, with the planters placed on the plaza level and receiving runoff from the tower roofs above. Runoff from the plaza level is typically managed separately by additional flow-through planters or bioretention facilities located at street level.

Steep slopes. Flow-through planters provide a means to detain and treat runoff on slopes that cannot accept infiltration from a bioretention facility. The planter can be built into the slope similar to a retaining wall. The design should consider the need to access the planter for periodic maintenance. Flows from the planter underdrain and overflow must be directed in accordance with local requirements. It is sometimes possible to disperse these flows to the downgradient hillside.



Flow-through planter built into a hillside. Flows from the underdrain and overflow must be directed in accordance with local requirements.

Design Checklist for Flow-through Planter

- ❐ Location is on an upper-story plaza, adjacent to a building foundation, where seasonal high groundwater would be within 10 feet of the facility, where mobilization of pollutants in soil or groundwater is a concern, or where potential geotechnical hazards are associated with infiltration
- ❐ Reservoir depth is 4"-6" minimum.
- ❐ 18" depth "loamy sand" soil mix with minimum long-term infiltration rate of 5"/hour.
- ❐ Surface area of soil mix meets or exceeds minimum.
- ❐ "Class 2 perm" drainage layer.
- ❐ No filter fabric.
- ❐ Perforated pipe (PVC SDR 35 or approved equivalent) underdrain with outlet located flush or nearly flush with planter bottom.
- ❐ Connection with sufficient head to storm drain or discharge point.
- ❐ Underdrain has a clean-out port consisting of a vertical, rigid, non-perforated PVC pipe, with a minimum diameter of 4" and a watertight cap.
- ❐ Overflow outlet connected to a downstream storm drain or approved discharge point.
- ❐ Location and footprint of facility are shown on site plan and landscaping plan.
- ❐ Planter is set level.
- ❐ Emergency spillage will be safely conveyed overland.
- ❐ Plantings are suitable to the climate, exposure, and a well-drained soil.
- ❐ Irrigation system with connection to water supply, on a separate zone.

For treatment-and-flow-control flow-through planters only

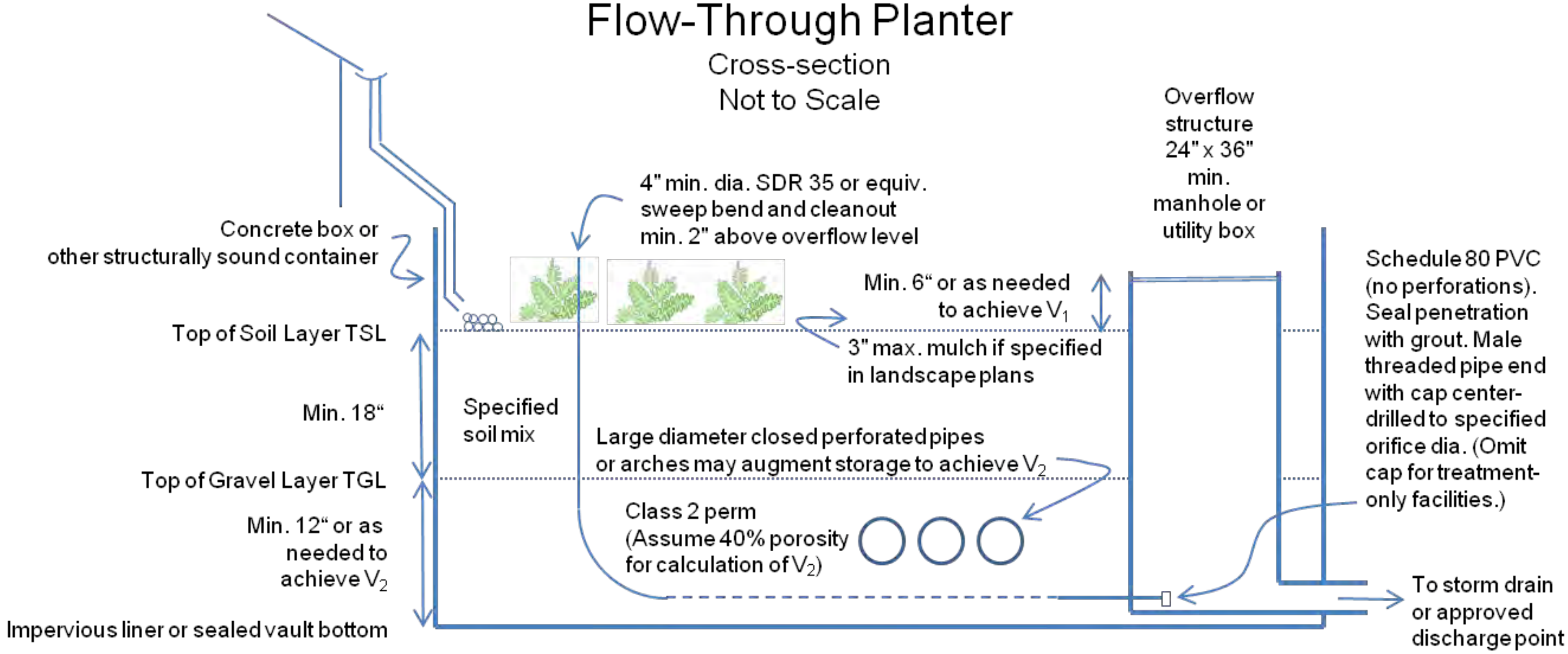
- ❐ Volume of surface storage meets or exceeds minimum.
- ❐ Volume of subsurface storage meets or exceeds minimum.
- ❐ Underdrain is connected via an appropriately sized orifice or other flow-limiting device.

RB-AR32895

Flow-Through Planter

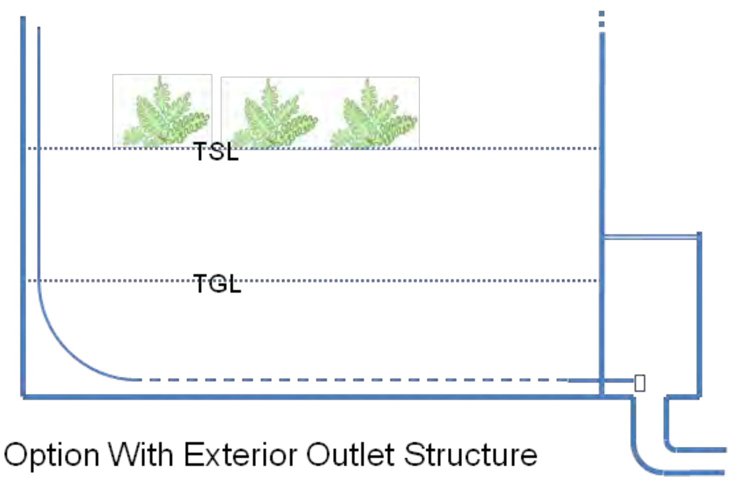
Cross-section

Not to Scale

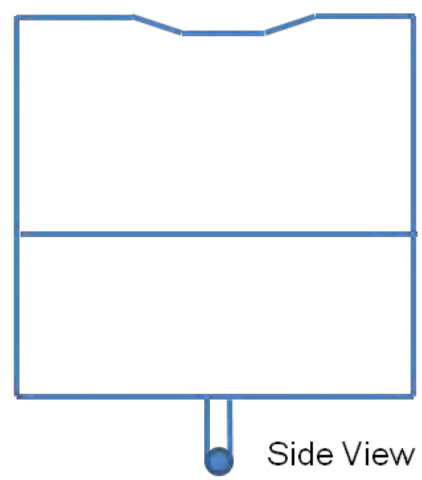


Notes:

- Underdrain to be min. 4" PVC SDR 35 or equiv. with holes facing down.
- Locate underdrain as close as possible to bottom.
- No filter fabric, no landscape cloth.
- See Appendix B for soil specification and planting guidance.
- See Chapter 4 for factors and equations used to calculate V_1, V_2 and orifice diameter



Option With Exterior Outlet Structure suitable for smaller planters



Side View

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Dry Wells and Infiltration Basins

The typical dry well is a prefabricated structure, such as an open-bottomed vault or box, placed in an excavation or boring. The vault may be empty, which provides maximum space efficiency, or may be filled with rock.

An infiltration basin has the same functional components—a volume to store runoff and sufficient area to infiltrate that volume into the native soil—but is open rather than covered.

► CRITERIA

Dry wells and infiltration basins must be designed with the minimum volume and infiltrative area calculated by Equation 4-5 using the sizing factors in Table 4-8.

Consult with the local municipal engineer regarding the need to verify soil permeability and other site conditions are suitable for dry wells and infiltration basins. Some proposed criteria are on Page 5-12 of Caltrans' 2004 *BMP Retrofit Pilot Study Final Report* (CTSW-RT-01-050).

► DETAILS

Dry wells should be sited to facilitate maintenance and allow for the potential future need for removal and replacement.

In locations where native soils are coarser than a medium sand, the area directly beneath the facility should be over-excavated by two feet and backfilled with sand as a groundwater protection measure.

Best Uses

- Projects on sites with permeable soils

Advantages

- Compact footprint
- Can be installed in paved areas

Limitations

- Can be used only on sites with Group "A" or Group "B" soils
- Requires minimum of 10' from bottom of facility to seasonal high groundwater
- Not suitable for drainage from some industrial areas or arterial roads
- Must be maintained to prevent clogging.
- Typically not as aesthetically pleasing as bioretention facilities

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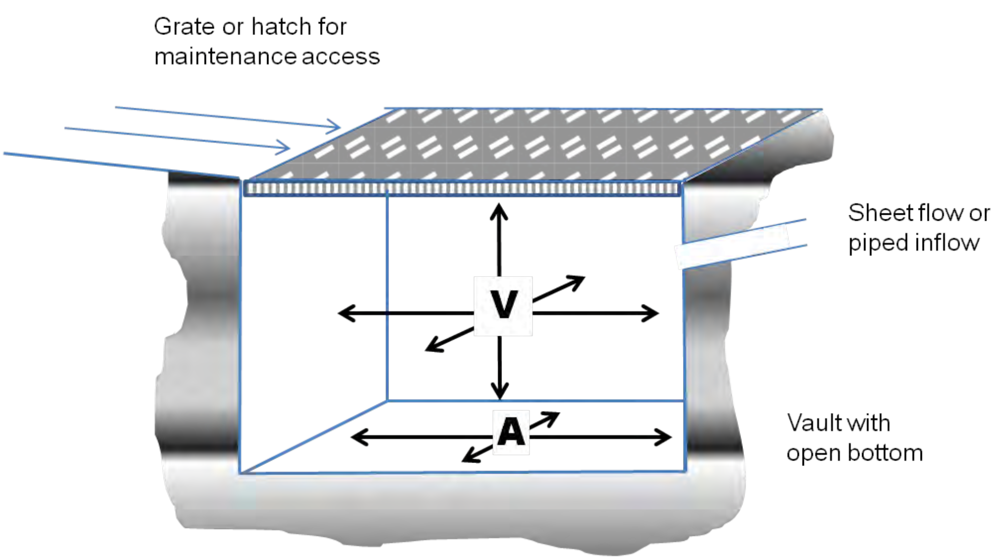
Design Checklist for Dry Wells and Infiltration Basins

- ❐ Volume (V) and infiltrative area (A) meet or exceed minimum.
- ❐ Overflow connected to a downstream storm drain or approved discharge point.
- ❐ Emergency spillage will be safely conveyed overland.
- ❐ Depth from bottom of the facility to seasonally high groundwater elevation is ≥10'.
- ❐ Areas tributary to the facility do not include automotive repair shops; areas subject to high vehicular traffic (25,000 or greater average daily traffic on main roadway or 15,000 or more average daily traffic on intersecting roadway), car washes; fleet storage areas (bus, truck, etc.); nurseries, or other uses that may present an exceptional threat to groundwater quality.
- ❐ Underlying soils are in Hydrologic Soil Group A or B. Infiltration rate is sufficient to ensure a full basin will drain completely within 72 hours. Soil infiltration rate has been confirmed.
- ❐ 10' setback from structures or as recommended by structural or geotechnical engineer



Cistern + Bioretention Facility

In this functional sculpture, a cistern captures roof runoff and drains it slowly to a landscaped area. Photo courtesy of the City of Seattle.

A cistern in series with a bioretention facility or flow-through planter can meet treatment and flow-control requirements where space is limited. The cistern includes an orifice for flow control. The downstream bioretention facility or flow-through planter is sized to accommodate the maximum flow from the cistern orifice.

► CRITERIA

Cistern. Size the cistern using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9. The cistern must also include an orifice or other device to limit outflow to the calculated maximum release rate.

Bioretention facility. Size the bioretention facility or flow-through planter using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9.

► DETAILS

Preventing mosquito harborage. Cisterns should be designed to drain completely, leaving no standing water. Drains should be located flush with the bottom of the cistern. Alternatively—or in addition—all entry and exit points should be provided with traps or sealed or screened to prevent mosquito entry. Note mosquitoes can enter through

Best Uses

- To meet flow-control requirements in limited space.
- Management of roof runoff
- Dense urban areas

Advantages

- Storage volume can be in any configuration
- Small footprint

Limitations

- Somewhat complex to design, build, and operate
- Requires head for both cistern and bioretention facility

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openings $\frac{1}{16}$" or larger and will fly for many feet through pipes as small as ¼".

Exclude debris. Provide leaf guards and/or screens to prevent debris from accumulating in the cistern.

Ensure access for maintenance. Design the cistern to allow for cleanout. Avoid creating the need for maintenance workers to enter a confined space. Ensure the outlet orifice can be easily accessed for cleaning and maintenance.

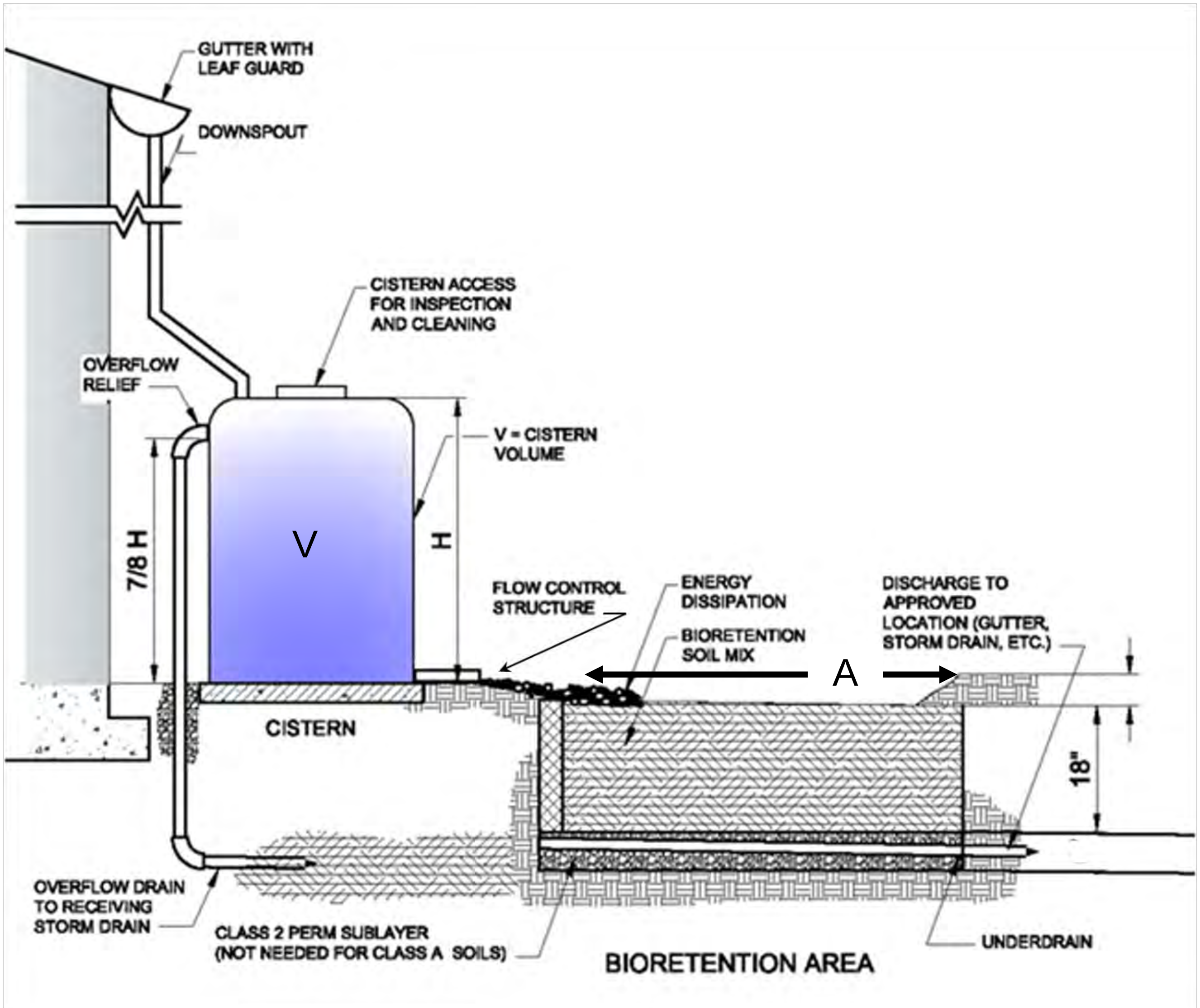
► APPLICATIONS

Shallow ponding on a flat roof. The "cistern" storage volume can be designed in any configuration, including simply storing rainfall on the roof where it falls and draining it away slowly. In sites with Group "D" soils, the required average depth amounts to about ¾".

Cistern attached to a building and draining to a planter. This arrangement allows the flow-through planter to be constructed at a height as low as 30".

Design Checklist for Cistern + Bioretention

- ❒ Cistern volume meets or exceeds calculated minimum V_1.
- ❒ Cistern outlet with orifice or other flow-control device restricts flow to calculated maximum. A center-drilled threaded cap is suggested for easy maintenance.
- ❒ Cistern outlet is piped to bioretention area or flow-through planter.
- ❒ Bioretention surface area meets or exceeds the calculated minimum.
- ❒ Except for surface area, bioretention facility is designed to the criteria for "treatment only" in the "Bioretention Facility" design sheet (p. 69) or "Flow-through Planter" design sheet (p. 79).
- ❒ Cistern is designed to drain completely and/or sealed to prevent mosquito harborage.
- ❒ Design provides for exclusion of debris and accessibility for maintenance.
- ❒ Overflow connected to a downstream storm drain or approved discharge point.
- ❒ Emergency spillage will be safely conveyed overland.


GUTTER WITH LEAF GUARD
DOWNSPOUT
CISTERN ACCESS FOR INSPECTION AND CLEANING
OVERFLOW RELIEF
V = CISTERN VOLUME
V
H
7/8 H
FLOW CONTROL STRUCTURE
ENERGY DISSIPATION
BIORETENTION SOIL MIX
DISCHARGE TO APPROVED LOCATION (GUTTER, STORM DRAIN, ETC.)
A
CISTERN
18"
OVERFLOW DRAIN TO RECEIVING STORM DRAIN
CLASS 2 PERM SUBLAYER (NOT NEEDED FOR CLASS A SOILS)
BIORETENTION AREA
UNDERDRAIN

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Bioretention + Vault

A bioretention facility in series with a vault can meet treatment and flow-control requirements where space is limited. In this configuration, the bioretention facility is sized to a minimum of 4% of the tributary impervious area. The underdrain and overflow from the bioretention facility are routed to a storage vault, which can be located beneath a plaza, sidewalk, or parking area. An orifice limits the rate of discharge from the vault to the storm drain system.

▶ CRITERIA

Bioretention facility. Size and design the bioretention facility to the treatment-only criteria (see Bioretention Facility design sheet, p. 69.)

Vault. Size the vault using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9. The vault must include an orifice or other device to limit outflow.

▶ DETAILS

Preventing mosquito harborage. Vaults should be designed to drain completely, leaving no standing water. Where possible, vaults should have an open bottom to allow infiltration into the native soil. If the vault is sealed, then drains should be located flush with the bottom of the vault. Alternatively—or in addition—all entry and exit points, should be provided with traps or sealed or screened to prevent mosquito entry. Note mosquitoes can enter through openings $\frac{1}{16}$" or larger and will fly for many feet through pipes as small as ¼".

Ensure access for maintenance. Design the vault to allow for cleanout. Avoid creating the need for maintenance workers to enter a confined space. Ensure the outlet orifice can be easily accessed for cleaning and maintenance.

▶ APPLICATIONS

Parking lot. Because the required landscaped bioretention facilities is only 4% of the tributary impervious area, the bioretention component can in many cases be integrated into parking lot medians and islands. The vault component can be located beneath aisles or driveways.

Best Uses

- To meet flow-control requirements in limited space
- Parking lots
- Dense urban areas

Advantages

- Smaller footprint than bioretention facility sized for flow control

Limitations

- Somewhat complex to design, build, and operate
- Requires head for both bioretention facility and vault

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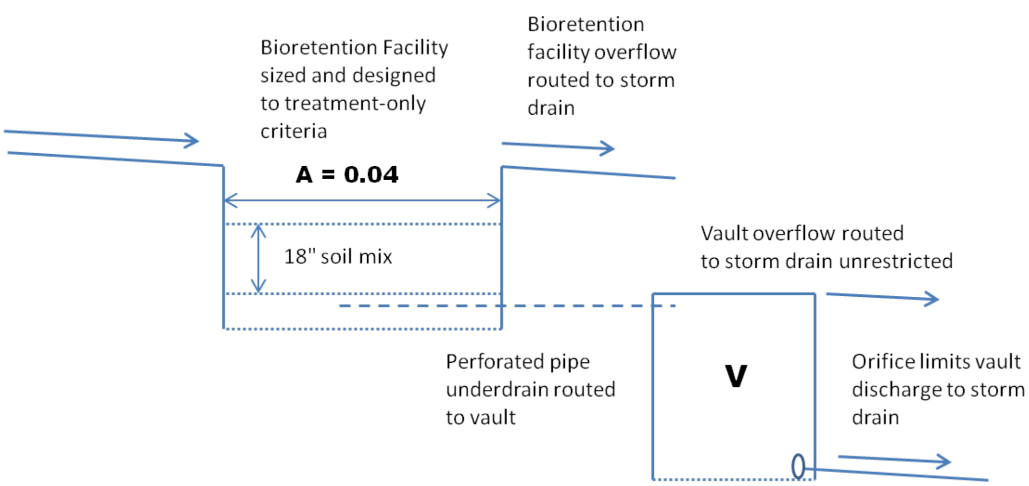
Multiple bioretention facilities draining to a single vault. Two or more bioretention areas can be connected to a single vault. The vault minimum volume and outlet maximum flow rate are the sum of those calculated for each individual bioretention facility.

Vault with pumped discharge. Where insufficient head exists, vaults may be equipped with pumps to discharge (at a rate no greater than the calculated maximum) to a storm drain or approved discharge point.

Design Checklist for Bioretention + Vault

- ❒ Bioretention facility is designed to the treatment-only criteria in the "Bioretention Facility" design sheet (pp. 69-78).
- ❒ Vault volume meets or exceeds calculated minimum.
- ❒ Vault outlet with orifice or other flow-control device restricts flow to calculated maximum.
- ❒ Bioretention facility underdrain is routed to the vault.
- ❒ Bioretention facility overflow is routed to the vault.
- ❒ Sufficient head exists to convey flow from the underdrain to the vault and from the vault to the discharge point.
- ❒ Vault is designed to drain completely and/or sealed to prevent mosquito harborage.
- ❒ Vault design provides for exclusion of debris and accessibility for maintenance.
- ❒ Vault outlet and overflow are connected to a downstream storm drain or approved discharge point.
- ❒ Emergency spillage will be safely conveyed overland.

Bioretention + Vault
Schematic



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Chapter 5

Construction of Integrated Management Practices

Guidance for preparing construction documents and overseeing construction of Integrated Management Practices

Details of construction are critical to ensuring stormwater facilities work properly. A misplaced inlet, an overflow at the wrong elevation, or the wrong soil mix can make a bioretention facility useless or ineffective even before it comes on-line, and could result in delays to project approvals and additional expense.

Your Stormwater Control Plan must contain enough detail to demonstrate your planned LID features and facilities are feasible and are coordinated with the project site plan, architectural renderings, landscape design, and other information submitted with your application for development approvals. Additional detail must be shown on plans submitted with applications for building and grading permits. During construction, municipal inspectors will check the work against the approved plans.

The Design Sheets in Chapter 4 include details, many of which are critical to proper functioning of the IMP. This chapter describes specific items to be checked during review of construction documents and during construction.

ICON KEY
☞ Helpful Tip
Submittal Requirement
Terms to Look Up
🕮 References & Resources

LID features and facilities have been routinely incorporated into development projects for only a few years. The community of land development professionals and municipal staff continue to compile and analyze "lessons learned" from their experience. The following guidance is based on those lessons.

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What to Show on Construction Plans

With few exceptions, the plan set should include separate sheets specifically incorporating the features and facilities described in the Stormwater Control Plan. The information on these sheets must be carefully coordinated and made consistent with grading plans, utility plans, landscaping plans, and (in many cases) architectural plans. Consider including the grading plan (screened) as background for the stormwater sheets. It may also be appropriate to show portions of the roofing plan wherever roof ridges define Drainage Management Areas (DMAs).

Design Note

Avoid creating bioretention areas that are deeper than necessary, and avoid having landscaped slopes draining on to the top of bioretention soil. Use surface drainage, such as valley gutters or trench drains, to keep drainage within a few inches below top of pavement. Or use a "bubble up" to bring drainage back up closer to the surface.

► GRADING IS KEY

Municipal staff will typically require plans showing the outline of each bioretention facility or other IMP, along with the delineation of DMAs. Call out elevations, including the following:

- At curb cut inlets, show elevations for top of paving, top of curb, and top of the bioretention soil layer.
- At overflow grates, show the grate elevation and the adjacent top of soil elevation.
- Call out elevations of piped inlets.

Show how DMAs follow grade breaks, consistent with the grading plan and the Stormwater Control Plan.

For treatment-and-flow-control IMPs, demonstrate how the minimum surface volume V_1 is attained by the design.

► SHOW HOW RUNOFF MOVES

As needed for clarity, show the direction of runoff flow across roofs and pavement and into IMPs. For runoff conveyed via pipes or channels, show locations, slopes, and elevations at the beginning and end of each run.

For roof drainage, show the routing of roof leaders. Use drawings or notes to make clear how drainage from leaders is routed under walkways, across pavement, through drainage pipes, or by other means to reach the IMP.

Show pipes or channels connecting the IMP underdrain and overflow to the site drainage system, municipal storm drain system, or other approved discharge point. Call out slopes and key elevations.

► SHOW IMPS IN CROSS-SECTION

Use one or more cross-section drawings to illustrate details and key IMP elevations, including bottom of excavation, top of gravel layer, top of soil layer, edge treatments, inlet elevations, overflow grate elevations, rim elevations, locations of rock for energy dissipation, moisture barriers, and other information. Call out specifications or refer to specifications elsewhere for gravel (Class 2 perm) and soil mix.

Show the arrangement and details of outlet structures, particularly for treatment-plus-flow-control IMPs. The details in the Chapter 4 design sheets for bioretention and flow-through planters may be used as a general guide.

Items to Be Inspected During Construction

Successful construction of IMPs requires attention to detail during every stage of the construction process, from initial layout to rough grading, installation of utilities, construction of buildings, paving, landscaping, and final clean-up and inspection.

Construction project managers need to understand the purpose and function of IMPs and know how to avoid common missteps that can occur during construction. For bioretention facilities, the following operating principles should be noted at a pre-construction meeting.

- Runoff flow from the intended tributary drainage management area must flow into the facility.
- The surface reservoir must fill to its intended volume during high inflows.
- Runoff must filter rapidly through the layer of imported soil mix.
- Filtered runoff must infiltrate into the native soil to the extent possible (or allowable).
- Remaining runoff must be captured and drained to a storm drain or other approved location.

See the model construction inspection checklist on the following pages.

RB-AR32908

IMP CONSTRUCTION CHECKLIST

LAYOUT (to be confirmed prior to beginning excavation)

- ❒ Square footage of the facility meets or exceeds minimum shown in Stormwater Control Plan
- ❒ Site grading and grade breaks are consistent with the boundaries of the tributary Drainage Management Area(s) (DMAs) shown in the Stormwater Control Plan
- ❒ Inlet elevation of the facility is low enough to receive drainage from the entire tributary DMA
- ❒ Locations and elevations of overland flow or piping, including roof leaders, from impervious areas to the facility have been laid out and any conflicts resolved
- ❒ Rim elevation of the facility is laid out to be level all the way around, or elevations are consistent with a detailed cross-section showing location and height of interior dams
- ❒ Locations for vaults, utility boxes, and light standards have been identified so that they will not conflict with the facility
- ❒ Facility is protected as needed from construction-phase runoff and sediment

EXCAVATION (to be confirmed prior to backfilling or pipe installation)

- ❒ Excavation conducted with materials and techniques to minimize compaction of soils within the facility area
- ❒ Excavation is to accurate area and depth
- ❒ Slopes or side walls protect from sloughing of native soils into the facility
- ❒ Moisture barrier, if specified, has been added to protect adjacent pavement or structures.
- ❒ Native soils at bottom of excavation are ripped or loosened to promote infiltration

OVERFLOW OR SURFACE CONNECTION TO STORM DRAINAGE
(to be confirmed prior to backfilling with any materials)

- ❒ Overflow is at specified elevation (typically no lower than two inches below facility rim)
- ❒ No knockouts or side inlets are in overflow riser
- ❒ Overflow location selected to minimize surface flow velocity (near, but offset from, inlet recommended)
- ❒ Grating excludes mulch and litter (beehive or atrium-style grates with ¼" openings recommended)
- ❒ Overflow is connected to storm drain via appropriately sized piping

UNDERGROUND CONNECTION TO STORM DRAIN/OUTLET ORIFICE
(to be confirmed prior to backfilling IMP with any materials)

- ❒ Perforated pipe undedrain (PVC SDR 35 or approved equivalent) is installed with holes facing down
- ❒ Perforated pipe is connected to storm drain (treatment only) or orifice (treatment-and-flow-control)
- ❒ Underdrain pipe is at elevation shown in plans. In facilities allowing infiltration, preferred elevation is above native soil but low enough to be covered by at least 2 inches of Class 2 perm; in sealed planter boxes or bioretention facilities with liners, preferred elevation is as near bottom as possible
- ❒ Cleanouts are in accessible locations and connected via sweeps
- ❒ Structures (arches or large diameter pipes) for additional surface storage are installed as shown in plans and specifications and have the specified volume

(continued)

IMP CONSTRUCTION CHECKLIST (CONTINUED)

DRAIN ROCK/SUBDRAIN (to be confirmed prior to installation of soil mix)

- ❒ Rock is installed as specified. Class 2 permeable, Caltrans specification 68-1.025 recommended, or 4"-6" pea gravel is installed at the top of the crushed rock layer
- ❒ Rock is smoothed to a consistent top elevation. Depth and top elevation are as shown in plans
- ❒ Slopes or side walls protect from sloughing of native soils into the facility
- ❒ No filter fabric is placed between the subdrain and soil mix layers

SOIL MIX

- ❒ Soil mix is as specified. Quality of mix is confirmed by delivery ticket or on-site testing as appropriate to the size and complexity of the facility
- ❒ Mix installed in lifts not exceeding 12"
- ❒ Mix is not compacted during installation but may be thoroughly wetted to encourage consolidation
- ❒ Mix is smoothed to a consistent top elevation. Depth of mix (18" min.) and top elevation are as shown in plans, accounting for depth of mulch to follow and required reservoir depth

IRRIGATION

- ❒ Irrigation system is installed so it can be controlled separately from other landscaped areas. Smart irrigation controllers and drip emitters are recommended
- ❒ Spray heads, if any, are positioned to avoid direct spray into outlet structures

PLANTING

- ❒ Plants are installed consistent with approved planting plan
- ❒ Any trees and large shrubs are staked securely
- ❒ No fertilizer is added; compost tea may be used
- ❒ No native soil or clayey material are imported into the facility with plantings
- ❒ 1"-2" mulch may be applied following planting; mulch selected to avoid floating
- ❒ Final elevation of soil mix maintained following planting
- ❒ Curb openings are free of obstructions

FINAL ENGINEERING INSPECTION

- ❒ Drainage Management Area(s) are free of construction sediment and landscaped areas are stabilized
- ❒ Inlets are installed to provide smooth entry of runoff from adjoining pavement, have sufficient reveal (drop from the adjoining pavement to the top of the mulch or soil mix, and are not blocked
- ❒ Inflows from roof leaders and pipes are connected and operable
- ❒ Temporary flow diversions are removed
- ❒ Rock or other energy dissipation at piped or surface inlets is adequate
- ❒ Overflow outlets are configured to allow the facility to flood and fill to near rim before overflow
- ❒ Plantings are healthy and becoming established
- ❒ Irrigation is operable
- ❒ Facility drains rapidly; no surface ponding is evident
- ❒ Any accumulated construction debris, trash, or sediment is removed from facility

Chapter

6

Operation & Maintenance of Stormwater Facilities

How to prepare a customized Stormwater Facilities Operation & Maintenance Plan for the treatment BMPs on your site.

Stormwater NPDES Permit Provision C.3.e requires each municipality verify stormwater treatment and flow-control facilities are adequately maintained. Municipalities must report the results of inspections to the Water Boards annually.

Facilities you install as part of your project will be incorporated into the local municipality's verification program. This is a six-stage process:

1. Determine who will own the facility and be responsible for its maintenance in perpetuity and document this in your Stormwater Control Plan. The Stormwater Control Plan must also identify the means by which ongoing maintenance will be assured (for example, a maintenance agreement that runs with the land).

2. Identify typical maintenance requirements, allow for these requirements in your project planning and preliminary design, and document the typical maintenance requirements in your Stormwater Control Plan.

3. Prepare an Operation and Maintenance Plan (O&M Plan) for the site incorporating detailed requirements for each treatment and flow-control facility. Typically, a draft O&M Plan must be submitted with the building permit application, and a final O&M Plan must be submitted for review and approved by the municipality prior to building permit final and issuance of a certificate of occupancy. Local requirements vary as to schedule. Check with municipal staff.

RB-AR32912

4. Maintain the facilities from the time they are constructed until ownership and maintenance responsibility is formally transferred.

5. Formally transfer operation and maintenance responsibility to the site owner or occupant. A warranty, secured by a bond, or other financial instrument, may be required to secure against lack of performance due to flaws in design or construction. A typical warranty period will cover two rainy seasons.

6. Maintain the facilities in perpetuity and comply with your municipality's self-inspection, reporting, and verification requirements.

See the schedule for these stages in Table 6-1. Again, local requirements will vary.

TABLE 6-1. SCHEDULE FOR PLANNING operation and maintenance of stormwater treatment and flow-control faciliites

Stage	*Description*	*Where documented*	*Schedule*
1	Determine facility ownership and maintenance responsibility	Stormwater Control Plan	Discuss with planning staff at pre-application meeting
2	Identify typical maintenance requirements	Stormwater Control Plan	Submit with planning & zoning application
3	Develop detailed operation and maintenance plan	O&M Plan	Submit draft with Building Permit application; final due before building permit final and applying for a Certificate of Occupancy
4	Interim operation and maintenance of facilities	As required by municipal O&M verification program	During and following construction including warranty period
5	Formal transfer of operation & maintenance responsibility	As required by municipal O&M verification program	On sale and transfer of property or permanent occupancy
6	Ongoing maintenance and compliance with inspection & reporting requirements	As required by municipal O&M verification program	In perpetuity

RB-AR32913

Stage 1: Ownership and Responsibility

Your Stormwater Control Plan must specify a means to finance and implement maintenance of treatment and flow-control facilities in perpetuity.

Depending on the intended use of your site and the policies of the local municipality, this may require one or more of the following:

- Execution of a maintenance agreement that "runs with the land."
- Creation of a homeowners association (HOA) and execution of an agreement by the HOA to maintain the facilities as well as an annual inspection fee.
- Formation of a new community facilities district or other special district, or addition of the properties to an existing special district.
- Dedication of fee title or easement transferring ownership of the facility (and the land under it) to the municipality.

Ownership and maintenance responsibility for treatment and flow-control facilities should be discussed at the beginning of project planning, typically at the pre-application meeting for planning and zoning review. Experience has shown provisions to finance and implement maintenance of treatment and flow-control facilities can be a major stumbling block to project approval, particularly for small residential subdivisions. (See "Applying C.3 to New Subdivisions" in Chapter 1.)

► PRIVATE OWNERSHIP AND MAINTENANCE

The municipality may require—as a condition of project approval—that a maintenance agreement be executed.

The CCCWP has prepared the following model agreements:

- Operation and Maintenance Agreement for a Single Parcel with a Stormwater Management Facility
- Operation and Maintenance Agreement for Subdivisions with Stormwater Management Facilities
- Operation and Maintenance Agreement for Subdivisions with Stormwater Management Facilities and a Homeowners Association
- CC&R and Subdivision Map Provisions for Subdivisions with Stormwater Management Facilities

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- CC&R Provisions for Subdivisions with Stormwater Management Facilities and a Homeowners Association

The model agreements "run with the land," so the agreement executed by a developer is binding on the owners of the subdivided lots. The agreement must be recorded prior to conveyance of the subdivided property.

ICON KEY
☞ Helpful Tip
Submittal Requirement
Terms to Look Up
🕮 References & Resources

The model agreements provide the municipality may collect a management and/or inspection fee established by the standard fee schedule. In addition, the agreements provide that, if the property owner fails to maintain the stormwater facility, the municipality may enter the property, restore the stormwater facility to good working order and obtain reimbursement, including administrative costs, from the property owner.

To augment and enforce maintenance requirements, the County established a two-tiered Community Facilities District (Mello-Roos) throughout the unincorporated area to cover the costs of inspections, reporting to the Water Board and, if necessary, code enforcement and maintenance and repair of individual facilities. Some cities and towns may have similar districts.

► TRANSFER TO PUBLIC OWNERSHIP

Municipalities may sometimes choose to have a treatment and flow-control facility deeded to the public in fee or as an easement and maintain the facility as part of the municipal storm drain system. The municipality may recoup the costs of maintenance through a special tax, assessment district, or similar mechanism.

Locating an IMP in a public right-of-way or easement creates an additional design constraint—along with hydraulic grade, aesthetics, landscaping, and circulation. However, because sites typically drain to the street, it may be possible to locate a bioretention swale parallel with the edge of the parcel. The facility may complement, or substitute for, an underground storm drain system.

Local Requirements

Cities, towns, or the County may have requirements that differ from, or are in addition to, this countywide Guidebook. See Appendix A and check with local planning and community development staff.

Even if the facility is to be deeded or transferred to the municipality after construction is complete, it is still the responsibility of the builder to identify general operation and maintenance requirements, prepare a detailed operation and maintenance plan, and to maintain the facility until that responsibility is formally transferred.

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Stage 2: General Maintenance Requirements

Include in your Stormwater Control Plan a general description of anticipated facility maintenance requirements. This will help ensure that:

- Ongoing costs of maintenance have been considered in your facility selection and design.
- Site and landscaping plans provide for access for inspections and by maintenance equipment.
- Landscaping plans incorporate irrigation requirements for facility plantings.
- Initial maintenance and replacement of facility plantings is incorporated into landscaping contracts and guarantees.

Fact sheets available on the CCCWP C.3 web page describe general maintenance requirements for the types of stormwater facilities featured in the LID Design Guide (Chapter 4). You can use this information to specify general maintenance requirements in your Stormwater Control Plan.

Maintenance fact sheets for conventional stormwater facilities are available in the California Stormwater BMP Handbooks.

Stage 3: Stormwater Facilities O&M Plan

Submit a draft O&M Plan with construction documents when you apply for permits to begin grading or construction on the site. Revise your draft O&M plan in response to any comments from your municipality, and incorporate new information and changes developed during project construction. Submit a revised, final O&M plan before construction is complete.

Your Final Stormwater Control O&M Plan must be submitted to and approved by your municipality before your building permit can be made final and a certificate of occupancy issued.

Your O&M Plan must be kept on-site for use by maintenance personnel and during site inspections. It is also recommended that a copy of the Stormwater Control Plan be kept onsite as a reference.

Municipal Regional Permit Provision C.3.h requires Contra Costa municipalities periodically verify operation and maintenance (O&M) of facilities installed in their jurisdiction. Each year, they must report to the Water Board the facilities inspected that year and the status of each.

RB-AR32916

The final O&M plan should incorporate solutions to any problems noted or changes that occurred during construction. For this reason, the final O&M plan may be submitted at the end of the construction period, before the application for final building permit and Certificate of Occupancy.

► TOOLS AND ASSISTANCE

The following step-by-step instructions—and forms available on the CCCWP website—will help you prepare your Stormwater Control Operation and Maintenance Plan. You may use, adapt, and assemble these documents to prepare your own Plan, which will be customized to the specific needs of your site.

These include:

- A form for stating or updating key contact information.
- An example Inspection and Maintenance Log.
- A format for an independent inspector's annual inspection report.
- An example maintenance matrix including necessary maintenance activities, recommended frequency of inspections of maintenance, and indications that maintenance is necessary.

Additional useful references, including links to additional documents, are available in "References and Resources" at the end of this chapter.

► YOUR O&M PLAN: STEP BY STEP

The following step-by-step guidance will help you prepare each required section of your Stormwater Control Operation and Maintenance Plan.

Preparation of the plan will require familiarity with your stormwater facilities as they have been constructed and a fair amount of "thinking through" plans for their operation and maintenance. The text and forms provided here will assist you, but are no substitute for thoughtful planning.

► STEP 1: DESIGNATE RESPONSIBLE INDIVIDUALS

To begin creating your O&M Plan, your organization must designate and identify:

- The individual who will have direct responsibility for the maintenance of stormwater controls. This individual should be the designated contact with municipal inspectors and should sign self-inspection reports and any correspondence with the municipality regarding verification inspections.

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- Employees or contractors who will report to the designated contact and are responsible for carrying out BMP operation and maintenance.

- The corporate officer authorized to negotiate and execute any contracts that might be necessary for future changes to operation and maintenance or to implement remedial measures if problems occur.

- Your designated respondent to problems, such as clogged drains or broken irrigation mains, that would require immediate response should they occur during off-hours.

It is recommended to use the form available on the CCCWP website to list this information. Updated contact information must be provided to the municipality immediately whenever a property is sold and whenever designated individuals or contractors change. Complete a new form—and mail or fax a copy to the municipality—whenever this occurs.

Draw or sketch an organization chart to show the relationships of authority and responsibility between the individuals responsible for O&M. This need not be elaborate, particularly for smaller organizations.

Describe how funding for BMP operation and maintenance will be assured, including sources of funds, budget category for expenditures, process for establishing the annual maintenance budget, and process for obtaining authority should unexpected expenditures for major corrective maintenance be required.

Describe how your organization will accommodate initial training of staff or contractors regarding the purpose, mode of operation, and maintenance requirements for the stormwater facilities on your site. Also, describe how your organization will ensure ongoing training as needed and in response to staff changes.

► STEP 2: SUMMARIZE DRAINAGE AND BMPS

Incorporate the following information from your Stormwater Control Plan into your O&M Plan:

- Figures delineating and designating pervious and impervious areas.

- Figures showing locations of stormwater facilities on the site.

- Tables of pervious and impervious areas served by each facility.

Review the Stormwater Control Plan narrative that describes each facility and its tributary drainage area and update the text to incorporate any changes that may have occurred during planning and zoning review, building permit review, or construction. Incorporate the updated text into your O&M Plan.

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► STEP 3: DOCUMENT FACILITIES "AS BUILT"

Include the following information from final construction drawings:

- Plans, elevations, and details of all facilities. Annotate if necessary with designations used in the Stormwater Control Plan.
- Design information or calculations submitted in the detailed design phase (i.e., not included in the Stormwater Control Plan)
- Specifications of construction for facilities, including sand or soil, compaction, pipe materials and bedding.

In the final O&M Plan, incorporate field changes to design drawings, including changes to any of the following:

- Location and layouts of inflow piping, flow splitter boxes, and piping to off-site discharge
- Depths and layering of soil, sand, or gravel
- Placement of filter fabric or geotextiles (not recommended between soil and gravel layers of bioretention facilities)
- Changes or substitutions in soil or other materials.
- Natural soils encountered (e.g. sand or clay lenses)

► STEP 4: PREPARE CUSTOMIZED MAINTENANCE PLANS

Prepare a maintenance plan, schedule, and inspection checklists (routine, annual, and after major storms) for each facility. Plans and schedules for two or more similar facilities on the same site may be combined.

Use the following resources to prepare your customized maintenance plan, schedule, and checklists.

- Specific information noted in Steps 2 and 3, above.
- Other input from the facility designer, municipal staff, or other sources.
- BMP Operation and Maintenance Fact Sheets (available on the CCCWP C.3 web page).

Note any particular characteristics or circumstances that could require attention in the future, and include any troubleshooting advice.

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Also include manufacturer's data, operating manuals, and maintenance requirements for any:

- Pumps or other mechanical equipment.
- Proprietary devices used as or in conjunction with BMPs.

Manufacturers' publications should be referenced in the text (including models and serial numbers where available). Copies of the manufacturers' publications should be included as an attachment in the back of your O&M Plan or as a separate document.

To better organize your maintenance plan, consider using the "O&M Maintenance Matrix" available on the Program's C.3 web page to present inspection frequencies, observations, and appropriate maintenance response.

► STEP 5: COMPILE O&M PLAN

Your O&M Plan should follow this general outline:

I. Inspection and Maintenance Log

II. Updates, Revisions and Errata

III. Introduction

  A. Narrative overview describing the site; drainage areas, routing, and discharge points; and treatment and flow control facilities

IV. Responsibility for Maintenance

  A. General

    (1) Name and contact information for responsible individual(s).

    (2) Organization chart or charts showing organization of the maintenance function and location within the overall organization.

    (3) Reference to Operation and Maintenance Agreement (if any). A copy of the agreement should be attached.

    (4) Maintenance Funding

      (a) Sources of funds for maintenance

      (b) Budget category or line item

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(c) Description of procedure and process for ensuring adequate funding for maintenance

B. Staff Training Program

C. Records

D. Safety

V. Summary of Drainage Areas and Stormwater Facilities

A. Drainage Areas

(1) Drawings showing pervious and impervious areas (copied or adapted from Stormwater Control Plan)

(2) Designation and description of each drainage area and how flow is routed to the corresponding facility.

B. Treatment and Flow Control Facilities

(1) Drawings showing location and type of each facility

(2) General description of each facility (Consider a table if more than two facilities)

(a) Area drained and routing of discharge.

(b) Facility type and size

VI. BMP Design Documentation

A. "As-built" drawings of each facility (design drawings in the draft Plan)

B. Manufacturer's data, manuals, and maintenance requirements for pumps, mechanical or electrical equipment, and proprietary facilities (include a "placeholder" in the draft plan for information not yet available).

C. Specific operation and maintenance concerns and troubleshooting

VII. Maintenance Schedule or Matrix

A. Maintenance Schedule for each facility with specific requirements for:

(1) Routine inspection and maintenance

(2) Annual inspection and maintenance

(3) Inspection and maintenance after major storms

B. Service Agreement Information

Assemble and make copies of your O&M Plan. One or more copies must be submitted to the municipality, and at least one copy kept on-site. Here are some suggestions for formatting the O&M Plan:

- Format plans to 8½" x 11" to facilitate duplication, filing, and handling.
- Include the revision date in the footer on each page.
- Scan graphics and incorporate with text into a single electronic file. Keep the electronic file backed-up so that copies of the O&M Plan can be made if the hard copy is lost or damaged.

► STEP 6: UPDATES

Your Stormwater Control Operation and Maintenance Plan will be a living document.

Operation and maintenance personnel may change; mechanical equipment may be replaced, and additional maintenance procedures may be needed. Throughout these changes, the O&M Plan must be kept up-to-date.

Updates may be transmitted to your municipality at any time. However, at a minimum, updates to the O&M Plan must accompany the annual inspection report. These updates should reference the sections of the Plan being changed and should be placed in reverse chronological order (most recent at the top) in Section II of the binder. If the entire O&M Plan is updated, as it should be from time to time, these updates should be removed from the first section, but may be filed (perhaps in the back of the binder) for possible future reference.

Stage 4: Interim Operation & Maintenance

In accordance with NPDES Permit Provision C.3.e.ii, include the following statement in your Stormwater Control Plan:

> The property owner accepts responsibility for interim operation and maintenance of stormwater treatment and flow-control facilities until such time as this responsibility is formally transferred to a subsequent owner.

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Applicants will typically be required to warranty stormwater facilities against lack of performance due to flaws in design or construction for a minimum of two rainy seasons following completion of construction. The warranty may need to be secured by a bond or other financial instrument.

Stage 5: Transfer Responsibility

As part of the final O&M plan, note the expected date when responsibility for operation and maintenance will be transferred. Notify your municipality when this transfer of responsibility takes place.

Stage 6: Operation & Maintenance Verification

Each Contra Costa municipality will implement a Stormwater Treatment Measures Operation and Maintenance Verification Program, including periodic site inspections.

Local stormwater ordinances state municipalities may require an annual certificate of compliance certifying operation and maintenance of treatment and flow-control facilities. To obtain a certificate of compliance, the responsible party must request and pay for an inspection from the municipality each year. Alternatively, owners or lessees may arrange for inspection by a private company authorized by the municipality. Based on the results of the inspection, the municipality may issue a certificate, issue a conditional certificate requiring correction of noted deficiencies by a specific date, or deny the certificate.

Some municipalities have established alternative procedures. Check with local staff for requirements.

References and Resources

- *Model Stormwater Ordinance (CCCWP, 2005)*
- *Start at the Source* (BASMAA, 1999) pp. 139-145.
- *Urban Runoff Quality Management* (WEF/ASCE, 1998). pp 186-189.
- *Stormwater Management Manual* (Portland, 2004). Chapter 3.
- *California Storm Water Best Management Practice Handbooks* (CASQA, 2003).
- *Best Management Practices Guide* (Public Telecommunications Center for Hampton Roads, 2002).
- Contra Costa Clean Water Program *Vector Control Plan*
- Operation, Maintenance, and Management of Stormwater Management Systems (Watershed Management Institute, 1997)

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Appendix
A

Local Exceptions & Requirements

Municipality-specific procedures, policies, and submittal requirements.
Obtain from your municipal planning and community development department.

The Contra Costa Clean Water Program C.3 web page includes links to each Contra Costa municipality's C.3 information.

Appendix B

Soils, Plantings, and Irrigation for Bioretention Facilities

Additional guidance for design and construction of bioretention facilities and flow-through planters

Bioretention facility owners are responsible for ensuring the following standards of performance are achieved throughout the life of the facility:

- Runoff must percolate through the imported bioretention soil mix at a minimum rate of 5" per hour.
- Plantings must be maintained in a healthy condition without use of conventional fertilizers or pesticides.
- Irrigation systems must minimize water use and be controlled to prevent overwatering and underdrain flow during dry weather.

As described in Chapter 5, municipalities will periodically verify these standards continue to be achieved. Operation and maintenance verification is required by the municipalities' stormwater NPDES permit issued by the Regional Water Quality Control Board.

The design criteria and checklists and other guidance in Chapter 4—including the design sheets—aim to ensure new bioretention facilities and planter boxes can reliably meet these standards of performance.

The additional guidance in this Appendix will assist applicants and their designers as they proceed from

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initial planning through design and construction.

Responsibility for design, construction, maintenance, and performance of stormwater treatment and flow-control facilities and their components rests with the applicant or property owner.

Soils

Soils for bioretention areas must meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Some native loamy sands may be suitable for both objectives; however, such soils are rare in Contra Costa and are not generally available from suppliers.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

The Contra Costa Clean Water Program has developed specifications for two bioretention soil mixes. Local soil products suppliers have expressed interest in developing "brand-name" mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a "brand-name" mix from a soil supplier. A list of suppliers who have submitted test results and certification to the Program is on the Program website. Updated soil and compost test results may be required; tests must be within 120 days prior to the delivery date of the bioretention soil to the project site.

Credit
This Appendix was prepared based on recommendations by WRA Environmental Consultants, Inc.
www.wra-ca.com

Typically, batch-specific test results and certification will be required for projects installing more that 100 cubic yards of bioretention soil.

► SOIL SPECIFICATION

Bioretention soils should meet the following criteria.

1. General Requirements
   Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth.

Bioretention Soil shall be a mixture of topsoil or fine sand, and compost, measured on a volume basis.

Mix A – Topsoil Blend
10%-20% Topsoil
50%-60% Fine Sand
30%-40% Compost

Mix B – Fine Sand Blend
60%-70% Fine Sand
30%-40% Compost

1.1. Submittals
The applicant must submit to the municipality for approval:

A. A sample of mixed bioretention soil.

B. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

C. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

D. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 1.4.

E. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

F. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

G. Provide the following information about the testing laboratory(ies) name of laboratory(ies) including

1) contact person(s)

2) address(es)

3) phone contact(s)

4) e-mail address(es)

5) qualifications of laboratory(ies), and personnel including date of current certification by STA, ASTM, or approved equal

1.2. Sand for Bioretention Soil

A. General
Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be non-plastic.

B. Sand for Bioretention Soil Texture
Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40, #30, #16. #8, #4, and 3/8 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight)	
	Min	*Max*
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40	5	55
No. 100	0	15
No. 200	0	5

Note all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

1.3. Topsoil for Bioretention Soil

A. General
Topsoil shall be free of wood, waste, or any other deleterious material.

B. Topsoil for Bioretention Soil Texture
The overall topsoil texture shall be loamy sand as analyzed by an accredited laboratory. The overall dry weight percentages shall be 60-90% sand, with less than 20% passing than the #200 sieve and less than 5% clay of the total weight with no gravel.

1.4. Composted Material

Compost shall be a well decomposed, stable, weed free organic matter source meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

A. Compost Quality Analysis

Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Evaluation of Composting and Compost (TMECC). The lab report shall verify:

1) Feedstock Materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.

2) Organic Matter Content: 35% - 75% by dry wt.

3) Carbon and Nitrogen Ratio: C:N < 25:1.

4) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable. In addition any one of the following is required to indicate stability:

a. Oxygen Test < 1.3 O2 /unit TS /hr

b. Specific oxy. Test < 1.5 O2 / unit BVS /

c. Respiration test < 8 C / unit VS / day

d. Dewar test < 20 Temp. rise (°C)

e. e. Solvita® > 5 Index value

5) Toxicity: any one of the following measures is sufficient to indicate non-toxicity.

a. NH4- : NO3-N < 3

b. Ammonium < 500 ppm, dry basis

c. Seed Germination > 80 % of control

d. Plant Trials > 80% of control

e. e. Solvita® > 5 Index value

6) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.

a. Total Nitrogen content 0.9% or above preferred.

b. Boron: Total shall be <80 ppm; Soluble shall be <2.5 ppm

7) Salinity: Must be reported; < 6.0 mmhos/cm

8) pH shall be between 6.5 and 8. May vary with plant species.

B. Particle size: 95% passing a 1/2" screen.

C. Bulk density: shall be between 500 and 1100 dry lbs/cubic yard

D. Moisture Content shall be between 30% - 55% of dry solids.

E. Inerts: compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.

F. Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.

G. Select Pathogens: Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.

H. Trace Contaminants Metals (Lead, Mercury, Etc.) Product must meet US EPA, 40 CFR 503 regulations.

I. Compost Testing
The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

► PLACEMENT AND COMPACTION OF BIORETENTION SOILS

Place the bioretention soil in 8" to 12" lifts. Lifts are not to be compacted but are placed to reduce the possibility of excessive settlement. Allow time for natural compaction and settlement prior to planting. Bioretention soil may be watered to encourage compaction.

Plantings

► PLANT SELECTION GUIDELINES

The plants tabulated in Attachment B-1 were selected for the following characteristics:

- Adaptation to Contra Costa's climate
- Drought tolerance
- Adaptation to well-drained soils
- Adaptation to low soil fertility
- Allow infiltration
- Are not invasive weeds
- Do not have aggressive roots

Characteristics noted in the table, including irrigation preferences and ability to tolerate heat, coastal conditions, flooding, and wind should be considered when selecting plants.

This list is not comprehensive, nor will all these species succeed at every site. Selection for a particular site should be done by experienced professionals familiar with the plants and site conditions. Avoid planting species on the California Invasive Plant Council's invasive plant inventory list.

► PLANT INSTALLATION

Trees and large shrubs installed in bioretention facilities are susceptible to blowing over before roots are established. They should be staked securely. Three stakes per tree are recommended at windy sites. Straps should be inspected once or twice a year and removed once trees are established to prevent girdling.

► FERTILIZATION

Due to the potential for conveying nutrients to storm drains, no fertilizer should be added to bioretention facilities or planter boxes. Compost tea, available from various nurseries and garden supply retailers, may be applied at a recommended rate of 5 gallons mixed with 15 gallons of water per acre.

Compost tea can be applied up to two weeks prior to planting and once per year between March and June. Application is not recommended when temperatures are

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below 50°F or above 90°F or when rain is forecast in the next 48 hours. Additional applications may be made as needed to correct nutrient deficiencies.

► MULCH

Mulch is not required but is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. Apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

Compared to bark mulch, aged mulch has somewhat less of a tendency to float into overflow inlets during intense storms. To reduce mulch entering overflow inlets, it is recommended to use atrium or beehive grates with ¼" openings over overflow inlets.

► WEED CONTROL

Weeds should be controlled primarily by manual methods and soil amendment. In response to problem areas or threatening invasions, corn gluten, white vinegar, vinegar-based products such as Burn-out, or non-selective natural herbicides such as Safer's Sharpshooter may be used.

► PEST AND DISEASE CONTROL

Synthetic pesticides should not be used on bioretention facilities. Beneficial nematodes and non-toxic controls may be used. Acceptable natural pesticides include Safer® Aphid, Whitefly, and Mealybug Killer, Safer® Tree and Shrub Insect Attach, Safer® for Evergreens, and Neem oil.

Irrigation

Bioretention soils have a high infiltration rate and require a different irrigation system design than what is typically used for heavy clay soils in Contra Costa County. Irrigation systems must be designed to minimize water use, avoid overwatering, and prevent the underdrain discharges during dry weather.

Bioretention facilities and planter boxes may need to be irrigated more than once a day. Irrigation controls should allow separate control of times and durations of irrigation for bioretention facilities and planter boxes vs. other landscape areas.

Smart irrigation controllers are strongly encouraged. Available controllers may access weather stations, use sensors to measure soil temperature and moisture, and allow input of soil types, plant types, root depth, light conditions, slope, and usable rainfall.

Drip emitters are strongly recommended over spray irrigation. Use multiple, lower-flow (one-half to two gallons per hour) emitters in fast-draining bioretention soils. Use two or more emitters for perennials, ground covers, and bunchgrasses. Four to six emitters may be needed for larger shrubs and trees. Some types of emitters encourage horizontal distribution of water.

Spray heads must be positioned to avoid direct spray into bioretention facility or planter box outlet structures.

References and Resources

- *Recommendations for Soils Specification, Planting, and Irrigation of Bioretention Facilities*, WRA Environmental Consultants, November 5, 2008.
- US Composting Council
- ASTM International
- *Plant List and Planting Guidance for Landscape-Based Stormwater Measures.* Appendix B in the *Alameda County Clean Water Program C.3 Technical Guidance* (2006).
- *Plants and Landscapes for Summer Dry Climates.* Nora Harlow, Ed. East Bay Municipal Utility District, Oakland
- *California Native Plants for Your Garden and Wildlife*, Las Pilitas Nursery, 2008.
- *Native Treasures: Gardening with the Plants of California.* M. Nevin Smith, 2006. University of California Press.
- *The Califlora Database, 2008.*
- California Invasive Plant Council
- *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*, University of California Cooperative Extension and California Department of Water Resources
- Our Water Our World, website to developed to assist consumers in managing home and garden pests in a way that helps protect water.
- Bay-Friendly Landscaping for Professionals, a whole systems approach to the design, construction, and maintenance of the landscape to support the integrity of the San Francisco Bay watershed.
- University of California Statewide Integrated Pest Management (IPM) Program

Plant Recommendations for Bioretention Facilities and Planter Boxes

Grasses and Grass-like Plants

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Bromus carinatus California brome	✓			2	1	✓			ok	✓		✓	✓	✓	
Bouteloua gracilis blue grama	✓			1.5	1	✓				✓		✓	✓		Tolerates no summer water, good for non-irrigated remote sites
Carex densa dense sedge	✓			1	1		✓	✓	✓	✓		✓		✓	
Carex obnupta slough sedge	✓			2	1		✓	✓	✓	✓	✓	✓	✓	✓	
Carex praegracilis clustered field sedge	✓	✓		1.5	1.5		✓	✓	✓	✓	✓	✓	✓	✓	
Carex subfusca rusty sedge	✓	✓		1	1		✓		ok	✓	✓	✓	✓	✓	Great for swales
Carex divulsa Berkeley sedge		✓	✓	1	1		✓		ok		✓	✓	✓	✓	AKA *Carex tumulicola*,. Full sun along coast.
Deschampsia cespitosa tufted hairgrass	✓			2	1		✓		ok			✓	✓	✓	Can look weedy
Distichlis spicata salt grass	✓			0.3	3		✓	✓	✓	✓	✓	✓	✓	✓	Looks like bermuda grass, withstands foot traffic, for soils with high salt
Eleocharis palustris creeping spikerush	✓			1	1		✓	✓	ok	✓	✓	✓	✓	✓	
Elymus glaucus blue wildrye	✓			1.5	2		✓	✓	ok	✓	✓	✓	✓	✓	good for grazing, difficult to mow, messy looking lawn
Festuca californica California fescue	✓	✓	✓	2	2	✓			ok	✓	✓		✓	✓	
Festuca idahoensis Idaho fescue	✓	✓		1	1	✓	✓		ok	✓	✓		✓	✓	Can mow. Needs light summer water at hot sites
Festuca rubra red fescue	✓	✓		1	1.5	✓	✓		ok	✓	✓	✓	✓	✓	Can mow. Lawn alternative
Festuca rubra 'molate' molate fescue	✓	✓		1	1.5	✓	✓		ok	✓	✓		✓	c	Can mow. Lawn alternative
Hordeum brachyantherum	✓	✓		1.5	1		✓	✓	ok	✓	✓		✓	✓	

Plant Recommendations for Bioretention Facilities and Planter Boxes

meadow barley															
Juncus patens blue rush	✓			2	1		✓	✓	✓	✓		✓		✓	
Leymus triticoides creeping wildrye	✓	✓		3	1	✓	✓		ok	✓	✓	✓	✓	✓	Can mow. Recommended for swales.
Melica californica California melica	✓	✓		1	1	✓				✓			✓	✓	
Melica imperfect melic	✓	✓		1	1	✓			ok		✓	✓		✓	Part shade inland, light water in Summer to keep green or goes dormant
Muhlenbergia rigens deergrass	✓			3	3	✓	✓		ok	✓		✓		✓	
Nasella pulchra purple needlegrass	✓	✓		2	1	✓	✓		ok	✓		✓	✓	✓	
Nassella lepida foothill needlegrass	✓	✓	✓	1.5	1	✓	✓		ok	✓	✓		✓	✓	
Phalaris californica California canarygrass		✓	✓	1.5	1		✓	✓	ok		✓	✓	✓	✓	Can be aggressive spreader

Herbaceous Perennials and Groundcovers

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Achillea filipendulina fernleaf yarrow	✓			3	3	✓			✓	✓					
Achillea millefolium common yarrow	✓			1.5	1	✓			ok	✓				✓	Good for hot sites
Achillea tomentosa woolly yarrow	✓	✓		1	1.5	✓	✓		ok	✓			✓		
Aloe striata coral aloe	✓	✓		2	2	✓			ok						Sun along coast, afternoon shade inland
Arctostaphylos hookeri Monterey manzanita	✓	✓		1	4	✓	✓		ok		✓		✓	✓	Better in part shade in hot sites
Arctostaphylos uva-ursi kinnick-kinnick	✓	✓		1	15	✓	✓		ok		✓		✓	✓	Full sun at coast, part shade inland. Cultivars to try include 'emerald carpet,' 'Point Reyes,' 'San Bruno Mountain' depending on site
Ceratostigma plumbaginoides dwarf plumbago		✓		0.75	5	✓	✓		✓	✓					
Epilobium canum California fuchsia	✓	✓		1	4	✓			ok					✓	
Eriogonum fasciculatum flattop buckwheat	✓			3	4	✓				✓				✓	
Eschscholzia californica California poppy	✓			1	1	✓			ok	✓	✓	✓	✓	✓	
Fragaria chiloensis beach strawberries	✓	✓	✓	0.3	2	✓			ok		✓			✓	
Gazania spp. treasure flower	✓			0.5	2	✓	✓		✓	✓			✓		
Iris douglasiana Douglas iris	✓	✓		1.5	2	✓	✓		ok	✓			✓	✓	Also, Iris hybrids

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name	Light Preference			Size (feet)		Watering				Tolerates				CA	
Common name	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind	Native	Other Notes
Lotus scoparius deerweed	✓			4	3	✓				✓		✓		✓	
Lupinus bicolor miniature lupine	✓			1	1	✓					✓	✓		✓	Adds nitrogen
Mimulus aurantiacus common monkeyflower	✓	✓		3	3	✓			ok			✓		✓	
Mimulus cardinalis scarlet monkeyflower	✓	✓	✓	3	3	☐	✓	✓	✓			✓		✓	Aggressive seeder
Polygonum capitatum pink knotweed	✓	✓		0.5	4	✓			✓	✓	✓		✓		
Prunella vulgaris self heal	✓	✓				✓	✓		ok		✓	✓	✓	✓	
Rudebeckia californica California coneflower	✓			3	2	✓	✓		ok	✓		✓		✓	
Salvia clevelandii Cleveland sage						✓									
Scaevola 'mauve clusters' fan flower	✓	✓		1	4	✓				✓			✓		
Sedum spathulifolium stone crop	✓					✓			ok	✓			✓	varies	For above the high water line
Sisyrinchium bellum blue eyed grass				1	1	✓			ok	✓	✓	✓	✓	✓	
Sisyrinchium californicum yellow eyed grass	✓	✓		1	1		✓		✓	✓	✓	✓	✓	✓	
Solidago californica California goldenrod		✓		3	2	✓	✓		ok	✓		✓		✓	
Stachys byzantine lamb's ears	✓	✓		1	3	✓			ok	✓	✓		✓		
Verbena tenuisecta moss verbena	✓			0.5	5	✓			ok	✓	✓		✓		

Plant Recommendations for Bioretention Facilities and Planter Boxes

Small Shrubs

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Artemisia californica California sagebrush	✓			2-5	4-5	✓				✓	✓		✓	✓	Will not tolerate sprinklers
Baccharis pilularis 'Twin Peaks' or Pigeon Point' dwarf coyote brush	✓			2	6	✓	✓		ok	✓	✓	✓	✓	c	
Cistus skanbergii hybrid rockrose	✓			3	5	✓	✓		✓	✓	✓	✓	✓		Best with annual shearing
Correa 'Carmine Bells' or 'ivory bells' Australian fuchsia	✓	✓		3	6	✓	✓		✓	✓			✓		Ivory bells does not tolerate wind. Attracts hummingbirds. Sunset Zones 16-17 (not recommended for E. Contra Costa)
Erigeron glaucus seaside daisy	✓			1	1.5				ok		✓			✓	
Eriogonum crocatum saffron buckwheat	✓			1.5	1.5	✓				✓	✓		✓	✓	
Eriogonum umbellatum sulfur buckwheat	✓			0.7	3	✓			ok	✓			✓	✓	
Grevillea lanigera woolly grevillea	✓			4	6	✓				✓			✓		Sunset Zones 15-24 (not recommended for E. Contra Costa)
Lavendula spp. lavender	✓			1.5	1.5	✓			ok	✓	✓				
Mahonia pinnata California holly grape	✓	✓	✓	4	4	✓	✓			✓		✓	✓	✓	
Mahonia repens creeping Oregon grape	✓	✓		2	3	✓	✓		ok		✓	✓		✓	
Rosmarinus officinalis rosemary	✓			2.5	5	✓			✓	✓	✓		✓		
Rubus ursinus California blackberry		✓	✓	3	5		✓	✓	ok	✓	✓	✓	✓	✓	Thorns. Harbors beneficial insects

Plant Recommendations for Bioretention Facilities and Planter Boxes

Symphorocarpos albus common snowberry	✓	✓	✓	4	4	✓	✓	✓	ok	✓				✓	Adaptable to many conditions
Westringia fruticosa coast rosemary	✓			4	8	✓				✓	✓		✓		
Whipplea modesta whipplevine		✓	✓	0.5	3		✓	✓	✓		✓	✓		✓	Sunset zones 16-17, 19-24 only (not recommended E. Contra Costa), best for moist shady spots

Large Shrubs

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Alyogyne huegelil blue hibiscus	✓			6	5	✓				✓					Very low water after second year, Sunset zones 15-17 & 20-24 (not recommended E. Contra Costa)
Arctostaphylos densiflora 'Howard Mcminn' McMinn manzanita	✓	✓		3	7	✓				✓			✓	c	
Baccharis pilularis coyote brush	✓			6	7	✓	✓		ok	✓	✓	✓	✓		Fast-growing, short-lived
Berberis darwinii Darwin's barberry	✓	✓		6	6	✓				✓		✓	✓		Sprinklers will kill foliage
Carpenteria californica Bush anemone	✓	✓		6	4	✓	✓		✓	✓				✓	Interior climate with occasional water otherwise low water needs
Ceanothus spp. Various ceanothus	✓	✓		varies	varies	✓			☐	✓			✓	✓	fast-growing but short-lived
Cercis occidentalis western redbud	✓			12	8	✓			☐	✓		✓	✓	✓	Prune low branches for small tree form, susceptible to disease if overwatered
Cotinus coggygia smoke bush	✓			15	15	✓			☐			✓	✓		No water after second year
Eriogonum arborescens Santa Cruz Island buckwheat	✓			3	5	✓			✓	✓	✓	✓	✓	✓	Low water after second year

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Eriogonum giganteum St. Catherines lace	✓			5	6	✓			☐		✓	✓	✓	✓	best at coast, tolerant of unwatered inland garden
Fremontodendron californicum flannel bush	✓			20	14	✓			☐	✓		✓		✓	Fast-growing, short-lived
Garrya elliptica Coast silktassel	✓	✓		8	8	✓	✓		✓	✓		✓	✓	✓	'Evie' is compact variety
Heteromeles arbutifolia toyon	✓	✓	✓	7	5	✓	✓		✓	✓	✓	✓		✓	Doesn't respond well to pruning low branches
Juniperus chinensis 'Mint Julep" mint julep juniper	✓	✓		3	6	✓	✓		✓	✓	✓	✓	✓		
Lonicera hispidula California honeysuckle	✓	✓	✓	4	2		✓	✓	✓		✓	✓		✓	Climbing vine-like. Best in part shade. Attracts birds
Lonicera involucrate twinberry honeysuckle	✓	✓	✓	6	3		✓	✓	✓		✓	✓		✓	Best in part shade. Attracts birds
Nandina domestica heavenly bamboo	✓	✓		4	3	✓	✓		✓	✓		✓			
Philadelphus coronaries sweet mock orange	✓	✓		10	10		✓		✓				✓		Best with annual pruning
Physocarpus capitatus Pacific ninebark	✓	✓		5	5	✓	✓	✓	ok		✓	✓		✓	Part shade and summer water required in hot locations
Pittosporum eugeniodes Pittosporum	✓	✓		40	15	✓	✓		✓	✓		✓	✓		shear to control height
Pittosporum tenuifolium Pittosporum	✓	✓		40	15	✓	✓		✓	✓		✓	✓		shear to control height
Prunus illicifolia holly leaf cherry	✓	✓		15	15	✓	✓			✓	✓	✓	✓	✓	
Prunus lyonii Catalina cherry	✓	✓		15	15	✓	✓			✓	✓	✓	✓	✓	
Rhamnus californica California coffeeberry	✓	✓		3-15	6	✓			✓	✓		✓	✓	✓	'Eve Case' is compact with broad foliage
Rhus integrifolia	✓	✓		8	6	✓			✓	✓			✓	✓	Shear to hedge if desired

Plant Recommendations for Bioretention Facilities and Planter Boxes

lemonade berry															
Ribes malvaceum chaparral currant	✓	✓		5	5	✓	✓		ok	✓				✓	
Ribes sanguineum flowering currant		✓	✓	5-12	5-12	✓	✓		✓	✓	✓	✓		✓	Needs good air movement to avoid white fly
Ribes speciosum fuchsia-flowered gooseberry	✓	✓	✓	3-6	3-6	✓	✓		✓	✓	✓	✓		✓	
Rosa californica California wild rose	✓	✓		3	3-6		✓	✓	ok	✓	✓	✓	✓	✓	hooked thorns not compatible with foot traffic
Rosa gymnocarpa wood rose	✓	✓		2	3		✓		ok	✓	✓	✓		✓	
Vitis californica California grape	✓	✓		10	2-10	✓	✓		✓	✓	✓	✓	✓	✓	Climbing vine. Best in full sun. Can be aggressive in moist area.
Vitis girdiana desert grape	✓			8	2-11	✓	✓		✓	✓		✓	✓	✓	Climbing vine. May be more suited to biofilter soils than californica.

Small Trees

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Acer Negundo box elder	✓	✓	✓	30	30	✓	✓		ok	✓	✓	✓	✓	✓	Tough shade tree, deciduous
Arbetus unedo strawberry tree	✓	✓				✓	✓		✓	✓	✓	✓			'Elfin King' is dwarf from 6' tall
Arctostaphylos manzanita common manzanita	✓			6-15	8-12	✓				✓			✓	✓	Prune to be small tree. "Dr. Hurd" is more tolerant of summer water.
Cercis occidentalis western redbud	✓	✓		12	8	✓				✓			✓	✓	Prune low branches for small tree form; susceptible to disease if overwatered.
Eriobotrya deflexa bronze loquat	✓	✓		18	25	✓	✓		✓	✓		✓			Monthly deep watering
Eriobotrya japonica Japanese loquat	✓	✓		25	20	✓	✓		✓	✓		✓			Susceptible to blight under stress
Fraxinus angustfolia Raywood ash	✓			30	30		✓		✓	✓					Fall color
Fraxinus dipetala California ash	✓	✓		20	20				ok	✓		✓		✓	

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name	Light Preference			Size (feet)		Watering				Tolerates				CA	
Common name	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind	Native	Other Notes
Fraxinus latifolia Oregon ash	✓	✓	✓	30	25	✓			✓	✓	✓	✓		✓	
Fraxinus velutina velvet ash	✓			25	15	✓	✓		ok	✓		✓	✓		
Garrya elleptica coast silk tassel	✓	✓		20	20	✓	✓		ok		✓				Afternoon shade inland, responds well to pruning
Laurus 'Saratoga' hybrid laurel	✓	✓		12-40	12-40	✓				✓		✓	✓		prune for tree form
Myrica californica Pacific wax myrtle	✓	✓	✓	10-30	10-30	✓	✓				✓				best at coast
Pinus thumbergiana Japanese black pine	✓	✓		25	20	✓			✓	✓	✓			✓	Asymmetrical, often leaning habit
Pittosporum undulatum victorian box	✓	✓		15	15	✓	✓		✓	✓					Sunset zones 16-17, 21-24 only (not recommended E. Contra Costa. Prune low branches for tree form.
Prunus ilicifolia holly leaf cherry	✓	✓		15	15	✓	✓			✓	✓		✓	✓	
Prunus lyonii Catalina cherry	✓	✓		15	15	✓	✓			✓	✓		✓	✓	
Prunus serrulata "shirofugen' cherry	✓			25	25		✓				✓	✓	✓		Additional cultivars

Plant Recommendations for Bioretention Facilities and Planter Boxes

Key

Water Preference-Low/Moderate/High	We have provided recommendations for irrigation. All plants should be watered with more frequency during the first two years after planting. After this establishment period, Low water use plants will only need supplemental irrigation at the hottest and driest sites. Plants with Moderate irrigation needs will be best with occasional supplemental water (once per week to once per month) and plants with High irrigation needs will be best with more frequent watering especially during periods of drought in the cooler seasons.
Water Preference-Summer Irrigation	Plants with a check in this column will not withstand a long period of summer drought without irrigation. Plants with an 'ok' in this column are tolerant of, but do not require, frequent summer irrigation. Plants with nothing in this column may not tolerate summer irrigation.
Tolerates Heat	A check in the heat column indicates that the plant will tolerate hot sites. It should not be confused with a plants preference for sun. Absence of the check indicates it should only be used in areas close to the Bay or other cool sites.
Tolerates Coast	The coast column indicates plants that perform well within 1,000 feet of the ocean or bay. Most of these plants tolerate some amount of salt air, fog, and wind.
Tolerates Flooding	
Tolerates Wind	A check in the wind column means that the plant will tolerate winds of ten miles per hour or more.
CA Native - c	Cultivar of California native. Cultivars offer habitat benefits to native wildlife and are adapted to the local climate but have reduced genetic diversity.
Other Notes - Sunset Climate Zones	Under the Other Notes category, we have indicated appropriate Sunset Climate Zones only for plants that will not do well across all of Contra Costa County. Please refer to the *Sunset Western Garden Book* which defines climate zones in the Bay Area based on elevation, influence of the Pacific Ocean, presence of hills and other factors.

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Appendix C

Flow Control

Instructions and tools for meeting flow-control (hydrograph modification management) requirements.

Provision C.3.g in the MRP states:

> Stormwater discharges from [applicable] projects shall not cause an increase in the erosion potential of the receiving stream over the pre-projct (existing) condition. Increases in runoff flow and volume shall be managed so that post-proejct runoff shall not exceed pre-project rates and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force.

As required by a 2003 amendment to the previous NPDES permit, the CCCWP submitted a **Hydrograph Modification Management Plan (HMP)**, including a proposed **flow-control** standard, in July 2005. The flow-control standard was retained in the MRP issued in October 2009. See Attachment C-1.

The flow-control standard applies to projects which create or replace one acre or more of impervious area and for which applications for development approvals are deemed complete after October 14, 2006. See Chapter 1, including Table 1-1.

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The flow-control standard is preventative: project proponents are encouraged to design their projects so there will be no increase in runoff as compared to the pre-project condition of the development site. The CCCWP has created designs and design aids for Low Impact Development Integrated Management Practices (IMPs) which may be used to achieve this criterion.

However, increased runoff is allowed if it can be demonstrated the increases are unlikely to cause downstream erosion or other impacts on beneficial uses of streams. This may be the case either because the drainage downstream between the project site and the Bay/Delta is in pipes or in channels that are tidally influenced or aggrading. Or the applicant may propose a stream restoration project or projects which fully mitigate the erosion risk.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

Comparison of post-project to pre-project flows is based on continuous simulation of runoff over a period of 30 years or more, using local hourly rainfall data, and statistical analysis of peak flow recurrence and of the cumulative duration of flows. See the discussion in Chapter 2.

To demonstrate compliance with the standard, select one of the following four options:

Option 1. Demonstrate the project produces no net increase in impervious area. A simple inventory and accounting of existing and proposed impervious area is required. You will also need to show, qualitatively, that changes to drainage facilities will not increase the efficiency of drainage collection and conveyance.

Option 2. Implement IMPs such as planters, swales, and bioretention areas using the Program's low-impact development site design procedure and facility sizing tool. Applicable criteria, including runoff factors and IMP sizing ratios, have been selected to meet the flow-control standard and are incorporated into the tool.

Option 3. Use a continuous-simulation hydrologic computer model such as USEPA's Hydrologic Simulation Program—Fortran (HSPF) to simulate pre-project and post-project runoff, including the effect of proposed IMPs, detention basins, or other storwmater management facilities. An hourly rainfall record of at least 30 years must be used. Compile flow statistics and produce summary peak flow and flow duration graphics to demonstrate the following criteria are met:

> For flow rates from 10% of the pre-project 2-year runoff event (0.1Q2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve.

For flow rates from 0.5Q2 to Q2, the post project peak flows shall not exceed pre-project peak flows. For flow rates from Q2 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.

Option 4. Show that, because of the specific characteristics of the stream receiving runoff from the project site, or because of proposed channel restoration projects, or both, there is little likelihood the cumulative impacts from new development could increase the net rate of stream erosion significantly.

Option 4a. Low Risk. Show all downstream reaches, from the project site to the Bay/Delta, are enclosed pipes, hardened channels, subject to tidal action, or aggrading.

Option 4b. Medium Risk. Use the methods and criteria in this Appendix to confirm each reach downstream from the project to the Bay/Delta meets criteria for the "medium risk" (or "low-risk") classification. Implement an in-stream mitigation project to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values. The expected environmental benefits of the mitigation project must substantially outweigh the potential impacts of an increase in runoff from the development project.

Option 4c. High Risk. Implement a comprehensive program of in-stream measures to improve stream channel hydrological and ecological functions while accommodating increased flows.

Whichever option is used to demonstrate flow control compliance, projects must also meet the C.3 treatment requirements. Under Option 2, projects can meet both the treatment and flow control requirements by using the low-impact development site design procedure and facility sizing tool. The following sections contain instructions and references to assist you.

Option 1: No increase in impervious area

This option applies to sites which have been previously developed. To use Option 1, simply compare existing to proposed impervious area. You will also need to show, qualitatively, that changes to drainage facilities will not increase the efficiency of drainage collection and conveyance.

► RATIONALE

In many cases, redevelopment of a previously built site will result in decreases in total impervious area—because of setback and landscaping requirements and use

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of IMPs to treat runoff. Even when sized for stormwater treatment only, IMPs also reduce runoff peaks and durations considerably. The combination of decreased impervious area and IMPs practically assures that post-project runoff will not exceed pre-project peaks and durations.

► MEETING THE REQUIREMENTS

Use a base map or aerial photo.

- Identify existing roofs, paved areas, and other impervious surfaces.
- Delineate the impervious areas, dividing them to facilitate identification of each area and estimation of its square footage.
- Mark each delineated area with a unique identifier and calculated square footage.
- Prepare a table listing each delineated area and its square footage and show a total for the project site.

Refer to the table of areas you prepared for the design of treatment facilities (Chapter 3, Step 3). Sum the impervious areas. Do not include pervious pavements or other pervious surfaces in this sum.

► PREPARING YOUR SUBMITTAL

See the instructions in Chapter 3, Step 2, regarding assessment of site opportunities and constraints to reduce imperviousness and retain or detain site drainage and in Chapter 3, Step 3, regarding design features and surface treatments used to minimize imperviousness. Make sure this information is included in your Stormwater Control Plan.

Include in your Stormwater Control Plan, as an attachment, figure, or exhibit, the marked-up base map or aerial photo showing existing impervious surfaces.

Include in your Stormwater Control Plan the tabulation and sum of existing impervious areas and a comparison to the total proposed impervious area.

If you used the recommended Low Impact Development design procedure (Chapter 4), including sizing IMPs for stormwater treatment only, no further documentation of reduced drainage efficiency is required. If you used a different design procedure to design stormwater treatment facilities, describe the existing and proposed drainage systems and explain, qualitatively or quantitatively:

- Why the time of concentration is increased as a result of the proposed development, and
- Why the total volume of runoff is reduced as a result of the proposed development.

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Option 2: Integrated Management Practices

Most applicants will find it easiest and most cost-effective to use this option. Use the Program's Design and Documentation Procedure for Low Impact Development (Chapter 4) to select and size swales, planter boxes, bioretention areas, or other IMPs to meet both treatment and flow-control requirements for your project.

► RATIONALE

The Program developed designs and sizing factors for a variety of IMPs. The sizing factor applicable to a particular IMP is dependent on the soil type and rainfall pattern at the development site. The sizing factors were calculated to ensure runoff discharged from the IMP does not exceed the pre-project peaks and durations of runoff from the area tributary to the IMP. See Chapter Two, Chapter Four, and the Program's Hydrograph Modification Management Plan for more background on calculation of the IMP sizing factors.

► MEETING THE REQUIREMENTS

Follow the instructions in Chapter Four to size IMPs. The Program's IMP sizing tool, which is available on the Program's C.3 web page, may be used to facilitate calculations. Select the "Treatment and Flow Control" option to size IMPs to provide both treatment and flow control for site runoff.

► PREPARING YOUR SUBMITTAL

Show calculations as described in Chapter 4. Or incorporate the output from the Program's IMP sizing tool into your Stormwater Control Plan.

Option 3: Model Pre- and Post-Project Runoff

This option is for applicants who wish to design their own flow-control facilities customized to the needs and character of their development projects. It requires the development of a continuous simulation hydrologic model of the project under pre-project and post-project conditions, including the effect of proposed IMPs, detention basins, or other storwmater management facilities

Building a continuous-simulation hydrologic model for a project, and analyzing its output to compare post-project to pre-project hydrology, may be a better option than the Program's IMP designs and sizing factors:

- When it is proposed to use facilities such as detention basins, constructed wetlands, or other facilities for which the Program has not developed sizing factors.
- For large drainage areas with complex drainage, steep slopes, dense vegetation, thin top soil, or other hydrological conditions where a site-

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specific model can provide a better representation of post-project and pre-project hydrology.

Because of the time and resources required to implement this option, it is typically applicable to larger developments (sites greater than 20 acres).

Projects that select Option 3 to meet the flow control requirements (Table 1-1) must also meet stormwater treatment requirements and LID requirements. Treatment requirements and flow-control requirements can be met via separate facilities in series, or a single facility may be designed for both treatment and flow-control. For example, a pond or wetland can serve as a treatment facility if it detains the required water quality volume for 48 hours and contains suitable design elements. To show the same pond or wetland also meets flow-control requirements, the applicant would need to construct a computer model to compare post-project to pre-project hydrology on the development site, including the hydrologic effects of the proposed pond or wetland.

Development of continuous simulation hydrologic model for a specific development site requires specialized expertise and substantial resources. Municipal staff may require the applicant to establish a force account or similar financial mechanism to provide for independent, third-party review of model documentation and output. Engineering and other design considerations related to flow-control may need to be coordinated with considerations related to flood protection and controlling other potential environmental impacts of the development.

Consult with municipal staff before beginning work on a computer model, and coordinate implementation with environmental agencies from which project approvals must be obtained.

► RATIONALE

Conventionally, drainage facilities have been designed to accommodate peak flows or volumes generated by a specific hypothetical rainfall event (design storm). The design storm is typically characterized by its recurrence interval (e.g., a 10-year or 100-year storm). Conventional drainage facilities, including flood-control basins, are designed for protection from flooding, not to protect streams from erosion.

As regulatory agencies began to develop criteria to protect streams from accelerated erosion caused by urbanization and increased imperviousness, many agencies limited the allowable increase in peak discharge associated with a specific design storm. The science of fluvial geomorphology showed that, for stable streams in undeveloped watersheds, the "channel forming flow"—the event with the most capability to move sediment—recurred approximately every 1-2 years. Initial criteria for stream protection focused on designing facilities to control peak flows from runoff events at and near this magnitude.

Further analysis of urbanizing streams indicated increases in the frequency and duration of lower flows can also contribute to accelerated stream erosion. Rainfall

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events which would produce little or no runoff in a pre-development watershed produce significant runoff from impervious surfaces—and that runoff is typically piped directly to streams. To fully protect streams in urbanizing watersheds from accelerated erosion, it may be necessary to control the entire regime of large and small flows.

Continuous simulation models, which typically use as input hourly rainfall data over 30 years or more, can simulate the entire runoff flow regime under existing and post-project conditions. Two sets of criteria are generally used to compare modeled pre-project and post-project flows over the long term: peak flows for each event contained in the simulation, and duration of flows at the full range of simulated flow rates.

Regardless of the hydrologic calculation method used, estimation of runoff from a particular development site requires selection of appropriate parameters to represent the quantity of rainfall that runs off versus that which puddles, infiltrates into the ground, or is absorbed by vegetation. The rational method uses "C" factors and the SCS methodology uses curve numbers to represent these relationships. Continuous simulation models, such as USEPA's Hydrologic Simulation Program—Fortran (HSPF), use a more complex suite of parameters to characterize soils and vegetation. Values for these parameters can be calibrated to stream flow data for whole watersheds. For individual development sites, or where stream flow data is not available, appropriate values for each parameter must be estimated.

► MEETING THE REQUIREMENTS

After discussing the process for technical review with municipal staff, build and run a continuous-simulation hydrologic model of the existing site and the proposed development including detention/retention facilities. Procedures and parameters must be consistent with the instructions in the Attachment 3 to the CCCWP's HMP. Prepare a statistical analysis of the results as described in that guidance.

► PREPARING YOUR SUBMITTAL

Provide a detailed report on the hydrologic modeling that includes, at a minimum:

- An **introduction** that provides a description of existing site conditions, land uses and land cover and a description of the proposed project.

- Separate **site maps** for pre-project and post-project conditions. The site maps should delineate the sub-basins used to characterize the site within the model under pre-project and post-project conditions and show a basin number or other identifier for each sub-basin. Show on your maps: hydraulic structures, roadways, drainageways, stormwater management facilities, and topography; the post-project map should also include proposed grading and site layout.

- An estimate of the Mean Seasonal Precipitation at the project site and identification of the long-term rainfall data set used in the simulation. The data should be from the Contra Costa gauge site with the most similar mean seasonal precipitation to the project site, as indicated by the Contra Costa County Public Works Department Mean Seasonal Isohyets Map (rainfall data and Isohyetal map available on the Program's web site).

- A table of model parameters used to characterize each sub-basin shown on the pre-project and post-project site maps. The table should include the sub-basin identifier, total basin area, pervious area, impervious area, NRCS soil type, and other model parameters used to define infiltration and runoff characteristics of the sub-basin. Applicants submitting an HSPF hydrologic analysis should include PWATER parameter values for each pervious land segment. (Common HSPF parameter values are provided in Appendix A of the CCCWP modeling guidance.)

- A detailed description of proposed facilities for stormwater treatment and flow control. Describe the type of facility, design dimensions, overflow capacity, underdrain sizing parameters (control device), emergency overflow route, and any other hydraulic controls. Describe how the facilities were characterized in the model and methods used for facility sizing; if IMPs are modeled, include a detailed discussion of the assumed water movement hydraulics describing infiltration, soil water storage, and soil water movement. Provide a sketch of each facility showing key hydraulic design elements such as orifice sizing and placement.

- A table of model parameters used to characterize proposed stormwater management facilities, such as FTABLEs (HSPF), rating curves etc.

- A description of runoff routing that explains how runoff from each sub-basin is routed through the project site. For sub-basins which drain to a single stormwater management facility, a discussion of the basin routing is sufficient. For more complex sub-basins or series of sub-basins, with explicit routing, provide a table describing the reach parameters and transform methods in addition to the detailed routing description. (Routing parameters will vary depending on hydrologic model and routing method selected.)

- Modeling results, summarized as partial duration statistics and flow duration tables. To compute partial duration statistics and separate the long-term HSPF output time series into discrete storm events, use a 24 hour period with flows less than 0.02 cfs per acre to signify the end of an event. The partial duration statistics table should list for each flow event: start date, event duration, peak flow, flow volume and recurrence

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interval. Show peak flow frequency and flow duration curves that illustrate the proposed project meets the peak flow control and flow duration control standard (as outlined in HMP Attachment 3).

Option 4a: Low Risk of Accelerated Erosion

This option may be applicable if your project is in low-elevation areas near the Bay/Delta or an adjacent urbanized area drained by underground pipes or hardened channels. It is the responsibility of the applicant to demonstrate all downstream channels between the project site and the Bay/Delta meet the "low risk" criteria.

► RATIONALE

Flow control is not necessary if it can be demonstrated that increased flow peaks and durations would have no effect on downstream channels. "No effect" can be stipulated if it is demonstrated that the entire drainage route from the site to the Bay/Delta is in pipes, engineered hardened channels, channels subject to tidal action, or channels subject to accumulation of sediments.

For some projects, this demonstration can be a simple reference to municipal storm drain maps (for example). However, drainage channels, particularly small channels, are not always well documented. Even where drainage is documented, the boundaries of areas tributary to the drainage may be difficult to discern. For this reason, Contra Costa has not prepared a comprehensive map showing where Option 4a applies. Where necessary, applicants may need to provide field notes, photographs, or other documentation to verify the characteristics of specific reaches along the route between their project site and the Bay/Delta.

Many reaches of Contra Costa's major creeks are natural or unhardened; Option 4a cannot be used to establish compliance with flow-control requirements for projects upstream of these reaches.

► MEETING THE REQUIREMENTS

Trace the drainage route from the project site down to the Bay/Delta. Divide the route into reaches based on the type and characteristics of drainage structures (pipe, engineered channel, natural channel). Assemble documentation and confirm each reach is in one of the following categories:

1. Enclosed pipe.

2. Channel with continuous hardened beds and banks engineered to withstand erosive forces and composed of concrete, engineered riprap, sackcrete, gabions, mats, etc. (Channel hardening must be an engineered continuous installation and not piecemealed in response to localized bank failure and erosion.)

3. Channel subject to tidal action.

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4.

TABLE C-1. Suggested format for presentation of reach-by-reach information for "low risk" (Option 4a).

Reach ID	*Description*	*"Low Risk" Category*	*Reference or documentation*

h
i
ch is aggrading, i.e. consistently subject to accumulation over decades and with no indicators on erosion on the channel banks.

► PREPARING YOUR SUBMITTAL

Your report, signed by an engineer or qualified environmental professional, should include as necessary a map or diagram showing each reach, a narrative briefly describing the reaches in order from site to Bay/Delta, and a tabulated presentation of the documentation used to confirm the status of each reach. The format illustrated in Table C-1 can be used.

You can facilitate review of your submittal by attaching photocopies of, or providing links to, the key source materials used to establish each "low risk" classification. Examples of sources are in Table C-2.

TABLE C-2. Examples of source materials which could document "low risk" (Option 4a).

	"Low Risk" Category	*Examples of Source Materials*
1	Enclosed pipes	Municipal storm drain map or personal communication with municipal staff
2	Channel with continuous hardened beds and banks	Project name or number for original construction of the channel, or personal communication with staff of the agency responsible for channel maintenance, or field reconnaissance.
3	Tidally influenced channel	Elevation of outfall to channel (from construction drawings or field reconnaissance), or personal communication with Flood Control District staff.
4	Aggrading channel	Visual survey by a qualified geomorphologist or personal communication with Flood Control District staff confirming the history of sediment accumulation and removal.

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Option 4b: Medium Risk of Accelerated Erosion

This option allows an applicant, in certain cases, to mitigate potential effects of increased runoff on a stream reach by sponsoring a bed or bank restoration project of limited scope.

The option is only available to projects smaller than 20 acres total area.

The applicant must first confirm downstream reaches have characteristics indicating channel beds and banks are, in the main, relatively resistant to accelerated erosion from increased runoff.

The applicant must then have a qualified geomorphologist confirm this finding and develop a proposal for a mitigation project, the benefits of which must substantially outweigh potential impacts of an increase in runoff from the proposed development project.

The applicant must also obtain concurrence from staff of regulatory agencies having jurisdiction—including Regional Water Board staff—that the mitigation project is feasible and desirable.

► RATIONALE

In a "medium risk" stream reach, the channel is stable under current conditions and may be able to absorb a slight increase in watershed imperviousness, but accelerated erosion cannot be ruled out. For some development projects upstream of these reaches, flow-control facilities may be costly or difficult to build, and the resulting benefit may be uncertain and small.

Detailed studies of the potential effects of a development on a stream can be costly, time consuming, and (in the case of a "medium risk" stream reach) could simply reiterate that increased erosion is not likely, but is possible.

As an alternative to extensive study of the stream, applicants have the option of proposing a mitigation project. Contra Costa streams have a substantial backlog of needed (but unfunded) maintenance to prevent or repair localized bank failures. Properly designed and executed, localized restoration projects can have substantial environmental benefits. Mitigation projects should seek to attenuate or reduce excessive erosive stresses (for example, by increasing channel cross section or reducing gradient), rather than just increasing shear resistance by stabilizing banks.

The benefits of the mitigation project must substantially outweigh the incremental increase in the risk of erosion due to the increased runoff represented by the project. This balance is established by the opinion of a qualified geomorphologist and then confirmed by consensus among staff of the agencies having jurisdiction.

Program consultants outlined a process and created technical tools applicants may use to implement this option. To begin the process, an engineer or qualified environmental professional can use the Program's Basic Geomorphic Assessment

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procedure to evaluate downstream reaches and show each reach is either "low risk" (see Option 4a) or "medium risk."

► MEETING THE REQUIREMENTS

Implementation of Option 4b proceeds in two phases. In the first phase, an engineer or qualified environmental professional makes a preliminary determination whether all reaches of drainage downstream from the project site to the Bay/Delta are either "low risk" or "medium risk" according to the Program's criteria. If this determination is affirmative, the applicant may proceed to the second phase, in which a qualified stream geomorphologist confirms the preliminary determination and proposes an appropriate mitigation project.

Applicants are strongly encourage to coordinate with municipal staff, staff of the Contra Costa Flood Control and Water Conservation District, property owners of stream reaches and adjacent parcels, and regulatory agencies having jurisdiction (including the Regional Water Board and the California Department of Fish and Game) during the first phase and/or before proceeding the second phase.

First phase (conducted by an engineer, stream geomorphologist, or other qualified environmental professional): As in Option 4a, trace the drainage route from the project site down to the Bay/Delta. Divide the route into reaches based on the type and characteristics of drainage structures. Identify and assemble documentation for any "low risk" reaches as in Option 4a.

Conduct the field site review and collect the field data described in the Basic Geomorphic Assessment procedure to each of the remaining reaches downstream to the point where:

- all further downstream reaches are "low risk," or
- the channel enters a publicly managed reservoir.

For each of these reaches, complete a Geomorphic Assessment Form, including field notes and photographs, to calculate the channel vulnerability indicators and evaluate the appropriate risk class. Write a narrative risk justification to accompany each assessment form.

Second phase (conducted by a qualified stream geomorphologist): Confirm the findings of the preliminary report using the information in the assessment forms, additional field data, and other available information.

Identify and describe a suitable mitigation project to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values. If a suitable project exists in the same stream reach or watershed, that project should be proposed; otherwise, a project in another watershed may be acceptable.

► PREPARING YOUR SUBMITTAL

Prepare a preliminary plan and proposal for the mitigation project including milestones, schedule, cost estimates, and funding. Include a written commitment from the developer or project proponent to implement the mitigation project timely in connection with the proposed development project.

Provide an opinion and supporting analysis by one or more qualified environmental professionals that the expected environmental benefits of the mitigation project substantially outweigh the potential impacts of an increase in runoff from the development project.

To complete documentation of compliance with flow-control requirements under Option 4b, obtain letters or meeting notes in which staff representatives of regulatory agencies having jurisdiction state the project is feasible and desirable. This must include a letter signed by the Regional Water Board Executive Officer or designee referencing this requirement.

Option 4c: High Risk of Accelerated Erosion

As noted at the beginning of this appendix, the Program's flow-control standard is preventative: project proponents are encouraged to design their projects so that there will be no increase in runoff as compared to the pre-project condition of the development site. This policy aims to ensure watershed-wide increases in runoff and the attendant impacts are minimized, while obviating the need for extensive analysis to characterize the complex and unpredictable relationship between increased runoff and accelerated stream erosion in a particular watershed.

However, where it is very difficult or infeasible to achieve no increase in runoff—or in cases where a stream channel is to be restored as mitigation for other environmental impacts—an applicant may propose to alter the receiving stream channel to accommodate the predicted post-project flow regime.

The analysis required to determine design objectives for in-stream measures will typically involve watershed-scale continuous hydrologic modeling of pre-project and post-project runoff flows, sediment transport modeling, collection and/or analysis of field data to characterize channel morphology including analysis of bed and bank materials and bank vegetation, selection and design of in-stream structures, and project environmental permitting.

► RATIONALE

Stream channels which do not meet the criteria for "low-risk" (Option 4a) or "medium-risk" (Option 4b) are considered at "high-risk" of accelerated erosion due to increased watershed imperviousness. High risk channels are geomorphically unstable under existing conditions, and therefore vulnerable to any increase in impervious area.. It is presumed that increases in runoff flows to these channels will accelerate bed and bank erosion.

If downstream drainage includes high-risk channels, the applicant must either control runoff flows to pre-project peaks and durations or propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows.

► MEETING THE REQUIREMENTS

To obtain approval for a project which discharges increased runoff peaks and durations to a high-risk channel, the project proponent must perform a comprehensive analysis to determine the design objectives for channel restoration and must propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows. Specific requirements are developed case-by-case in consultation with regulatory agencies having jurisdiction.

Different project types, channels, and locations will demand different investigative approaches; however, the following framework can be tailored to most situations:

- Evaluation of watershed historic conditions.
- Evaluation of channel geomorphic conditions.
- Evaluation of project impacts on hydrology and sediment yield.
- Prediction of impacts on receiving channels.
- Design of avoidance or mitigation.
- Monitoring and adaptive management.

HMP Attachment 4 includes additional detail regarding this framework and recommended evaluation method and design methods.

► PREPARING YOUR SUBMITTAL

The analysis for compliance with flow-control requirements may, and in many cases should be, integrated with analyses conducted pursuant to obtaining Clean Water Act Section 401 or Section 404 certification, CEQA, California Department of Fish and Game Stream Alteration Permits, and other regulatory approvals which may be required for the development project or implementation of in-stream measures, or both.

Discuss the contents of required submittals with the staff of agencies having jurisdiction prior to the start of the analytical work.

References and Resources

- Municipal Regional Permit Provision C.3.g. and Attachment C.
- *Contra Costa Clean Water Program Final Hydrograph Modification Management Plan*, revised April 19, 2006.

I. Demonstrating Compliance with the Standard

Contra Costa Permittees shall ensure project proponents shall demonstrate compliance with the HM standard by demonstrating that any one of the following four options is met:

1. **No increase in impervious area.** The project proponent may compare the project design to the pre-project condition and show the project will not increase impervious area and also will not facilitate the efficiency of drainage collection and conveyance.

2. **Implementation of hydrograph modification IMPs.** The project proponent may select and size IMPs to manage hydrograph modification impacts, using the design procedure, criteria, and sizing factors specified in the Contra Costa Clean Water Program's *Stormwater C.3 Guidebook*. The use of flow-through planters shall be limited to upper-story plazas, adjacent to building foundations, on slopes where infiltration could impair geotechnical stability, or in similar situations where geotechnical issues prevent use of IMPs that allow infiltration to native soils. Limited soil infiltration capacity in itself does not make use of other IMPs infeasible.

3. **Estimated post-project runoff durations and peak flows do not exceed pre-project durations and peak flows.** The project proponent may use a continuous simulation hydrologic computer model such as USEPA's Hydrograph Simulation Program—Fortran (HSPF) to simulate pre-project and post-project runoff, including the effect of proposed IMPs, detention basins, or other stormwater management facilities. To use this method, the project proponent shall compare the pre-project and post-project model output for a rainfall record of at least 30 years, using limitations and instructions provided in the Program's *Stormwater C.3 Guidebook*, and shall show the following criteria are met:

   a. For flow rates from 10% of the pre-project 2-year runoff event (0.1Q2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve.

   b. For flow rates from 0.5Q2 to Q2, the post-project *peak flows* shall not exceed pre-project peak flows. For flow rates from Q2 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.

4. **Projected increases in runoff peaks and durations will not accelerate erosion of receiving stream reaches.** The project proponent may show that, because of the specific characteristics of the stream receiving runoff from the project site, or because of proposed stream restoration projects, or both, there is little likelihood that the cumulative impacts from new development could increase the net rate of stream erosion to the extent that beneficial uses would be significantly impacted. To use this option, the project proponent shall evaluate the receiving stream to determine the relative risk of erosion impacts and take the appropriate actions as described below and in Table A-1. Projects 20 acres or larger in total area shall not use the medium risk methodology in "b" below.

   a. **"Low Risk."** In a report or letter report, signed by an engineer or qualified environmental professional, the project proponent shall show that all downstream channels between the project site and the Bay/Delta fall into one of the following "low-risk" categories.

i. Enclosed pipes.

ii. Channels with continuous hardened beds and banks engineered to withstand erosive forces and composed of concrete, engineered riprap, sackcrete, gabions, mats, etc. This category excludes channels where hardened beds and banks are not engineered continuous installations (i.e., have been installed in response to localized bank failure or erosion).

iii. Channels subject to tidal action.

iv. Channels shown to be aggrading, i.e., consistently subject to accumulation of sediments over decades, and to have no indications of erosion on the channel banks.

b. **"Medium Risk."** Medium risk channels are those where the boundary shear stress could exceed critical shear stress as a result of hydrograph modification, but where either the sensitivity of the boundary shear stress to flow is low (e.g., an oversized channel with high width to depth ratios) or where the resistance of the channel materials is relatively high (e.g., cobble or boulder beds and vegetated banks). In "medium-risk" channels, accelerated erosion due to increased watershed imperviousness is not likely but is possible, and the uncertainties can be more easily and effectively addressed by mitigation than by additional study.

In a preliminary report, the project proponent's engineer or qualified environmental professional will apply the Program's "Basic Geomorphic Assessment"[1] methods and criteria to show each downstream reach between the project site and the Bay/Delta is either at "low-risk" or "medium-risk" of accelerated erosion due to watershed development. In a following, detailed report, a qualified stream geomorphologist[2] will use the Program's Basic Geomorphic Assessment methods and criteria, available information, and current field data to evaluate each "medium-risk" reach. For *each* "medium-risk" reach, the detailed report shall show one of the following:

i. A detailed analysis, using the Program's criteria, showing the particular reach may be reclassified as "low-risk."

ii. A detailed analysis, using the Program's criteria, confirming the "medium-risk" classification, and:

1. A preliminary plan for a mitigation project for that reach to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values, and
2. A commitment to implement the mitigation project timely in connection with the proposed development project (including milestones, schedule, cost estimates, and funding), and
3. An opinion and supporting analysis by one or more qualified environmental professionals that the expected environmental benefits of the mitigation project

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[1] Contra Costa Clean Water Program *Hydrograph Modification Management Plan*, May 15, 2005, Attachment 4, pp. 6-13. This method must be made available in the Program's *Stormwater C.3 Guidebook*.

[2] Typically, detailed studies will be conducted by a stream geomorphologist retained by the lead agency (or, on the lead agency's request, another public agency such as the Contra Costa County Flood Control and Water Conservation District) and paid for by the project proponent.

substantially outweigh the potential impacts of an increase in runoff from the development project, and

4. Communication, in the form of letters or meeting notes, indicating consensus among staff representatives of regulatory agencies having jurisdiction that the mitigation project is feasible and desirable. In the case of the Regional Water Board, this must be a letter, signed by the Executive Officer or designee, specifically referencing this requirement. (This is a preliminary indication of feasibility required as part of the development project's Stormwater Control Plan. All applicable permits must be obtained before the mitigation project can be implemented.)

c. **"High Risk."** High-risk channels are those where the sensitivity of boundary shear stress to flow is high (e.g., incised or entrenched channels, channels with low width-to-depth ratios, and narrow channels with levees) or where channel resistance is low (e.g., channels with fine-grained, erodible beds and banks, or with little bed or bank vegetation). In a "high-risk" channel, it is presumed that increases in runoff flows will accelerate bed and bank erosion.

To implement this option (i.e., to allow increased runoff peaks and durations to a high-risk channel), the project proponent must perform a comprehensive analysis to determine the design objectives for channel restoration and must propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows. Specific requirements are developed case-by-case in consultation with regulatory agencies having jurisdiction. The analysis will typically involve watershed-scale continuous hydrologic modeling (including calibration with stream gauge data where possible) of pre-project and post-project runoff flows, sediment transport modeling, collection and/or analysis of field data to characterize channel morphology including analysis of bed and bank materials and bank vegetation, selection and design of in-stream structures, and project environmental permitting.

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APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

How to use this worksheet (also see instructions on page 28 of the *Stormwater C.3 Guidebook*):

1. Review Column 1 and identify which of these potential sources of stormwater pollutants apply to your site. Check each box that applies.

2. Review Column 2 and incorporate all of the corresponding applicable BMPs in your Stormwater Control Plan drawings.

3. Review Columns 3 and 4 and incorporate all of the corresponding applicable permanent controls and operational BMPs in a table in your Stormwater Control Plan. Use the format shown in Table 3-1 on page 27 of the *Guidebook*. Describe your specific BMPs in an accompanying narrative, and explain any special conditions or situations that required omitting BMPs or substituting alternative BMPs for those shown here.

IF THESE SOURCES WILL BE ON THE PROJECT SITE …	… THEN YOUR STORMWATER CONTROL PLAN SHOULD INCLUDE THESE SOURCE CONTROL BMPs		
1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ A. **On-site storm drain inlets**	❑ **Locations of inlets.**	❑ **Mark all inlets with the words "No Dumping! Flows to Bay" or similar.**	❑ **Maintain and periodically repaint or replace inlet markings.** ❑ **Provide stormwater pollution prevention information to new site owners, lessees, or operators.** ❑ **See applicable operational BMPs in Fact Sheet SC-44, "Drainage System Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com** ❑ **Include the following in lease agreements: "Tenant shall not allow anyone to discharge anything to storm drains or to store or deposit materials so as to create a potential discharge to storm drains."**
❑ B. **Interior floor drains and elevator shaft sump pumps**		❑ **State that interior floor drains and elevator shaft sump pumps will be plumbed to sanitary sewer.**	❑ **Inspect and maintain drains to prevent blockages and overflow.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

IF THESE SOURCES WILL BE ON THE PROJECT SITE ...	... THEN YOUR STORMWATER CONTROL PLAN SHOULD INCLUDE THESE SOURCE CONTROL BMPs		
1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ C. **Interior parking garages**		❑ **State that parking garage floor drains will be plumbed to the sanitary sewer.**	❑ **Inspect and maintain drains to prevent blockages and overflow.**
❑ D1. **Need for future indoor & structural pest control**		❑ **Note building design features that discourage entry of pests.**	❑ **Provide Integrated Pest Management information to owners, lessees, and operators.**
❑ D2. **Landscape/ Outdoor Pesticide Use**	❑ **Show locations of native trees or areas of shrubs and ground cover to be undisturbed and retained.** ❑ **Show self-retaining landscape areas, if any.** ❑ **Show stormwater treatment and hydrograph modification management BMPs. (See instructions in Chapter 3, Step 5 and guidance in Chapter 5.)**	**State that final landscape plans will accomplish all of the following.** ❑ **Preserve existing native trees, shrubs, and ground cover to the maximum extent possible.** ❑ **Design landscaping to minimize irrigation and runoff, to promote surface infiltration where appropriate, and to minimize the use of fertilizers and pesticides that can contribute to stormwater pollution.** ❑ **Where landscaped areas are used to retain or detain stormwater, specify plants that are tolerant of saturated soil conditions.** ❑ **Consider using pest-resistant plants, especially adjacent to hardscape.** ❑ **To insure successful establishment, select plants appropriate to site soils, slopes, climate, sun, wind, rain, land use, air movement, ecological consistency, and plant interactions.**	❑ **Maintain landscaping using minimum or no pesticides.** ❑ **See applicable operational BMPs in Fact Sheet SC-41, "Building and Grounds Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com** ❑ **Provide IPM information to new owners, lessees and operators.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

IF THESE SOURCES WILL BE ON THE PROJECT SITE …	… THEN YOUR STORMWATER CONTROL PLAN SHOULD INCLUDE THESE SOURCE CONTROL BMPs		
1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ E. **Pools, spas, ponds, decorative fountains, and other water features.**	❑ **Show location of water feature and a sanitary sewer cleanout in an accessible area within 10 feet. (Exception: Public pools must be plumbed according to County Department of Environmental Health Guidelines.)**	**If the local municipality requires pools to be plumbed to the sanitary sewer, place a note on the plans and state in the narrative that this connection will be made according to local requirements.**	❑ **See applicable operational BMPs in Fact Sheet SC-72, "Fountain and Pool Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ F. **Food service**	❑ **For restaurants, grocery stores, and other food service operations, show location (indoors or in a covered area outdoors) of a floor sink or other area for cleaning floor mats, containers, and equipment.** ❑ **On the drawing, show a note that this drain will be connected to a grease interceptor before discharging to the sanitary sewer.**	❑ **Describe the location and features of the designated cleaning area.** ❑ **Describe the items to be cleaned in this facility and how it has been sized to insure that the largest items can be accommodated.**	❑ **See the brochure, "Water Pollution Prevention Tips to Protect Water Quality and Keep Your Food Service Facility Clean." Provide this brochure to new site owners, lessees, and operators.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

IF THESE SOURCES WILL BE ON THE PROJECT SITE ...	... THEN YOUR STORMWATER CONTROL PLAN SHOULD INCLUDE THESE SOURCE CONTROL BMPs		
1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ G. **Refuse areas**	❑ **Show where site refuse and recycled materials will be handled and stored for pickup. See local municipal requirements for sizes and other details of refuse areas.** ❑ **If dumpsters or other receptacles are outdoors, show how the designated area will be covered, graded, and paved to prevent run-on and show locations of berms to prevent runoff from the area.** ❑ **Any drains from dumpsters, compactors, and tallow bin areas shall be connected to a grease removal device before discharge to sanitary sewer.**	❑ **State how site refuse will be handled and provide supporting detail to what is shown on plans.** ❑ **State that signs will be posted on or near dumpsters with the words "Do not dump hazardous materials here" or similar.**	❑ **State how the following will be implemented:** **Provide adequate number of receptacles. Inspect receptacles regularly; repair or replace leaky receptacles. Keep receptacles covered. Prohibit/prevent dumping of liquid or hazardous wastes. Post "no hazardous materials" signs. Inspect and pick up litter daily and clean up spills immediately. Keep spill control materials available on-site. See Fact Sheet SC-34, "Waste Handling and Disposal" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ H. **Industrial processes.**	❑ **Show process area.**	❑ **If industrial processes are to be located on site, state: "All process activities to be performed indoors. No processes to drain to exterior or to storm drain system."**	❑ **See Fact Sheet SC-10, "Non-Stormwater Discharges" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ I. **Outdoor storage of equipment or materials. (See rows J and K for source control measures for vehicle cleaning, repair, and maintenance.)**	❑ **Show any outdoor storage areas, including how materials will be covered. Show how areas will be graded and bermed to prevent run-on or run-off from area.** ❑ **Storage of non-hazardous liquids shall be covered by a roof and/or drain to the sanitary sewer system, and be contained by berms, dikes, liners, or vaults.** ❑ **Storage of hazardous materials and wastes must be in compliance with the local hazardous materials ordinance and a Hazardous Materials Management Plan for the site.**	**Include a detailed description of materials to be stored, storage areas, and structural features to prevent pollutants from entering storm drains.** **Where appropriate, reference documentation of compliance with the requirements of Contra Costa Hazardous Materials Programs for:** ▪ **Hazardous Waste Generation** ▪ **Hazardous Materials Release Response and Inventory** ▪ **California Accidental Release (CalARP)** ▪ **Aboveground Storage Tank** ▪ **Uniform Fire Code Article 80 Section 103(b) & (c) 1991** ▪ **Underground Storage Tank** **www.cchealth.org/groups/hazmat/**	❑ **See the Fact Sheets SC-31, "Outdoor Liquid Container Storage" and SC-33, "Outdoor Storage of Raw Materials " in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

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❑ J. **Vehicle and Equipment Cleaning**	❑ **Show on drawings as appropriate:** **(1) Commercial/industrial facilities having vehicle/equipment cleaning needs shall either provide a covered, bermed area for washing activities or discourage vehicle/equipment washing by removing hose bibs and installing signs prohibiting such uses.** **(2) Multi-dwelling complexes shall have a paved, bermed, and covered car wash area (unless car washing is prohibited on-site and hoses are provided with an automatic shut-off to discourage such use).** **(3) Washing areas for cars, vehicles, and equipment shall be paved, designed to prevent run-on to or runoff from the area, and plumbed to drain to the sanitary sewer.** **(4) Commercial car wash facilities shall be designed such that no runoff from the facility is discharged to the storm drain system. Wastewater from the facility shall discharge to the sanitary sewer, or a wastewater reclamation system shall be installed.**	❑ **If a car wash area is not provided, describe measures taken to discourage on-site car washing and explain how these will be enforced.**	**Describe operational measures to implement the following (if applicable):** ❑ **Washwater from vehicle and equipment washing operations shall not be discharged to the storm drain system.** ❑ **Car dealerships and similar may rinse cars with water only.** **See Fact Sheet SC-21, "Vehicle and Equipment Cleaning," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

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❑ K. **Vehicle/Equipment Repair and Maintenance**	❑ **Accommodate all vehicle equipment repair and maintenance indoors. Or designate an outdoor work area and design the area to prevent run-on and runoff of stormwater.** ❑ **Show secondary containment for exterior work areas where motor oil, brake fluid, gasoline, diesel fuel, radiator fluid, acid-containing batteries or other hazardous materials or hazardous wastes are used or stored. Drains shall not be installed within the secondary containment areas.** ❑ **Add a note on the plans that states either (1) there are no floor drains, or (2) floor drains are connected to wastewater pretreatment systems prior to discharge to the sanitary sewer and an industrial waste discharge permit will be obtained.**	❑ **State that no vehicle repair or maintenance will be done outdoors, or else describe the required features of the outdoor work area.** ❑ **State that there are no floor drains or if there are floor drains, note the agency from which an industrial waste discharge permit will be obtained and that the design meets that agency's requirements.** ❑ **State that there are no tanks, containers or sinks to be used for parts cleaning or rinsing or, if there are, note the agency from which an industrial waste discharge permit will be obtained and that the design meets that agency's requirements.**	**In the Stormwater Control Plan, note that all of the following restrictions apply to use the site:** ❑ **No person shall dispose of, nor permit the disposal, directly or indirectly of vehicle fluids, hazardous materials, or rinsewater from parts cleaning into storm drains.** ❑ **No vehicle fluid removal shall be performed outside a building, nor on asphalt or ground surfaces, whether inside or outside a building, except in such a manner as to ensure that any spilled fluid will be in an area of secondary containment. Leaking vehicle fluids shall be contained or drained from the vehicle immediately.** ❑ **No person shall leave unattended drip parts or other open containers containing vehicle fluid, unless such containers are in use or in an area of secondary containment.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ L. **Fuel Dispensing Areas**	❑ **Fueling areas[1] shall have impermeable floors (i.e., portland cement concrete or equivalent smooth impervious surface) that are: a) graded at the minimum slope necessary to prevent ponding; and b) separated from the rest of the site by a grade break that prevents run-on of stormwater to the maximum extent practicable.** ❑ **Fueling areas shall be covered by a canopy that extends a minimum of ten feet in each direction from each pump. [Alternative: The fueling area must be covered and the cover's minimum dimensions must be equal to or greater than the area within the grade break or fuel dispensing area[1].] The canopy [or cover] shall not drain onto the fueling area.**		❑ **The property owner shall dry sweep the fueling area routinely.** ❑ **See the Business Guide Sheet, "Automotive Service—Service Stations" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

[1] **The fueling area shall be defined as the area extending a minimum of 6.5 feet from the corner of each fuel dispenser or the length at which the hose and nozzle assembly may be operated plus a minimum of one foot, whichever is greater.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ M. **Loading Docks**	❑ **Show a preliminary design for the loading dock area, including roofing and drainage. Loading docks shall be covered and/or graded to minimize run-on to and runoff from the loading area. Roof downspouts shall be positioned to direct stormwater away from the loading area. Water from loading dock areas shall be drained to the sanitary sewer, or diverted and collected for ultimate discharge to the sanitary sewer.** ❑ **Loading dock areas draining directly to the sanitary sewer shall be equipped with a spill control valve or equivalent device, which shall be kept closed during periods of operation.** ❑ **Provide a roof overhang over the loading area or install door skirts (cowling) at each bay that enclose the end of the trailer.**		❑ **Move loaded and unloaded items indoors as soon as possible.** ❑ **See Fact Sheet SC-30, "Outdoor Loading and Unloading," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ N. **Fire Sprinkler Test Water**		❑ **Provide a means to drain fire sprinkler test water to the sanitary sewer.**	❑ **See the note in Fact Sheet SC-41, "Building and Grounds Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

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O. **Miscellaneous Drain or Wash Water or Other Sources** ❑ **Boiler drain lines** ❑ **Condensate drain lines** ❑ **Rooftop equipment** ❑ **Drainage sumps** ❑ **Roofing, gutters, and trim.** ❑ **Other sources**		❑ **Boiler drain lines shall be directly or indirectly connected to the sanitary sewer system and may not discharge to the storm drain system.** ❑ **Condensate drain lines may discharge to landscaped areas if the flow is small enough that runoff will not occur. Condensate drain lines may not discharge to the storm drain system.** ❑ **Rooftop equipment with potential to produce pollutants shall be roofed and/or have secondary containment.** ❑ **Any drainage sumps on-site shall feature a sediment sump to reduce the quantity of sediment in pumped water.** ❑ **Avoid roofing, gutters, and trim made of copper or other unprotected metals that may leach into runoff.** ❑ **Include controls for other sources as specified by local reviewer.**	
❑ P. **Plazas, sidewalks, and parking lots.**			❑ **Sweep plazas, sidewalks, and parking lots regularly to prevent accumulation of litter and debris. Collect debris from pressure washing to prevent entry into the storm drain system. Collect washwater containing any cleaning agent or degreaser and discharge to the sanitary sewer not to a storm drain.**

International Stormwater BMP Database 2007 Release
Cost Data Available for Media Filters & Green Roofs

Test Site Name	State	BMP Name	Type of BMP Being Tested	Permanent Pool Volume Upstream of Filter Media, If Any	Units	Permanent Pool's Surface Area	Units	Media Filter's Surface Area	Units	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Basin Construction Costs	Filter Construction Costs	Structural Control Devices Costs	Engineering and Overhead Costs	Land Costs or Value	Average Annual Sediment Removal and Media Replacement Costs
Foothill MS (Sand Filter)	CA	Foothill SF	FS	216.6	m^3	0.01	ha	0.004	ha	0.728	ha	2000			$476,106				
La Costa P&R	CA	La Costa PR	FS	285.7	m^3	0.02	ha	0.007	ha	1.133	ha	2000			$225,285				
Via Verde P&R	CA	Via Verde	FP	123.0	m^3	0.00	ha	0.002	ha	0.445	ha	2000			$375,617				
Eastern Regional MS	CA	Eastern SF	FS	115.5	m^3	0.01	ha	0.003	ha	0.607	ha	2000			$342,660				
Hamilton Ecoroof West Roof 2001	OR	West Roof Media Filter 2001	FL	0.0	m^3	0.00	ha	0.039	ha	0.039	ha	1999							
Hamilton Ecoroof East Roof 2001	OR	East Roof Media Filter 2001	FL	0.0	m^3	0.00	ha	0.039	ha	0.039	ha	1999							
Hamilton Ecoroof West Roof 2002	OR	West Roof Media Filter 2002	FL	0.0	m^3	0.00	ha	0.034	ha	0.034	ha	2002							
Lakewood P&R	CA	Lakewood	FP	173.0	m^3	0.01	ha	0.003	ha	0.769	ha	2000			$456,567				
Rosemead MS (StreamGuard)	CA	Rosemead SG	FV							0.486	ha	2000			$1,186				
Las Flores MS (StreamGuard)	CA	Las Flores SG	FV							0.081	ha	2000			$1,186				
Las Flores MS (FossilFilter)	CA	Las Flores FF	FV							0.324	ha	2000			$1,186				
Foothill MS (StreamGuard)	CA	Foothill SG	FV							0.081	ha	2000			$1,186				
I-5/SR-78 P&R	CA	5/78	FS	105.6	m^3	0.01	ha	0.003	ha	0.324	ha	2000			$220,000				
Rosemead MS (FossilFilter)	CA	Rosemead FF	FV							0.081	ha	2000			$1,186				
Hamilton Ecoroof East Roof 2002	OR	East Roof Media Filter 2002	FL	0.0	m^3	0.00	ha	0.036	ha	0.036	ha	2002							
Foothill MS (FossilFilter)	CA	Foothill FF	FV							0.647	ha	2000			$2,372				
Downtown Street Inlet Filter Traps	TX	Downtown SIFT	FO	0.0	m^3	0.00	ha	0.006	ha	4.968	ha	1994	$0.00	$0.00	$200	$0	$1,000	$0	$800
Termination P&R	CA	Termination	FS	222.3	m^3	0.01	ha	0.006	ha	1.133	ha	2000			$463,461				
Zilker Park Street Inlet Filter Traps	TX	Zilker Park SIFT	FO	0.0	m^3	0.00	ha	0.006	ha	44.615	ha	1994	$0.00	$0.00	$200	$0	$1,000	$0	$800
Barton Spgs. Street Inlet Filter Traps	TX	Barton Spgs. SIFT	FO	0.0	m^3	0.00	ha	0.006	ha	5.406	ha	1994	$0.00	$0.00	$200	$0	$1,000	$0	$800
Lakewood RP SF Vault (95)	CO	Lakewood Sand Filter (95)	FS	9.2	m^3	0.00	ha	0.002	ha	0.658	ha	1995							
Lake Stevens compost filter	WA	compost 1	FO	0.7	m^3	0.00	ha	0.000	ha	0.093	ha	1998	$0.00	$0.00	$14,200	$0	$2,000	$0	$500
Escondido MS	CA	Escondido	FS	12.2	m^3	0.00	ha	0.003	ha	0.324	ha	2000			$450,000				
Lakewood RP - MF Vault (96)	CO	Lakewood Media Filter (96)	FV	0.0	m^3	0.00	ha	0.002	ha	0.658	ha	1996							
Kearny Mesa MS	CA	Kearny Mesa	FO							0.607	ha	2000			$305,355				
Gillis Park Street Inlet Filter Traps	TX	Gillis Park SIFT	FO	0.0	m^3	0.00	ha	0.006	ha	8.543	ha	1994	$0.00	$0.00	$200	$0	$1,000	$0	$800
Parkrose Sand Filter	OR	Parkrose SF	FS	0.0	m^3	0.00	ha	0.001	ha	0.332	ha	2001							

International Stormwater BMP Database 2007 Release
Cost Data Available for Porous Pavement

Test Site Name	State	BMP Name	Type of BMP Being Tested	Porous Pavement Surface Area	Units	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Structural and Piping Costs	Granular Fill Costs	Paving Costs	Curb and Gutter Costs	Engineering and Overhead Costs	Land Costs or Value	Average Annual Vegetation Replacement and Granular Media Replacement Costs
Austin Porous Asphalt Lot	TX	Austin Porous Asphalt Lot	PA	0.14	ha	0.14	ha	1981			8,596			2,644		
Dayton Grass Pavement Parking Lot	OH	Dayton Grass Pavement Parking Lot	PM	0.28	ha	0.32	ha	1981				13,012				516
UDFCD Modular Porous Pavement 94 to 04	CO	Modular Block Porous Pavement	PM	0.84	ha	0.08	ha	1994	3,000		2,000	7,800		2,000		21,300

International Stormwater BMP Database 2007 Release
Cost Data Available for Infiltration Basins &Trenches

Test Site Name	State	BMP Name	Type of BMP Being Tested	Capture Volume of Basin	Units	Surface Area of Capture Volume When Full	Units	Infiltrating Surface Area	Units	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Structural Materials Cost	Basin Construction Cost	Structural Control Devices Cost	Vegetation and Landscaping Cost	Engineering and Overhead Cost	Land Cost or Value	Average Annual Sediment Removal Cost	Average Annual Revegetation Cost
VUSP Bio-Infiltration Traffic Island	PA	TI	IB	34.5	m³	139.3	m²	0.154	ha	0.47	ha	2001	$8,912	$16,500							

International Stormwater BMP Database 2007 Release
Cost Data Available for Hydrodynamic Devices

Test Site Name	State	BMP Name	Type of BMP Being Tested	Volume of Permanent Pool	Units	Water Quality Surcharge Detention Volume When Full	Units	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Structural Materials Cost	Device Installation Costs	Structural Control Devices Costs	Engineering and Overhead Costs	Land Costs or Value	Average Annual Sediment Removal Costs
I-210 / Orcas Ave	CA	Orcas	HD	1.04	m³			0.45	ha	2000			$40,000				
Warrenton Isoilater Oil/Grit Separator	VA	Warr Oil and Grit Separator	OS	5.83	m³	7.57	m³	0.08	ha	2000		$10,200	$7,000				$1,780
I-210 / Filmore Street	CA	Filmore CDS	HD	1.04	m³			1.01	ha	2000			$50,000				
Jensen Precast (UVA) - Phase II	VA	UVA Stormvault Phase II	HD	17.33	m³	17.33	m³	0.11	ha	2001	$15,000	$19,866			$4,172		$150
Charlottesville Stormceptor	VA	Stormceptor STC 3600	HD	8.71	m³	14.20	m³	1.01	ha	2000		$16,700	$5,050				$4,250
Alameda MS	CA	Alameda	OS	18.92	m³			0.32	ha	2000			$165,138				
Sunset Park Baffle Box	FL	Sunset Park Baffle Box #2	HD	2.88	m³	2.98	m³	9.91	ha	1998			$23,421				
Jensen Precast (Sacramento)	CA	Sacramento Stormvault	HD	49.61	m³	49.61	m³	0.81	ha	2000	$23,000			$33,518	$5,000		$275
Austin Rec Center OSTC	TX	ARC Oil Seperator	HD					36.42	ha	1996	$10,000	$20,000	$0	$10,000	$10,000	$10,000	$1,250
Indian River Lagoon CDS Unit	FL	CDS Unit	HD	7.39	m³	3.41	m³	24.87	ha	1997			$55,000				

International Stormwater BMP Database 2007 Release
Cost Data Available for Wetland Channels

Test Site Name	State	BMP Name	Type of BMP Being Tested	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Control Devices	Vegetation and Landscaping Costs	Engineering and Overhead	Land Costs or Values	Average Annual Sediment Removal and Disposal Costs	Average Annual Revegetation Cost
USA Brookley Golf Course	AL	Mobile Bay Constructed Wetland	BW	1.0	ha	1994			$16,000				
Mobile County Extension Service	AL	8-Mile Wetland	BW	4.9	ha	1996				$1,500			

International Stormwater BMP Database 2007 Release
Cost Data Available for Wetland Basins

Test Site Name	State	BMP Name	Type of BMP Being Tested	Water Quality Surcharge Surface Area, When Full	Units	Permanent Pool Surface Area	Units	Volume of Permanent Pool	Units	Water Quality Surcharge Detention Volume	Units	Total Watershed Area	Units	Year of Cost Estimate	Excavation Costs	Structural Materials Costs	Basin Construction Costs	Structural Control Devices Costs	Vegetation and Landscaping Costs	Engineering and Overhead Costs	Land Costs and Value	Average Annual Sediment Removal Costs	Average Annual Revegetation Costs
Rt. 211 Covington River	VA	Rt 211 Mitigated Wetland	WB											1991	$13,288			$4,511	$22,726		$7,000		
Hank Aaron Stadium - NW Wetland	AL	NW - Wetland Basin	WB									4.37	ha	1998	$2,000				$1,000	$2,000			
Hank Aaron Stadium - SW Wetland	AL	SW - Wetland Basin	WB									7.24	ha	1998	$2,000				$1,000	$2,000			
Swift Run Wetland	MI	Swift Run Wetland	WB					11890.24	m^3			488.50	ha	1983				$33,750		$15,000	$101,000		

RB-AR32981

County of Los Angeles Department of Public Works

Analysis of 85th Percentile 24-hour Rainfall Depth Analysis Within the County of Los Angeles

Water Resources Division
Hydrology Section

February 2004

RB-AR32982

Analysis of 85th Percentile 24-hour Rainfall Depths Within the County of Los Angeles

County of Los Angeles Department of Public Works
Water Resources Division / Hydrology Section

Prepared by

Ben Willardson, P.E.

Adam Walden, P.E.

Reviewed by

Iraj Nasseri, P.E.

Thuong Do, P.E.

Martin Araiza, P.E.

Peter Imaa, P.E.

Hartun Khachikian, P.E.

Mark Lombos, P.E.

Introduction

Rainfall within the County of Los Angeles varies spatially. The Los Angeles Regional Water Quality Control Board (RWQCB) agreed to use a spatially distributed statistical rainfall distribution for water quality studies. The RWQCB allows the use of 85th percentile 24-hour rainfall event or the 0.75-inch event for Standard Urban Storm Water Mitigation Plan (SUSMP) and Best Management Practices (BMP) design hydrologic studies.

The 85th percentile 24-hour rainfall depths vary from 0.30 to 1.50 inches within the County of Los Angeles. This report provides the analysis used to determine the spatial distribution of the 85th percentile 24-hour rainfall within the County of Los Angeles.

Analysis

The County of Los Angeles Department of Public Works maintains an extensive network of rain gages throughout the county. The 85th percentile 24-hour rainfall spatial distribution analysis required selection of gages to represent rainfall throughout the county. The analysis began with the selection of ninety-nine rain gages. Rain gage selection was based on spatial distribution and rainfall record length. Historic precipitation data includes 40 to 80 years of rainfall at most of the selected gages. Most rain gages in the Antelope Valley had approximately 15 years of historic record available for analysis.

Percentile Analysis

Percentile analysis determines a data value for a specified percentage. For example, if the 85th percentile rainfall depth is analyzed and a value of 1.00 inches is determined, 85 percent of all rainfall events produce 1.00 inch or less of precipitation. The analysis includes 24-hour periods with measurable rainfall and excludes all other 24-hour periods. The analysis provided the average 24-hour rainfall, the 50th, 75th, 85th, 90th, 95th, and 99th percentile 24-hour rainfall depth at each rain gage. The average rainfall represents the sum of all 24-hour rainfall depths divided by the number of records. Appendix A provides the percentile analysis for each rain gage.

Statistical Analysis

A statistical analysis of the data sample confirmed the validity of the percentile analysis. Each data sample was broken into groups of 0.50-inch depths and plotted as a histogram. The probability of occurrence for each 0.50-inch group was determined. Plotting the cumulative probability for the groups resulted in values very similar to the percentile analysis values. The 85th percentile 24-hour rainfall depths ranged from 0.50 to 1.5 inches for the various gages distributed throughout the County. Appendix B shows the histogram, the probability distribution tables, and cumulative distribution chart for the ninety-nine gages analyzed.

Mapping 85th Percentile 24-hour Isohyets

A Geographic Information System (GIS) shape file was created using latitude and longitude coordinates for each rain gage. The GIS shape file also contained the data associated with the 24-hour rainfall analysis. The Spatial Analyst program extension was used with ArcView to create a rainfall grid based on the 85th percentile data for each gage. Contours were created from the grid file to represent the 85th percentile rainfall depth throughout the County of Los Angeles. These isohyets were compared to the NOAA 2-year 24-hour isohyets. The NOAA 2-year 24-hour isohyets reflect topographic influences on spatial rainfall patterns within the County of Los Angeles. The isohyets were also compared to county topography. Rain gages that caused anomalies in the isohyets were discarded. The final isohyetal map used ninety rain gages. The nine discarded gages had small data sets.

A new grid and isohyetal contours were produced after discarding the nine gages. The contours were again compared to the NOAA contours and topographic features in the county. In the County of Los Angeles, areas of higher elevation generally receive more rainfall due to changes in pressure and temperature. The isohyetal map of the 85th percentile 24-hour storm shows this orographic affect. Higher rainfall occurs over the mountains and hills.

Two dummy rain gages added near the county border keep the isohyetal distribution consistent with topography. Accurate portrayal of the isohyets along the Malibu Coast and in the Antelope Valley requires the dummy gages.

Appendix C contains the 85th percentile 24-hour isohyetal map, a map of the rain gage locations, and a description of the settings and process used to create the rainfall grid and contour lines in ArcView. This report also contains an electronic copy of all the data used for the 85th percentile 24-hour rainfall depth analysis.

Appendices

Appendix A

Summary of 24-hour Rain Gage Data

Summary of Rain Gage Data

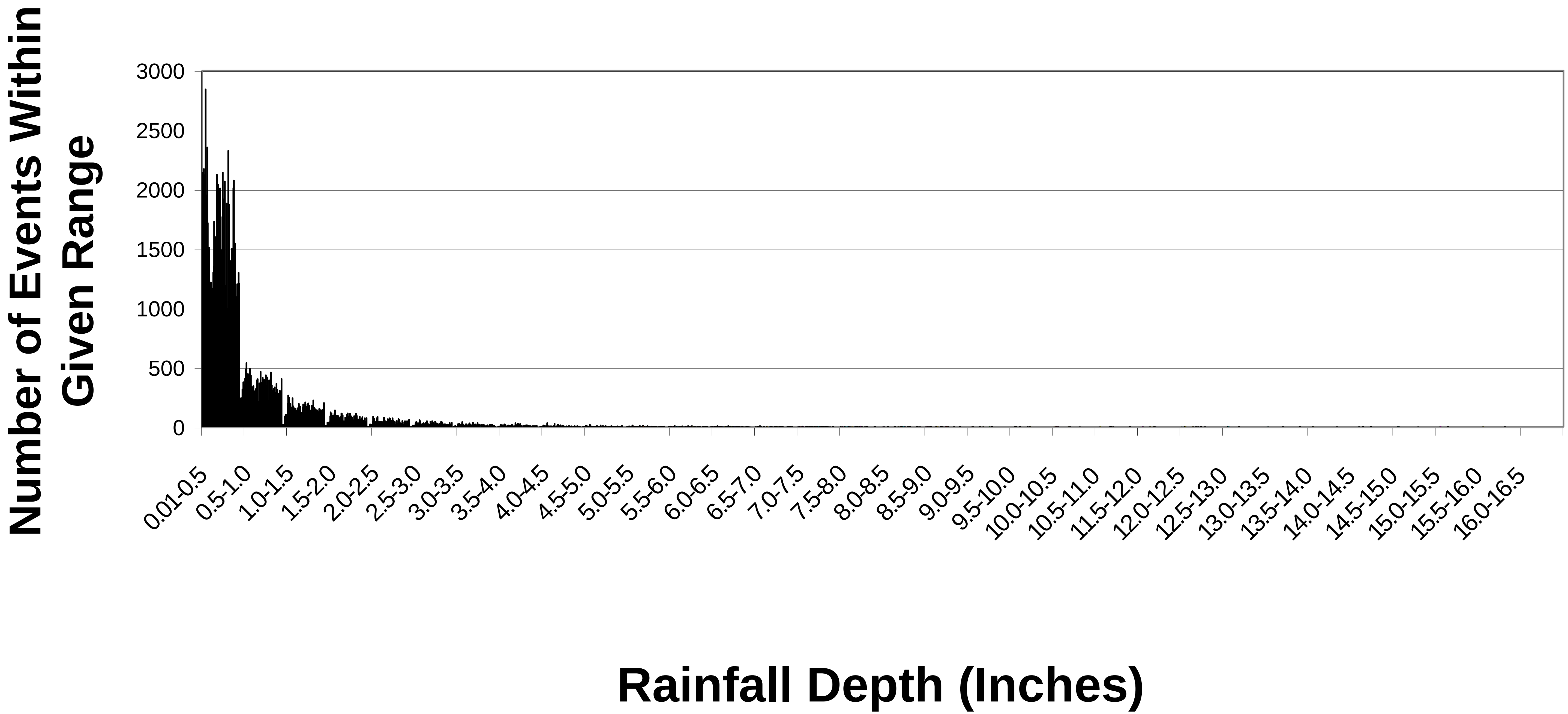
			24-hour Rainfall Total					
Gage No.	**Gage Name**	**Mean**	**50th Percentile**	**75th Percentile**	**85th Percentile**	**90th Percentile**	**95th Percentile**	**99th Percentile**
5	Calabasas	0.57	0.24	0.74	1.10	1.41	2.07	4.23
6	Topanga Canyon Patrol Station	0.54	0.20	0.69	1.11	1.44	2.10	4.05
13	North Hollywood - Lakeside	0.53	0.23	0.66	1.06	1.40	2.02	3.69
17	Sepulveda Canyon at Mulholland Hwy.	0.44	0.24	0.77	1.26	1.64	2.31	4.31
23	Chatsworth Reservoir	0.47	0.20	0.60	0.94	1.23	1.82	3.34
43	Palos Verdes Estates	0.26	0.13	0.34	0.52	0.67	0.94	1.67
44	Point Vicente Lighthouse	0.28	0.10	0.34	0.55	0.75	1.07	2.00
53	Colby's Sleepy Hollow Ranch	0.70	0.26	0.80	1.36	1.85	2.74	5.63
63	Santa Anita Dam	0.55	0.20	0.69	1.12	1.53	2.20	4.16
82	Table Mountain	0.51	0.23	0.57	0.96	1.26	1.91	4.11
107	Downey Fire Station	0.50	0.28	0.66	0.97	1.25	1.77	3.00
120	Vincent Patrol Station	0.30	0.16	0.39	0.60	0.79	1.13	1.67
125	San Francisquito Canyon Power House #1	0.44	0.20	0.59	0.91	1.20	1.69	3.02
128	Elizabeth Lake - Warm Springs Camp	0.66	0.34	0.90	1.35	1.63	2.32	4.16
156	La Mirada - Standard Oil Company	0.43	0.17	0.45	0.72	0.95	1.43	2.84
172	Duarte	0.66	0.35	0.88	1.32	1.67	2.34	3.77
176	Altadena - Rubio Canyon	0.60	0.25	0.76	1.20	1.61	2.28	3.95
201	Puente Hills - Alta Mira Ranch	0.58	0.30	0.78	1.12	1.40	2.03	3.38
223	Big Dalton	0.50	0.14	0.59	1.00	1.38	2.11	3.82
225	Montana Ranch - Lakewood	0.44	0.24	0.60	0.88	1.10	1.57	2.69
227	San Gabriel - Bruington - Orton	0.56	0.27	0.75	1.15	1.45	2.03	3.58
237	Stone Canyon Reservoir	0.58	0.22	0.77	1.20	1.66	2.35	3.95
238	Hollywood Dam	0.48	0.21	0.63	0.96	1.27	1.92	2.93
277	Sawmill Mountain	0.65	0.27	0.89	1.38	1.77	2.32	4.39
283	Crystal Lake East Pine Flat	0.70	0.24	0.77	1.32	1.90	2.89	5.89
291	Los Angeles 96th and Central	0.49	0.30	0.65	0.92	1.18	1.60	2.96
293	Lake Los Angeles	0.49	0.23	0.69	1.01	1.31	1.87	3.10
298	Gorman Sherriff Station	0.39	0.12	0.37	0.60	0.82	1.25	2.29
299	Little Rock - Schwab	0.29	0.09	0.29	0.48	0.65	0.95	1.65
304	Sawpit Canyon - Deer Park	0.60	0.19	0.73	1.20	1.76	2.45	4.88
306	Zuma Beach	0.31	0.16	0.40	0.60	0.78	1.10	2.07
322	Munz Valley Ranch	0.47	0.26	0.60	0.90	1.15	1.67	2.99
334	Cogswell Dam	0.77	0.22	0.86	1.52	2.23	3.41	6.27
356	Spadra Pacific Colony	0.49	0.25	0.62	0.98	1.27	1.78	3.01
372	San Francisquito Canyon Power House #2	0.45	0.21	0.60	0.90	1.15	1.68	3.00
373	Brigg's Terrace - Pickens Canyon	0.65	0.16	0.63	1.13	1.56	2.33	4.20
379	San Gabriel Canyon East Fork	0.65	0.23	0.76	1.30	1.70	2.60	5.18
390	Morris Dam	0.55	0.19	0.67	1.12	1.52	2.26	4.31
391	Montebello Fire Department	0.51	0.17	0.54	0.87	1.13	1.56	3.05
405	Soledad Canyon	0.48	0.20	0.56	0.90	1.18	1.73	3.20
406	West Azusa	0.51	0.26	0.68	1.03	1.36	1.85	2.93
409	Pyramid Reservoir	0.54	0.17	0.63	1.07	1.50	2.29	4.41
425	San Gabriel Dam	0.63	0.20	0.75	1.28	1.79	2.61	4.83
434	Agoura	0.41	0.13	0.44	0.75	1.03	1.58	3.46
435	Monte Nido	0.47	0.20	0.60	0.96	1.28	1.79	3.46
438	Los Angeles-University of Southern Cal	0.60	0.32	0.75	1.10	1.43	2.05	4.22
443	Latigo Canyon - Beach Ranch	0.47	0.16	0.57	0.95	1.33	1.96	3.66
446	Aliso Canyon - Oat Mountain	0.57	0.27	0.74	1.13	1.45	2.10	3.57
447	Carbon Canyon	0.35	0.17	0.46	0.70	0.89	1.26	2.19
455	Lancaster State Highway Maintenance De	0.32	0.16	0.38	0.59	0.79	1.18	2.08
458	Zuma Canyon Patrol Station	0.48	0.22	0.60	0.90	1.20	1.80	3.17
491	Pacific Palisades	0.40	0.27	0.60	0.85	1.05	1.41	2.24
492	Chilao - State Highway Maintenance Sta	0.66	0.28	0.76	1.30	1.73	2.54	4.94
497	Claremont - Slaughter	0.47	0.21	0.61	0.96	1.27	1.85	3.07
517	Anderson Ranch	0.50	0.18	0.56	0.98	1.35	2.08	3.84
564	Llano	0.31	0.18	0.40	0.61	0.78	1.01	1.75
598	Neenach	0.36	0.14	0.45	0.69	0.93	1.35	2.75
610	Pasadena City Hall	0.48	0.18	0.60	1.00	1.35	2.00	3.54
619	San Antonio Canyon - Sierra Power Hous	0.44	0.11	0.40	0.70	1.00	1.71	4.29
627	San Gabriel Canyon Power House	0.48	0.17	0.59	1.00	1.37	2.04	3.56
634	Santa Monica	0.50	0.25	0.67	1.02	1.32	1.78	3.08
694	Big Tujunga Camp 15	0.58	0.29	0.71	1.10	1.50	2.05	4.29
716	Ducommons Street	0.47	0.24	0.62	0.94	1.24	1.74	3.33
735	Bell Canyon - Platt Ranch	0.37	0.13	0.43	0.74	0.98	1.55	2.99
750	Palmdale F.A.A. Airport	0.24	0.12	0.30	0.48	0.61	0.90	1.54
795	Pasadena - Jourdan	0.49	0.19	0.63	1.02	1.41	2.00	3.44
807	Ascot Reservoir	0.48	0.23	0.63	0.98	1.30	1.80	3.10
1006	San Pedro City Reservoir	0.27	0.14	0.36	0.53	0.69	1.02	1.60
1025	Malibu Beach - Dunne	0.33	0.16	0.43	0.64	0.84	1.17	2.20
1041	Santa Fe	0.53	0.27	0.71	1.09	1.40	1.93	3.18
1050	Old Topanga Canyon	0.50	0.18	0.60	1.01	1.38	2.04	3.67
1051	Canoga Park - Pierce College	0.50	0.20	0.65	1.00	1.33	1.95	3.56
1070	Manhattan Beach	0.41	0.22	0.54	0.82	1.05	1.39	2.39
1072	Little Tujunga Ranger Station	0.57	0.31	0.77	1.10	1.39	1.95	3.56
1074	Little Gleason	0.69	0.31	0.79	1.28	1.71	2.59	5.91
1081	Glendale - Gregg	0.55	0.24	0.71	1.11	1.45	2.09	3.79
1088	La Habra Heights - Mutual Water Co.	0.52	0.28	0.68	1.05	1.32	1.94	3.12
1107	La Tuna Debris Basin	0.55	0.30	0.70	1.07	1.40	1.89	3.49
1113	Dominguez Water Company	0.35	0.15	0.42	0.73	0.95	1.42	2.63
1242	Rocky Buttes Indian Museum	0.14	0.05	0.16	0.24	0.32	0.50	0.97
1243	Redman	0.26	0.10	0.29	0.44	0.60	0.88	2.65
1244	Lancaster - Roper	0.15	0.04	0.16	0.27	0.41	0.55	1.47
1246	Scott Ranch	0.14	0.08	0.20	0.40	0.60	0.96	1.51
1247	North Lancaster	0.13	0.04	0.12	0.24	0.32	0.50	0.80
1248	Mescal - Smith	0.22	0.08	0.20	0.36	0.60	1.20	2.32
1252	Palos Verdes Landfill	0.55	0.31	0.73	1.09	1.49	2.01	3.20
1253	Carson - County Sanitation	0.44	0.20	0.55	0.89	1.22	1.65	2.47
1259	Whittier Narrows Reclamation Plant	0.49	0.26	0.60	0.90	1.25	1.80	3.01
1262	Saugus Reclamation Plant	0.51	0.28	0.62	0.94	1.29	1.81	3.49
1263	Valencia Reclamation Plant	0.49	0.28	0.62	1.01	1.31	1.80	2.78
	Discarded Gages							
1248	Mescal - Smith	0.22	0.08	0.20	0.36	0.60	1.20	2.32
1249	Relay	0.32	0.08	0.20	0.30	0.46	0.60	1.15
1252	Palos Verdes Landfill	0.55	0.31	0.73	1.09	1.49	2.01	3.20
1253	Carson - County Sanitation	0.44	0.20	0.55	0.89	1.22	1.65	2.47
1259	Whittier Narrows Reclamation Plant	0.49	0.26	0.60	0.90	1.25	1.80	3.01
1262	Saugus Reclamation Plant	0.51	0.28	0.62	0.94	1.29	1.81	3.49
1263	Valencia Reclamation Plant	0.49	0.28	0.62	1.01	1.31	1.80	2.78

File: Final Gages Used for Rainfall Isohyet Analysis-85th Percentile-24hr Depth.xls
Worksheet: Gage Summary
Date: 03/16/2004

Appendix B

Statistical Analysis

24-hr Rainfall Depth Histogram



File: Probability Analysis of 85th Percentile 24-hr Rainfall.xls
Worksheet: Histogram
Date: 03/16/2004

Probability that Rainfall Depth will Occur in a Given Range

Rainfall Depth Inches / Gage #	5	6	10	13	17	23	25	43	44	53	57	63	82	107	120	125	128	156	172	176	201	223	225	227	237	238	277	283	291	293	298	299	304	306	322	334	352	356	372	373	379	390	391	405	406	409	425	434	435	438	443	446
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.01-0.5	0.660	0.666	0.674	0.670	0.652	0.710	0.722	0.831	0.816	0.643	0.586	0.685	0.715	0.659	0.806	0.708	0.577	0.767	0.581	0.632	0.611	0.715	0.698	0.649	0.647	0.688	0.631	0.651	0.660	0.675	0.760	0.818	0.669	0.796	0.689	0.655	0.717	0.689	0.702	0.638	0.660	0.685	0.659	0.705	0.665	0.692	0.658	0.761	0.693	0.618	0.697	0.637
0.5-1.0	0.168	0.151	0.162	0.166	0.148	0.151	0.151	0.120	0.120	0.146	0.146	0.142	0.141	0.195	0.127	0.159	0.194	0.137	0.197	0.179	0.199	0.133	0.178	0.168	0.163	0.169	0.147	0.148	0.206	0.170	0.137	0.130	0.130	0.137	0.178	0.121	0.164	0.165	0.165	0.157	0.145	0.141	0.185	0.161	0.176	0.139	0.147	0.127	0.157	0.211	0.145	0.176
1.0-1.5	0.081	0.082	0.069	0.076	0.081	0.065	0.067	0.032	0.038	0.076	0.075	0.070	0.068	0.079	0.051	0.069	0.100	0.048	0.098	0.073	0.097	0.060	0.069	0.088	0.074	0.071	0.091	0.066	0.075	0.071	0.058	0.035	0.074	0.045	0.068	0.072	0.066	0.073	0.066	0.079	0.073	0.071	0.085	0.061	0.076	0.068	0.070	0.057	0.072	0.077	0.066	0.090
1.5-2.0	0.037	0.038	0.034	0.035	0.050	0.032	0.028	0.011	0.014	0.046	0.051	0.040	0.030	0.029	0.007	0.029	0.061	0.022	0.056	0.047	0.041	0.034	0.027	0.043	0.047	0.024	0.053	0.042	0.026	0.041	0.023	0.010	0.040	0.010	0.031	0.036	0.024	0.035	0.033	0.043	0.044	0.039	0.032	0.035	0.040	0.032	0.042	0.023	0.033	0.040	0.038	0.041
2.0-2.5	0.019	0.027	0.024	0.021	0.023	0.017	0.013	0.003	0.006	0.029	0.035	0.025	0.016	0.020	0.005	0.018	0.029	0.011	0.026	0.024	0.022	0.022	0.015	0.022	0.023	0.023	0.036	0.028	0.013	0.020	0.014	0.004	0.037	0.006	0.016	0.030	0.014	0.015	0.017	0.031	0.023	0.024	0.016	0.016	0.023	0.026	0.028	0.013	0.019	0.018	0.021	0.022
2.5-3.0	0.010	0.011	0.017	0.012	0.014	0.011	0.010	0.001	0.002	0.017	0.026	0.014	0.010	0.007	0.001	0.007	0.016	0.008	0.013	0.017	0.012	0.011	0.006	0.015	0.019	0.015	0.013	0.018	0.009	0.011	0.002	0.001	0.014	0.004	0.008	0.021	0.006	0.012	0.007	0.020	0.020	0.012	0.009	0.007	0.010	0.012	0.017	0.005	0.010	0.009	0.014	0.014
3.0-3.5	0.010	0.007	0.004	0.009	0.010	0.006	0.003	0.001	0.001	0.011	0.019	0.007	0.007	0.005	0.002	0.004	0.008	0.002	0.011	0.012	0.008	0.009	0.004	0.003	0.012	0.004	0.011	0.012	0.008	0.007	0.003	0.001	0.011	0.001	0.005	0.017	0.003	0.005	0.005	0.008	0.010	0.006	0.007	0.006	0.004	0.010	0.013	0.006	0.007	0.012	0.006	0.010
3.5-4.0	0.004	0.006	0.006	0.003	0.007	0.003	0.002	0.000	0.001	0.010	0.010	0.005	0.003	0.003	0.000	0.002	0.004	0.002	0.008	0.006	0.006	0.008	0.001	0.006	0.006	0.002	0.006	0.006	0.001	0.002	0.001	0.001	0.006	0.000	0.004	0.014	0.002	0.001	0.005	0.009	0.008	0.010	0.004	0.002	0.003	0.007	0.009	0.001	0.003	0.004	0.004	0.003
4.0-4.5	0.003	0.004	0.002	0.003	0.005	0.002	0.002	0.000	0.000	0.003	0.015	0.003	0.001	0.001	0.000	0.002	0.004	0.001	0.004	0.003	0.001	0.003	0.001	0.003	0.004	0.003	0.004	0.011	0.000	0.001	0.001	0.000	0.005	0.000	0.001	0.009	0.001	0.003	0.002	0.003	0.004	0.005	0.001	0.003	0.001	0.004	0.004	0.001	0.003	0.004	0.002	0.003
4.5-5.0	0.002	0.004	0.002	0.002	0.002	0.001	0.001	0.000	0.000	0.004	0.009	0.002	0.003	0.000	0.000	0.001	0.001	0.002	0.002	0.003	0.001	0.000	0.001	0.001	0.002	0.001	0.003	0.003	0.001	0.000	0.001	0.001	0.004	0.000	0.001	0.006	0.000	0.001	0.001	0.003	0.004	0.002	0.001	0.001	0.001	0.003	0.003	0.002	0.001	0.002	0.001	0.002
5.0-5.5	0.002	0.001	0.002	0.001	0.002	0.000	0.001	0.000	0.000	0.002	0.006	0.002	0.002	0.001	0.000	0.000	0.002	0.000	0.001	0.001	0.001	0.001	0.000	0.001	0.002	0.000	0.002	0.004	0.001	0.001	0.001	0.000	0.002	0.000	0.000	0.005	0.001	0.000	0.000	0.001	0.002	0.001	0.000	0.001	0.000	0.004	0.001	0.002	0.000	0.002	0.001	0.002
5.5-6.0	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.003	0.004	0.001	0.000	0.000	0.000	0.000	0.003	0.000	0.001	0.001	0.000	0.000	0.000	0.001	0.002	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.002	0.000	0.000	0.000	0.002	0.002	0.002	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.001	0.003	0.001
6.0-6.5	0.000	0.001	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.002	0.003	0.001	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.002	0.000	0.000	0.003	0.000	0.000	0.000	0.002	0.002	0.000	0.001	0.002	0.000	0.001	0.002	0.001	0.000	0.000	0.000	0.000
6.5-7.0	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.001
7.0-7.5	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.002	0.002	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001
7.5-8.0	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.000
8.0-8.5	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
8.5-9.0	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
9.0-9.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000
9.5-10.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000
10.0-10.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.5-11.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.5-12.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.0-12.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.5-13.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.0-13.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.5-14.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14.0-14.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14.5-15.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.0-15.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.5-16.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

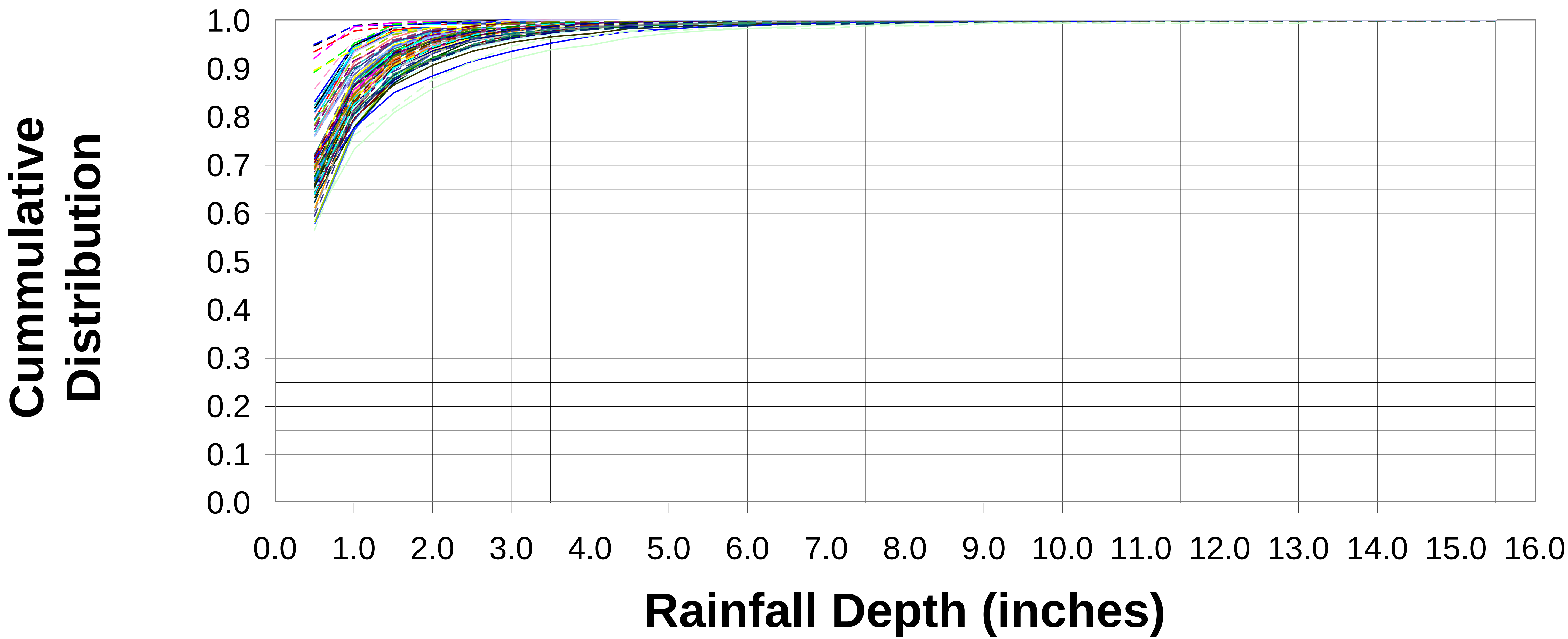
Probability that Rainfall Depth will Occur in a Given Range

Rainfall Depth Inches / Gage #	447	455	491	492	497	517	564	598	610	619	627	634	694	695	716	735	750	795	807	1005	1006	1025	1041	1050	1051	1070	1072	1074	1076	1081	1088	1107	1113	1217	1242	1243	1244	1246	1247	1248	1249	1252	1253	1259	1262	1263
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.5-1.0	0.759	0.809	0.782	0.644	0.708	0.697	0.794	0.776	0.708	0.797	0.715	0.671	0.648	0.566	0.699	0.762	0.860	0.692	0.683	0.673	0.826	0.785	0.661	0.700	0.693	0.721	0.604	0.624	0.644	0.656	0.661	0.642	0.783	0.595	0.947	0.877	0.935	0.893	0.950	0.896	0.921	0.641	0.720	0.677	0.695	0.696
1.0-1.5	0.153	0.123	0.151	0.166	0.148	0.144	0.146	0.140	0.140	0.104	0.134	0.169	0.170	0.196	0.161	0.133	0.100	0.154	0.168	0.200	0.118	0.137	0.165	0.141	0.155	0.165	0.207	0.181	0.165	0.167	0.174	0.187	0.122	0.199	0.043	0.084	0.043	0.059	0.040	0.044	0.066	0.184	0.144	0.187	0.167	0.149
1.5-2.0	0.051	0.042	0.038	0.066	0.067	0.066	0.046	0.042	0.068	0.036	0.062	0.085	0.080	0.053	0.072	0.049	0.027	0.064	0.070	0.072	0.040	0.048	0.087	0.068	0.070	0.074	0.101	0.075	0.080	0.080	0.090	0.081	0.053	0.100	0.005	0.026	0.011	0.041	0.000	0.037	0.008	0.076	0.068	0.063	0.069	0.078
2.0-2.5	0.022	0.012	0.012	0.044	0.034	0.037	0.007	0.012	0.034	0.020	0.035	0.035	0.046	0.063	0.032	0.022	0.010	0.039	0.037	0.028	0.011	0.014	0.039	0.037	0.033	0.022	0.039	0.036	0.032	0.040	0.030	0.046	0.024	0.037	0.005	0.000	0.011	0.004	0.005	0.007	0.004	0.045	0.046	0.032	0.028	0.038
2.5-3.0	0.007	0.006	0.011	0.029	0.020	0.020	0.001	0.014	0.020	0.008	0.023	0.022	0.026	0.037	0.015	0.014	0.002	0.023	0.023	0.015	0.002	0.008	0.021	0.022	0.019	0.009	0.021	0.031	0.029	0.025	0.018	0.017	0.007	0.030	0.000	0.000	0.000	0.004	0.000	0.004	0.000	0.024	0.011	0.022	0.018	0.022
3.0-3.5	0.004	0.003	0.005	0.016	0.011	0.015	0.003	0.007	0.013	0.009	0.015	0.007	0.008	0.032	0.011	0.008	0.002	0.011	0.007	0.008	0.001	0.002	0.012	0.010	0.009	0.005	0.011	0.021	0.021	0.012	0.016	0.012	0.004	0.018	0.000	0.000	0.000	0.000	0.005	0.011	0.000	0.018	0.007	0.007	0.006	0.010
3.5-4.0	0.003	0.003	0.000	0.011	0.007	0.006	0.000	0.005	0.006	0.009	0.005	0.004	0.003	0.016	0.004	0.004	0.000	0.007	0.005	0.001	0.000	0.002	0.006	0.009	0.009	0.002	0.005	0.010	0.011	0.008	0.005	0.004	0.003	0.005	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.009	0.006	0.004
4.0-4.5	0.001	0.000	0.000	0.008	0.002	0.006	0.001	0.002	0.004	0.004	0.006	0.002	0.004	0.005	0.006	0.005	0.000	0.004	0.005	0.003	0.000	0.001	0.003	0.004	0.004	0.001	0.006	0.004	0.004	0.004	0.005	0.002	0.002	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.006	0.000
4.5-5.0	0.000	0.001	0.000	0.005	0.001	0.001	0.001	0.001	0.002	0.004	0.003	0.002	0.005	0.011	0.003	0.001	0.000	0.002	0.002	0.000	0.000	0.000	0.004	0.002	0.002	0.000	0.001	0.003	0.004	0.002	0.002	0.005	0.001	0.002	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.002	0.002	0.000
5.0-5.5	0.000	0.000	0.001	0.002	0.000	0.002	0.000	0.000	0.002	0.001	0.002	0.002	0.002	0.000	0.001	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.001	0.003	0.002	0.001	0.001	0.001	0.002	0.003	0.000	0.002	0.001	0.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
5.5-6.0	0.000	0.000	0.000	0.003	0.001	0.001	0.000	0.001	0.000	0.002	0.000	0.001	0.000	0.005	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.002	0.002	0.002	0.001	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000
6.0-6.5	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002	0.000
6.5-7.0	0.000	0.001	0.000	0.001	0.000	0.002	0.000	0.000	0.001	0.003	0.000	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.001	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7.0-7.5	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7.5-8.0	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.005	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.0-8.5	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8.5-9.0	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9.0-9.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9.5-10.0	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.0-10.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10.5-11.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11.5-12.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.0-12.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12.5-13.0	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.0-13.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13.5-14.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14.0-14.5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14.5-15.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.0-15.5	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15.5-16.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

File: Probability Analysis of 85th Percentile 24-hr Rainfall.xls
Worksheet: Probability Analysis
Date: 03/16/2004

RB-AR32992

24-hour Rainfall Depth - Cumulative Distribution

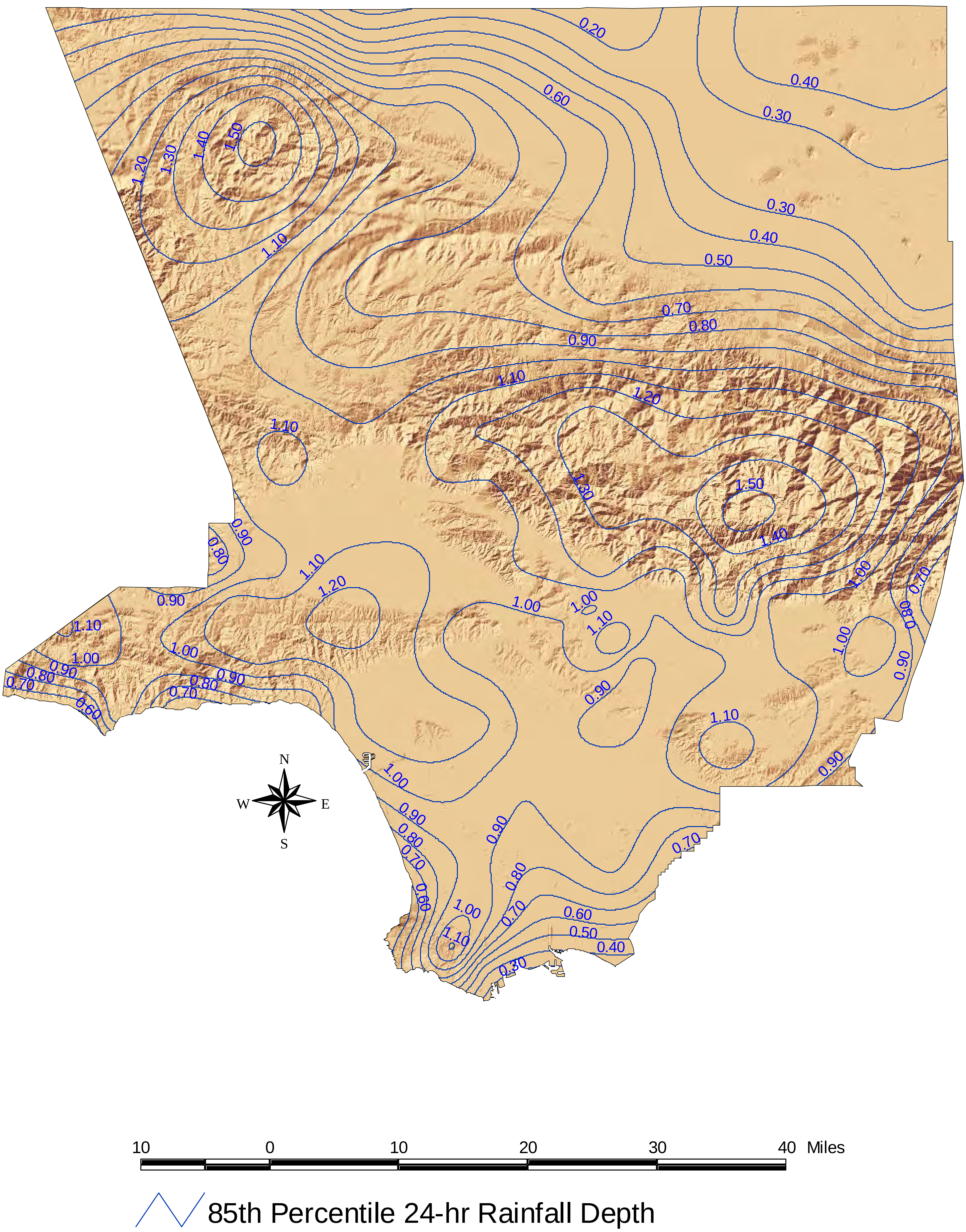


File: Probability Analysis of 85th Percentile 24-hr Rainfall.xls
Worksheet: CDF Graph
Date: 03/16/2004

Appendix C

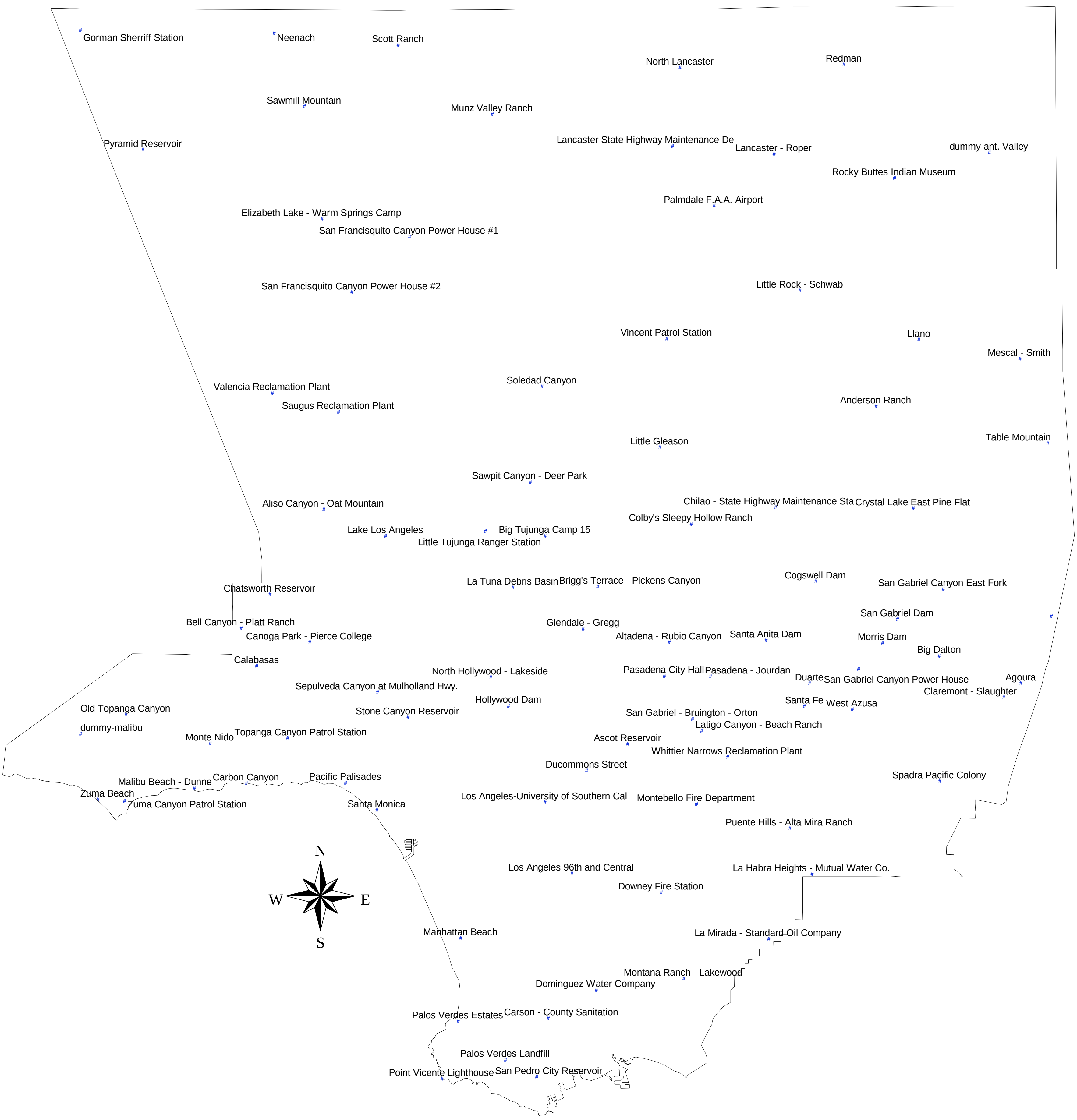
85th Percentile 24-hour Isohyetal Map and Rain Gage Locations

85th Percentile 24-hr Rainfall Isohyetal Map



RB-AR32995

85th Percentile 24-hr Isohyetal Map Gages



10 0 10 20 30 40 50 60 70 80 90 Miles

\# Rain Gage Name

File: final_85th-no_analyst-raingages.apr
Date: 02/10/2004

Procedure for Creating an Isohyetal Map

1. Create a shape file with rainfall depth data at given points throughout the county (rain gages).

2. Import shape file into ArcView and activate the Spatial Analyst extension.

3. Select the shape file with the rainfall data and then zoom to the extents of the shape file.

4. Choose the Interpolate Grid option from the Surface pull down menu.

5. Set the following levels for the input parameters:

    a. Output Extent – select the Same as Display option.
    b. Set the grid size at 1000.
    c. Leave the other settings alone and select the OK button.

6. Choose the spline method from the next pop-up menu.

7. Choose the data values corresponding to the contours desired (i.e., 85th percentile values).

8. Leave the weight value at 0.1.

9. Set the number of points to 50.

10. Select Tension as the type for the interpolation surface and select the OK button.

11. ArcView will create a grid file. If the grid file appears to be what was expected, select the grid file.

12. Select Create Contours from the Surface pull down menu.

13. Set the contour interval and the base (beginning) contour and select the OK button.

14. ArcView will create contours. Select Convert to Shape file from the Theme pull down menu.

15. Auto-label the contours and create a layout for the map.

agricultural commodities (60 FR 47487, September 13, 1995) (FRL–4973–3).

The Agency will take separate actions to propose revocation of any affected tolerances that are not supported for import purposes only.

B. Docket Content

1. *Review docket*. The registration review docket contains information that the Agency may consider in the course of the registration review. The Agency may include information from its files including, but not limited to, the following information:

- An overview of the registration review case status.
- A list of current product registrations and registrants.
- **Federal Register** notices regarding any pending registration actions.
- **Federal Register** notices regarding current or pending tolerances.
- Risk assessments.
- Bibliographies concerning current registrations.
- Summaries of incident data.
- Any other pertinent data or information.

The docket contains a document summarizing what the Agency currently knows about the ethylene case and a preliminary work plan for anticipated data and assessment needs. Additional documents provide more detailed information. During this public comment period, the Agency is asking that interested persons identify any additional information they believe the Agency should consider during the registration review of the pesticide ethylene. The Agency identifies in the docket the areas where public comment is specifically requested, though comment in any area is welcome.

2. *Other related information*. More information on the ethylene case, including the active ingredients for the case, may be located in the registration review schedule on the Agency's website at *http://www.epa.gov/oppsrrd1/registration_review/schedule.htm*. Information on the Agency's registration review program and its implementing regulation may be seen at *http://www.epa.gov/oppsrrd1/registration_review*.

3. *Information submission requirements*. Anyone may submit data or information in response to this document. To be considered during a pesticide's registration review, the submitted data or information must meet the following requirements:

- To ensure that EPA will consider data or information submitted, interested persons must submit the data or information during the comment period. The Agency may, at its discretion, consider data or information submitted at a later date.
- The data or information submitted must be presented in a legible and useable form. For example, an English translation must accompany any material that is not in English and a written transcript must accompany any information submitted as an audiographic or videographic record. Written material may be submitted in paper or electronic form.
- Submitters must clearly identify the source of any submitted data or information.
- Submitters may request the Agency to reconsider data or information that the Agency rejected in a previous review. However, submitters must explain why they believe the Agency should reconsider the data or information in the pesticide's registration review.

As provided in 40 CFR 155.58, the registration review docket for the ethylene case will remain publicly accessible through the duration of the registration review process; that is, until all actions required in the final decision on the registration review case have been completed.

List of Subjects

Environmental protection, Pesticides and pests.

Dated: December 16, 2009.

Keith A. Matthews,

Acting Director, Biopesticides and Pollution Prevention Division, Office of Pesticide Programs.

[FR Doc. E9–30622 Filed 12–24–09; 8:45 am]

BILLING CODE 6560–50–S

ENVIRONMENTAL PROTECTION AGENCY

[EPA–HQ–OW–2009–0817; FRL–9095–3]

Stakeholder Input; Stormwater Management Including Discharges From New Development and Redevelopment

AGENCY: Environmental Protection Agency.

ACTION: Notice.

SUMMARY: The Environmental Protection Agency (EPA) is announcing its plans to initiate national rulemaking to establish a comprehensive program to reduce stormwater discharges from new development and redevelopment and make other regulatory improvements to strengthen its stormwater program. The purpose of this notice is to request input from the public to help EPA shape such a comprehensive program and to announce EPA's intent to hold several public ''listening sessions'' in January 2010. EPA seeks input on this undertaking regarding performance, effectiveness and cost of stormwater control measures; ecological data, including ecological benefits from stormwater controls; technical information on design, implementation and operation and maintenance of stormwater control measures; suggestions for how the existing program may be modified to better meet the goals of the Clean Water Act; and any other information that may help EPA develop improvements to the existing program, including better control of pollutants in stormwater from the built environment created by development and redevelopment.

DATES: Written comments must be submitted on or before February 26, 2010.

ADDRESSES: Submit your comments, identified by Docket ID No. EPA–HQ–OW–2009–0817, by one of the following methods:

- *http://www.regulations.gov:* Follow the online instructions for submitting comments.
- *E-mail: OW-Docket@epa.gov,* Attention Docket ID No. EPA–HQ–OW–2009–0817.
- *Fax:* 202–566–9744.
- *Mail:* Water Docket, U.S. Environmental Protection Agency, Mail code: 4203M, 1200 Pennsylvania Ave., NW., Washington, DC 20460. Attention Docket ID No. EPA–HQ–OW–2009–0817.
- *Hand Delivery:* Water Docket, EPA Docket Center, EPA West Building Room 3334, 1301 Constitution Ave., NW., Washington, DC, Attention Docket ID No. EPA–HQ–OW–2009–0817. Such deliveries are only accepted during the Docket's normal hours of operation, and special arrangements should be made for deliveries of boxed information.

Instructions: Direct your comments to Docket ID No. EPA–HQ–OW–2009–0817. EPA's policy is that all comments received will be included in the public docket without change and may be made available online at *http://www.regulations.gov,* including any personal information provided, unless the comment includes information claimed to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through *http://www.regulations.gov* or e-mail. The *http://www.regulations.gov* Web site is an ''anonymous access'' system, which

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means EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an e-mail comment directly to EPA without going through *http://www.regulations.gov* your e-mail address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses. For additional information about EPA's public docket, visit the EPA Docket Center homepage at *http://www.epa.gov/epahome/dockets.htm*.

FOR FURTHER INFORMATION CONTACT: For further information on the notice, contact Jonathan Angier, EPA Headquarters, Office of Water, Office of Wastewater Management at tel.: 202–564–0729 or e-mail: *angier.jonathan@epa.gov*.

Public Listening Sessions: EPA will hold several informal public listening sessions in January 2010 to gather input on possible regulatory changes to the stormwater program. The public listening sessions will provide a review of EPA's current regulatory approach to permitting stormwater discharges, a summary of the recommendations from the National Research Council report *Urban Stormwater Management in the United States* (The National Academies Press, 2009), and potential considerations for regulatory changes to strengthen the program. The public listening sessions will afford an opportunity for the public to provide input on regulatory actions that EPA is considering. Brief oral comments (three minutes or less) will be accepted at the sessions, and written statements will be accepted. The dates and locations of the listening sessions are as follows:

- January 19, 2010, 10 a.m. to 3 p.m. at EPA Region 5 Office, 77 W. Jackson Blvd., Chicago, IL 60604
- January 20, 2010, 10 a.m. to 3 p.m. at EPA Region 9 Office, 75 Hawthorne Street, San Francisco, CA 94105
- January 25, 2010, 10 a.m. to 3 p.m. at EPA Region 8 Office, 1595 Wynkoop Street, Denver, CO 80202–1129
- January 26, 2010, 10 a.m. to 3 p.m. at EPA Region 6 Office, 1445 Ross Avenue, Suite 1200, Dallas, Texas 75202
- January 28, 2010, 10 a.m. to 3 p.m. at EPA HQ Office, Ariel Rios Building, 1200 Pennsylvania Ave. NW., Washington, DC 20004

In order to provide adequate seating for those wishing to attend EPA's public listening sessions, interested individuals must register to attend by January 15, 2010 on the Internet at *http://www.epa.gov/npdes/stormwater/rulemaking.*

SUPPLEMENTARY INFORMATION:

I. General Information

A. How Can I Get Copies of This Document and Other Related Information?

1. Docket. EPA has established an official public docket for this action under Docket ID No. EPA–HQ–OW–2009–0817. The official public docket is the collection of materials that is available for public viewing at the Water Docket in the EPA Docket Center, (EPA/DC) EPA West, Room 3334, 1301 Constitution Ave., NW., Washington, DC. Although all documents in the docket are listed in an index, some information is not publicly available, i.e., CBI or other information whose disclosure is restricted by statute. Publicly available docket materials are available in hard copy at the EPA Docket Center Public Reading Room, open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744, and the telephone number for the Water Docket is (202) 566–2426.

2. Electronic Access. You may access this **Federal Register** document electronically through the EPA Internet under the ''Federal Register'' listings at *http://www.epa.gov/fedrgstr/.* Electronic versions of this notice and other stormwater documents are available at EPA's stormwater Web site *http://www.epa.gov/npdes/stormwater/rulemaking.*

An electronic version of the public docket is available through EPA's electronic public docket and comment system, EPA Dockets. You may use EPA Dockets at *http://www.epa.gov/edocket/* to submit or view public comments, access the index listing of the contents of the official public docket, and to access those documents in the public docket that are available electronically. Once in the system, select ''search'', then key in the appropriate docket identification number.

Certain types of information will not be placed in the EPA Dockets. Information claimed as CBI and other information whose disclosure is restricted by statute, which is not included in the official public docket, will not be available for public viewing in EPA's electronic public docket. EPA policy is that copyrighted material will not be placed in EPA's electronic public docket but will be available only in printed, paper form in the official public docket. Although not all docket materials may be available electronically, you may still access any of the publicly available docket materials through the docket facility identified in Section I.A.1.

Submitting CBI. Do not submit this information to EPA through regulations.gov or e-mail. Clearly mark all of the information that you claim to be CBI. For CBI information on computer discs mailed to EPA, mark the surface of the disc as CBI. Also identify electronically the specific information contained in the disc or that you claim is CBI. In addition to one complete version of the specific information claimed as CBI, you must submit a copy that does not contain the information claimed as CBI for inclusion in the public document. Information so marked will not be disclosed except in accordance with procedures set forth in 40 CFR Part 2.

It is important to note that EPA's policy is that public input, whether submitted electronically or in paper, will be made available for public viewing in EPA's electronic public docket as EPA receives them and without change, unless the input contains copyrighted material, CBI, or other information whose disclosure is restricted by statute. When EPA identifies any input containing copyrighted material, EPA will provide a reference to that material in the version of the document that is placed in EPA's electronic public docket. The entire printed submittal, including the copyrighted material, will be available in the public docket.

Documents submitted on computer disks that are mailed or delivered to the docket will be transferred to EPA's electronic public docket. Input that is mailed or delivered to the Docket will be scanned and placed in EPA's electronic public docket. Where practical, physical objects will be photographed, and the photograph will be placed in EPA's electronic public docket along with a brief description written by the docket staff.

B. How and to Whom Do I Submit Input?

You may submit input electronically, by mail, through hand delivery/courier, or in person by attending one of the 5 listening sessions. To ensure proper receipt by EPA, identify the appropriate docket identification number in the subject line on the first page of your input. Please ensure that your input is submitted within the specified comment period.

1. Electronically. If you submit electronic input as prescribed below, EPA recommends that you include your name, mailing address, and an e-mail address or other contact information in the body of your comment. Also include this contact information on the outside of any disk or CD–ROM you submit, and in any cover letter accompanying the disk or CD–ROM. This ensures that you can be identified as the submitter of the comment and allows EPA to contact you in case EPA cannot read your submittal due to technical difficulties or needs further information on the substance of your input. EPA's policy is that EPA will not edit your input, and any identifying or contact information provided in the body of the text will be included as part of the input that is placed in the official public docket, and made available in EPA's electronic public docket. If EPA cannot read your submittal due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your input.

i. EPA Dockets. Your use of EPA's electronic public docket to provide input to EPA electronically is EPA's preferred method for receiving comments. Go directly to EPA Dockets at *http://www.epa.gov/edocket*, and follow the online instructions for submitting input. Once in the system, select ''search'', and then key in Docket ID No. EPA–HQ–OW–2009–0817. The system is an ''anonymous access'' system, which means EPA will not know your identity, e-mail address, or other contact information unless you provide it.

ii. E-mail. Input may be sent by electronic mail (e-mail) to *ow-docket@epa.gov*, Attention Docket ID No. EPA–HQ–OW–2009–0817. In contrast to EPA's electronic public docket, EPA's e-mail system is not an ''anonymous access'' system. If you send an e-mail directly to the Docket without going through EPA's electronic public docket, EPA's e-mail system automatically captures your e-mail address. E-mail addresses that are automatically captured by EPA's e-mail system are included as part of the submittal that is placed in the official public docket, and made available in EPA's electronic public docket.

iii. Disk or CD–ROM. You may submit input on a disk or CD–ROM that you mail to the mailing address identified in this section. These electronic submissions will be accepted in Microsoft Word or ASCII file format. Avoid the use of special characters and any form of encryption.

2. By Mail. Send the original and three copies of your input to: Water Docket, Environmental Protection Agency, Mailcode: 4101T, 1200 Pennsylvania Ave., NW., Washington, DC 20460, Attention Docket ID No. EPA–HQ–OW–2009–0817.

3. By Hand Delivery or Courier. Deliver your input to: Public Reading Room, Room B102, EPA West Building, 1301 Constitution Avenue, NW., Washington, DC 20004, Attention Docket ID No. EPA–HQ–OW–2009–0817. Such deliveries are only accepted during the Docket's normal hours of operation (8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays).

II. Background

Statutory and Regulatory Overview

Under section 402(p) of the Clean Water Act, the Environmental Protection Agency regulates stormwater discharges from municipal separate storm sewer systems (publicly owned conveyances or systems of conveyances that discharge to waters of the U.S. and are designed or used for collecting or conveying storm water, are not combined sewers, and are not part of a publicly owned treatment works), stormwater discharges associated with industrial activity, and stormwater discharges from construction sites of one acre or larger. See 40 CFR 122.26(a). Under EPA's regulations, these stormwater discharges are required to be covered by National Pollutant Discharge Elimination System (NPDES) permits.

EPA developed the stormwater regulations under section 402(p) in two phases, as directed by the statute. In the first phase, under section 402(p)(4), EPA promulgated regulations establishing application requirements for NPDES permits for stormwater discharges from medium and large municipal separate storm sewer systems (MS4s) (serving populations of 100,000 or more) and stormwater discharges associated with industrial activity. EPA published the final Phase I rule on November 16, 1990 (55 FR 47990). *See* 40 CFR 122.26. The Phase I rule, among other things, defined ''stormwater discharges associated with industrial activity'' to include construction sites of five acres or larger. 40 CFR 122.26(b)(14)(x). In the second phase, under section 402(p)(5) and (6), EPA was required to conduct a study to identify other stormwater discharges that needed further controls to protect water quality, report to Congress on the results of the study, and to designate for regulation additional categories of stormwater discharges not regulated in Phase I. EPA promulgated the Phase II rule on December 8, 1999, designating small MS4s and small construction sites (1–5 acres) and requiring NPDES permits for these discharges. 64 FR 68722.

With respect to MS4s, the Phase I regulations are primarily application requirements that identify components that must be addressed in permit applications from large and medium MS4s. The regulations require these MS4s to develop a stormwater management program (SWMP), track and oversee industrial facilities regulated under the NPDES stormwater program, conduct monitoring, and submit periodic reports.

Under the Phase II rule, regulated small MS4s are generally defined as any MS4 that is not already covered by the Phase I program and that are located within the urbanized area boundary as determined by the U.S. Decennial Census. Separate storm sewer systems such as those serving military bases, universities, large hospital or prison complexes, and highways are also included in the definition of ''small MS4.'' 40 CFR 122.26(b)(16). In addition, a small MS4 located outside of an urbanized area may be designated as a regulated small MS4 if the NPDES permitting authority determines that its discharges cause, or have the potential to cause, an adverse impact on water quality. *See* 40 CFR 122.32(a)(2), 123.35(b)(3).

Phase II stormwater regulations also require that the MS4, under the permit, implement stormwater management programs (SWMPs), and require that the SWMPs include six minimum control measures. The minimum control measures are: Public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff control, post construction runoff control, pollution prevention and good housekeeping. Regulations applicable to Phase II MS4 permits are found in 40 CFR 122.30–122.37. In general, Phase II MS4 permits are general permits, although small MS4s may apply for individual permits under the Phase I rule's application provisions in 40 CFR 122.26(d).

Under section 402(p)(6), EPA is authorized to designate additional stormwater discharges to be regulated other than those already regulated, and to establish a comprehensive program to regulate them. In addition, under EPA's stormwater regulations, EPA (or States authorized to administer the NPDES program) may require NPDES permits

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for currently unregulated stormwater discharges by designating discharges pursuant to 40 CFR 122.26(a)(9)(i)(C) or (D).

National Research Council Report

In 2006, EPA asked the National Research Council (NRC) to conduct a review of its stormwater program, considering all entities regulated under the program, i.e., municipal, industrial and construction. In October 2008, the National Research Council released the report *Urban Stormwater Management in the United States* (The National Academies Press, 2009) finding, among other things, that ''the rapid conversion of land to urban and suburban areas has profoundly altered how water flows during and following storm events, putting higher volumes of water and more pollutants into the nation's rivers, lakes, and estuaries. These changes have degraded water quality and habitat in virtually every urban stream system.''

This report recommends a number of actions, including conserving natural areas, reducing hard surface cover (e.g., roads and parking lots—impervious surface areas), and retrofitting urban areas with features that hold and treat stormwater (NRC, *Report in Brief,* 2008). EPA takes seriously the significant findings and recommendations included in the NRC Report, and continues to evaluate how the Agency's stormwater program can be strengthened in light of the report. The *Report in Brief* can be accessed at: *http://dels.nas.edu/dels/rpt_briefs/stormwater_discharge_final.pdf.* A full copy of the report can be obtained from The National Academies Press, *http://books.nap.edu/catalog.php?record_id=12465.* A prepublication copy is available at: *http://www.epa.gov/npdes/pubs/nrc_stormwaterreport.pdf.*

EPA shares the NRC Committee's perspective that it is imperative that the stormwater regulations be as effective as possible in protecting water quality. The NRC Report has provided EPA with the opportunity to reexamine the effectiveness of its stormwater programs, some of which are nearly 20 years old. For instance, EPA is interested in assessing the level of accountability that the regulations and the permits issued under the regulations provide to MS4s to minimize the discharge of pollutants in stormwater. The role of MS4s in reducing stormwater impacts from the built environment is crucial and growing, given that these sources of adverse water quality impacts are continually expanding. As the urban, suburban and exurban human environment expands, there is an increase in impervious land cover and therefore an increase in stormwater discharges. This increase in impervious land cover reduces or eliminates the natural infiltration of precipitation, which greatly increases the volume of stormwater discharges. This increased volume of stormwater discharges results in the scouring of rivers and streams; degrading the physical integrity of aquatic habitats, stream function and overall water quality. In addition, the increase in impervious land cover results in the increase of the pollutant load discharged from storm sewers. As precipitation moves across roads, rooftops, and other impervious surfaces, it picks up pollutants that are then discharged, either directly or through storm sewers, to our Nation's waters.

To address the degradation of water quality caused by stormwater discharges from impervious cover, EPA is exploring regulatory options that would strengthen the stormwater program, including establishing specific post construction requirements for stormwater discharges from, at a minimum, new development and redevelopment. EPA does not currently regulate stormwater discharges from new development and redevelopment directly. However, both Phase I MS4s and Phase II MS4s are required through the MS4 permit to address stormwater discharges from new development and redevelopment in their SWMPs, but the regulations do not include specific management practices or standards to be implemented. Among the Phase I requirements for a SWMP is a ''comprehensive master plan to develop, implement, and enforce controls to reduce the discharge of pollutants from municipal storm sewers, which receive discharges from areas of new development and significant redevelopment. Such plan shall address controls to reduce pollutants in discharges from municipal separate storm sewers after construction is completed.'' (40 CFR 122.26(d)(2)(iv)(A)(2)).

Phase II regulations include post construction requirements as one of the six minimum control measures to be addressed in the SWMP. Small MS4s must ''develop, implement, and enforce a program to address'' stormwater discharges from new development and redevelopment projects of one acre or greater to ''ensure that controls are in place that would prevent or minimize water quality impacts.'' 40 CFR 122.34(b)(5). The program must include strategies including structural and/or non-structural best management practices (BMPs) appropriate for the community; use of ordinances or other regulatory mechanisms to the extent allowable under State, Tribal or local law; and measures to ensure adequate long-term operation and maintenance of BMPs. The Phase II rule recommends (but does not require) that the program to address stormwater from new development and redevelopment should attempt to maintain pre-development runoff conditions by installing and implementing stormwater control measures.

As stated in the report, the NRC found that ''stormwater permits leave a great deal of discretion to the regulated community to set their own standards and to self-monitor.'' As a result, across the Nation there is inconsistency in the NPDES program and in stormwater management programs required by NPDES permit with respect to stormwater discharges from MS4s caused by stormwater discharges from development. Despite the lack of specificity in the current regulations, some permitting authorities have required controls for stormwater discharges from developed property that neutralize the impacts from stormwater by promoting practices that retain stormwater on-site through infiltration, evapotranspiration, or stormwater reuse. To help make permitting more consistent and robust nationally, EPA is considering ways to strengthen the MS4 permit regulations, including establishing specific requirements for stormwater discharges from, at a minimum, new development and redevelopment; expanding the area defined as MS4s to include rapidly developing areas; and devising a single set of consistent regulations for all MS4s. In addition, EPA is exploring regulatory options to directly address stormwater discharges from new development and redevelopment, including new and redeveloped sites outside the MS4 boundary, that may be contributing to waterbody impairment, through the designation of an additional category or categories of discharges under CWA section 402(p)(6).

Proposed Information Collection Request (ICR)

EPA has proposed an Information Collection Request (ICR) to collect data to support this effort to strengthen the stormwater regulations (published October 30, 2009, 74 FR 56191). The proposed ICR discusses the administration of three questionnaires: The first for the owners, operators, developers, and contractors of new development and redevelopment; the second for the owners and operators of MS4s (including those not federally regulated); and the third for the States and territories. The data collected through this ICR would support EPA's rulemaking activities by providing EPA with information to characterize the current level of stormwater controls and stormwater control measures; the area currently covered by federal and state stormwater requirements; the current burden and expenditures by States and MS4s associated with existing requirements; and technical, financial, and environmental data needed to quantify the incremental pollutant removals, compliance costs, and impacts for various regulatory options that EPA might consider. Under the proposed ICR, EPA seeks any available information concerning current stormwater control practices, including those referred to as green infrastructure or low-impact development. For further information, see: *http://www.epa.gov/npdes/stormwater/rulemaking*.

III. Input on Stormwater Practices and Considerations for Modifying Regulations

Today's notice is being issued to make the public aware of opportunities to provide input on current stormwater practices and to inform the public of and solicit comment on EPA's preliminary considerations for modifying or supplementing EPA's stormwater regulations. EPA is accepting information during the listening sessions and/or by submission of written comments in order to gain early public input on stormwater practices and regulations.

A. Solicitation for Additional Input Regarding Stormwater Control Practices

1. In addition to the information collection request described above, EPA is soliciting comment and input from the general public concerning current stormwater control practices, as well as information concerning innovative approaches to stormwater control. In particular, EPA is seeking information on the following aspects of structural approaches to stormwater control: design, performance, operation and maintenance, capital and lifetime cost, and environmental and economic benefit information on practices that retain stormwater on-site through infiltration, evapotranspiration, or stormwater reuse. EPA solicits comment and input on these retention practices that have been used for ''green field'' development, redevelopment (where there was some pre-existing infrastructure), and retrofitting existing development. While a significant amount of data has been collected and is available (see, EPA's Urban BMP Performance Tool (*http://www.epa.gov/npdes/stormwater/urbanbmp*) or the International Stormwater BMP Database (*http://www.bmpdatabase.org*)), EPA is accepting any more recent information that is not already available in these databases.

2. Cost comparisons of different stormwater management approaches for specific sites. EPA solicits comment and input on different stormwater management approaches, including comparison of stormwater management systems that rely primarily on conveyance and detention of excess discharge with stormwater management systems that relies primarily on on-site retention. Cost comparisons should preferably be between similar sized projects and/or between individual management methods of similar scope and capability.

3. Design, performance, operation and maintenance, capital and lifetime costs, and environmental and economic benefit information for communities and/or site owners or operators that have elected to modify or retrofit their stormwater management practices for existing development, as a separate effort that is not in conjunction with redevelopment. This may occur if the existing stormwater management practices were insufficient to reduce pollutants, restore habitat and stabilize stream morphology, or to correct past mistakes. This may also occur as part of a larger watershed restoration plan. EPA is also soliciting comments and input on: where retrofit practices have been installed, what the drivers were for the project, and information on the specific retrofit practices that were installed.

4. EPA is also soliciting comments and input on monitoring information that may have been collected to show the impacts of stormwater control measures on water quality and/or flow rates in the receiving waterbody. This includes information on the effects of retrofits for existing discharges (before and after installation, if possible), as well as any water monitoring information obtained before and after new development and redevelopment.

B. Preliminary Considerations for Modifying/Supplementing EPA's Stormwater Regulations

By today's notice, EPA is informing the public of its preliminary considerations for modifying or supplementing EPA's stormwater regulations and soliciting public input on these considerations. The following are ideas that EPA is considering for strengthening the stormwater requirements and for which EPA seeks input:

1. *Expand the area subject to federal stormwater regulations.* EPA currently requires MS4s within Census-designated urbanized areas to apply for permit coverage (see *http://www.epa.gov/npdes/stormwater/urbanmaps* for maps of all urbanized areas). Based on the 1990 Census, there are 405 urbanized areas in the United States that cover 2% of total U.S. land area and contain approximately 63 percent of the Nation's population. Under the present regulations, development that is occurring outside currently regulated MS4s may not be subject to federal controls to protect water quality notwithstanding the fact that the resulting stormwater discharges may be contributing to waterbody impairment. For example, for Phase II MS4s, only the portion of the municipal jurisdiction (i.e. township) that is within the Census-designated urbanized area is required to be regulated, which may leave stormwater discharges in parts of the jurisdiction unregulated.

EPA solicits comments and input from the public on the need for expanding the area subject to federal regulation, and, if needed, how to expand the coverage of the federal stormwater program beyond the Census urbanized area boundary. EPA would be interested in views on (1) How to identify the appropriate jurisdictional boundaries for permit coverage, including the township, county, sewer district, or others; (2) how to identify areas that should be covered based on development pressures and to protect water quality; and (3) whether EPA should consider regulating stormwater discharges from particular types or sizes of development that are not covered by an MS4 permit.

2. *Establish specific requirements to control stormwater discharges from new development and redevelopment.* EPA is considering establishing specific requirements, including standards, to control stormwater discharges from new development and redevelopment. EPA welcomes comments on what standard or standards could apply to new development and redevelopment that promote sustainable practices that mimic natural processes to (1) Infiltrate and recharge, (2) evapotranspire, and/or (3) harvest and reuse precipitation. For example, there could be a national requirement for on-site stormwater controls such that post development hydrology mimics predevelopment hydrology on a site-specific basis. EPA could establish a suite of specific options of standards for meeting such a requirement, for example, on-site retention of a specific size storm event in an area, limits on the amount of

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effective impervious surfaces (defined as impervious surfaces with direct hydraulic connection to the downstream drainage (or stream) system, also referred to as directly connected impervious area), use of site-specific calculations to determine predevelopment hydrology, and/or use of regional specific standards to reflect local circumstances. EPA could require these standards as part of the MS4 permit on a site-specific basis. EPA is interested in input regarding the need for and the type of standards to set. Should the standard be different for discharges from new development versus redevelopment and, if so, how should it differ? Are there specific circumstances in which (for example) a requirement for new development and redevelopment to maintain pre-development hydrology would not be advisable or would cause other environmental impacts? Finally, EPA is interested in input regarding responsibility for maintaining stormwater control measures that infiltrate, evapotranspirate and/or reuse water.

The impacts from stormwater discharges from new and redevelopment occur not only within the MS4 but also from sources outside the MS4 regulated areas. EPA is interested in input regarding the appropriate framework for implementing standards for new and redevelopment outside of the MS4 regulations.

3. Develop a single set of consistent requirements for Phase I and Phase II MS4s. EPA's Phase I regulations primarily contain application requirements that identify components that must be addressed in permit applications. The Phase II regulations establish six ''minimum measures'' that must be included in an MS4 permit that were more specific than Phase I. Many Phase I and Phase II permits address issues that are virtually identical. EPA requests input on whether EPA should modify the regulations to develop a consistent set of requirements that would apply to all regulated MS4s. For example, should EPA apply the six minimum measures to all MS4s? Should EPA add other measures? For instance, Phase I MS4s are required to implement a program to control discharges for industrial facilities in their service area. Should this requirement be extended to all MS4s? EPA also requests input on any other modifications to improve the stormwater regulations.

4. Require MS4s to address stormwater discharges in areas of existing development through retrofitting of the sewer system, drainage area, or individual structures with improved stormwater control measures. Stormwater discharge from large areas of impervious cover in developed areas is a significant contributor to water quality impairments in the receiving waters of urban areas. Changes to the stormwater management practices in areas of existing development will reduce these impacts. In some states, MS4 permits now require the MS4 to install retrofit practices that infiltrate or otherwise retain stormwater in areas of existing development to reduce these impacts. EPA requests input on whether it should consider requirements for the retrofit of existing development to address stormwater. In particular, EPA requests comment on requiring MS4s to develop a long-term retrofit implementation plan that is targeted to addressing stormwater problems in urban waters.

5. Whether EPA should include additional changes to the stormwater regulations (for example, requiring permits to include buffer requirements) in sensitive areas. EPA is interested in views on whether it should consider making any other changes to the current regulatory program (e.g., specific structural or nonstructural stormwater control measures) in addition to the ones described above to protect waterbodies in sensitive areas.

Dated: December 17, 2009.

Peter Silva,

Assistant Administrator, Office of Water.

[FR Doc. E9–30627 Filed 12–24–09; 8:45 am]

BILLING CODE 6560–50–P

FEDERAL DEPOSIT INSURANCE CORPORATION

Agency Information Collection Activities: Renewal of a Currently Approved Collection; Comment Request

AGENCY: Federal Deposit Insurance Corporation (FDIC).

ACTION: Notice and request for comment.

SUMMARY: In accordance with requirements of the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et seq.), the FDIC may not conduct or sponsor, and the respondent is not required to respond to, an information collection unless it displays a currently valid Office of Management and Budget (OMB) control number. The FDIC hereby gives notice that it is seeking public comment on renewal of its ''Foreign Banks'' information collection (OMB No. 3064–0114). At the end of the comment period, any comments and recommendations received will be analyzed to determine the extent to which the FDIC should modify the collection prior to submission to OMB for review and approval.

DATES: Comments must be submitted on or before February 26, 2010.

ADDRESSES: Interested parties are invited to submit written comments. All comments should refer to the name of the collection. Comments may be submitted by any of the following methods:

- *http://www.FDIC.gov/regulations/laws/federal/notices.html.*
- *E-mail: comments@fdic.gov.*
- *Mail:* Leneta G. Gregorie (202.898.3719), Counsel, Federal Deposit Insurance Corporation, 550 17th Street, NW., Washington, DC 20429.
- *Hand Delivery:* Comments may be hand-delivered to the guard station at the rear of the 550 17th Street Building (located on F Street), on business days between 7 a.m. and 5 p.m.

A copy of the comments may also be submitted to the FDIC Desk Officer, Office of Information and Regulatory Affairs, Office of Management and Budget, New Executive Office Building, Room 10235, Washington, DC 20503.

FOR FURTHER INFORMATION CONTACT: For further information about the information collection discussed in this notice, please contact Leneta G. Gregorie, by telephone at (202) 898–3719 or by mail at the address identified above.

SUPPLEMENTARY INFORMATION: The FDIC is proposing to renew, without change, the following information collection.

Title: Foreign Banks.

Estimated Number of Respondents and Burden Hours:

FDIC collection	Hours per response	Number of respondents	Times per year	Burden hours
Application to move a branch	8	1	1	8
Application for consent to operate a noninsured branch	8	1	1	8
Application to conduct activities	8	1	1	8
Recordkeeping	120	10	1	1,200

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Renee Purdy - Items 4 and 5 from our Recap (To Do List) for 9/28/11 LA MS4 permit meeting

From:	Wesley Ganter <wes.ganter@pgenv.com>
To:	"kemmerer.john@epa.gov" <kemmerer.john@epa.gov>, Renee Purdy <rpurdy@wat...
Date:	10/6/2011 2:56 PM
Subject:	Items 4 and 5 from our Recap (To Do List) for 9/28/11 LA MS4 permit meeting
CC:	Wesley Ganter <wes.ganter@pgenv.com>, Jim Parker <jim.parker@pgenv.com>,...
Attachments:	Core Permit Requirements_SummaryTable and Draft Language_Industrial and Commercial_PG_100611.docx; Core Permit Requirements_SummaryTable and Draft Language_Illicit Connection IllicitDischarge_PG_100611.docx

Hi everyone:

Per the recap email from our 9/28 meeting (see below), PG has attached two templates for Item 4 - **Core Permit Requirements Objectives, Elements, and Issue Tables.** Individual files are provided for the Industrial & Commercial and Illicit Connection and Illicit Discharge Elimination MCMs. You will note that the tables include objectives, draft citations, requirements, issues, and opportunity for flexibility amongst dischargers columns. These tables should be considered preliminary drafts and will be more formally completed throughout October. Nonetheless, the tables are intended to serve as templates and to solicit your feedback. At the present time we envision creating 8 such tables (e.g., all 6 MCMs plus monitoring and reporting).

You will also note that we have also included our proposed draft permit language for the respective MCM. PG had previously prepared this language and had held several discussions with Ivar to refine it so we thought it best to attach it now for your consideration. PG has also completed draft language for the Public Information and Participation Program and made significant progress on the Public Agencies Activities Program. Therefore we will be able to rapidly move forward with those elements and then turn our focus to Construction, Planning and New Development, Reporting, and Monitoring.

We hope that these tables will provide significant benefit at the planned November 10th informational Board meeting and possibly for other planned workshops or meetings. Likewise, they will help our team to readily see and digest the requirements and then identify and resolve issues before substantial permit writing occurs.

Please let us know if you have any suggested improvements or modifications to the template as we will be moving forward with the remaining tables quickly.

Also, I provided Renee the Item 5 - **Microsoft Project File** – earlier in the week.

Thanks much and contact me directly if you have questions or comments.

Wes Ganter
PG Environmental, LLC
607 10th Street, Suite 307
Golden, CO 80401
303-279-1778 Ext. 100 (office)
303-570-4336 (cell)
wes.ganter@pgenv.com

visit our website at www.pgenv.com

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Core Permit Requirements – Table of Objectives, Elements, and Issues

Minimum Control Measure – Industrial/Commercial Storm Water Sources

Primary Objectives:	• To identify and track industrial/commercial facilities which may be critical sources of storm water pollution to the MS4. • To educate and raise storm water awareness of industrial/commercial facility employees to ultimately change behaviors that will reduce pollutant discharges to the MS4. • To ensure the implementation of BMPs at from industrial/commercial facilities to reduce the contribution of pollutants to storm water from industrial/commercial activities and materials storage. • To increase the detection of illicit discharges and connections to the MS4 from industrial/commercial facilities. • To minimize the occurrence of illicit discharges and connections to the MS4 from industrial/commercial facilities.

Permit Citation[1]	Category	Description of Requirement	Issues to be Addressed by Regional Board	Opportunities for Flexibility amongst Dischargers
Part VI.C.8.a	General	Ensure implementation of pollutant reduction and control measures at industrial and commercial facilities, with the objective of reducing pollutants in storm water.		
Part VI.C.8.b.i	Track	Maintain an updated watershed-based inventory or database of all industrial and commercial facilities within the jurisdiction that are critical sources of storm water pollution. Incorporate this information into GIS.		
Part VI.C.8.b.ii	Track	This permit requirement lists the specific information which must be included in the inventory or database of critical sources.		
Part VI.C.8.b.iii	Track	Update the inventory or database of critical sources at least annually.		
Part VI.C.8.c.i	Inspect	Inspect all commercial facilities identified by the Permit twice during the 5-year term of the Order, with the first mandatory compliance inspection within 2 years after Order adoption date. This permit requirement includes subsections that detail inspection and BMP requirements for different types of facilities, such as, (1) restaurants, (2) automotive service facilities, (3) retail gasoline outlets and automobile dealerships,		

[1] Short-name permit citation from current Draft Los Angeles County MS4 Permit. Full permit citation includes suffix, "Part VII – Provisions, C - Special Provisions (Baseline) – 8 - Industrial/Commercial Business Program."

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		and (4) commercial nurseries and nursery centers.		
Part VI.C.8.c.ii.1	Inspect	Conduct compliance inspections at industrial facilities identified by the Permit. Initial inspection must be within 2 years after Order adoption date. Conduct follow-up inspections at 20 percent of no-exposure facilities each year after the initial inspections are complete.		
Part VI.C.8.c.ii.2	Inspect	During each inspection, confirm that each operator has a current WDID number, has a No Exposure Certification, if applicable, and is effectively implementing BMPs for the reduction of pollutants in storm water discharges from the facility.		
Part VI.C.8.d.i	Ensure Compliance	Ensure BMP implementation of the source control BMPs identified in the *California Stormwater BMP Handbook, Industrial and Commercial*		
Part VI.C.8.d.ii	Ensure Compliance	Ensure implementation of additional pollutant-specific controls for critical sources that discharge to MS4s that directly discharge to ESAs or to CWA § 303(d) listed impaired waterbodies.		
Part VI.C.8.d.ii	Ensure Compliance	Implement a progressive enforcement policy to ensure that facilities are brought into compliance with all storm water requirements within a reasonable time period, as specified in the Permit.		
Part VI.C.8.e.i	Interagency Coordination	A Permittee may refer a violation(s) of its municipal storm water ordinances and California Water Code § 13260 by Industrial and Commercial facilities to the Regional Water Board provided that the Permittee has conducted and documented at least two follow-up inspections and two warning letters or notices of violation.		
Part VI.C.8.e.ii	Interagency Coordination	For facilities in violation of municipal storm water ordinances and subject to the Industrial Activities Storm Water General Permit (IASGP), Permittees may escalate referral of such violations to the Regional Water Board (promptly via telephone or electronically) after one inspection and one written notice of violation		
Part VI.C.8.e.iii	Interagency Coordination	Initiate, within one business day of complaint transmittal by the Regional Water Board, investigation of complaints (other than non-storm water discharges to the MS4) from facilities.		
Part VI.C.8.e.iv	Interagency Coordination	Provide assistance to the Regional Water Board for enforcement actions, as directed by the Regional Water Board		

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		Executive Officer.		
Part VI.C.8.e.v	Interagency Coordination	Participate in an enforcement task force with the Regional Water Board and other public agencies.		

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Draft Permit Language

Part VI.C.8 – Industrial/Commercial Facilities Program

a. General

i. Each Permittee shall require implementation of pollutant reduction and control measures at industrial and commercial facilities, with the objective of reducing pollutants in storm water. At a minimum, the Industrial/ Commercial Facilities Control Program shall be implemented in accordance with the requirements listed in this part, consisting of the following components:

(1) Track

(2) Inspect

(3) Ensure compliance with municipal ordinances at industrial and commercial facilities that are critical sources of pollutants in storm water

b. Track Critical Sources

i. Each Permittee shall maintain an updated watershed-based inventory or database of all industrial and commercial facilities within its jurisdiction that are critical sources of storm water pollution. The incorporation of facility information into a Geographical Information System (GIS) is required. Critical Sources to be tracked are summarized below, and specified in Attachment "B":

(1) Commercial Facilities

(A) Restaurants

(B) Automotive service facilities

(C) RGOs and automobile dealerships

(D) Nurseries and Nursery Centers (Merchant Wholesalers, Nondurable Goods, and Retail Trade)

(2) U.S. EPA Phase I, II Facilities

(3) Other federally-mandated facilities [as specified in 40 CFR 122.26(d)(2)(iv)(C)]

(A) Municipal landfills

(B) Hazardous waste treatment, disposal, and recovery facilities

(C) Facilities subject to SARA Title III (also known as the Emergency Planning and Community Right-to-Know Act (EPCRA))

(4) All other commercial or industrial facilities tributary to an impaired water body segment, where the facility generates pollutants for which the water body segment is impaired

Comment [A1]: Per Ivar (6/27/11), no need to add additional categories. Mobile sources s/b handled in PIPP. Plastics already captured as EPA Phase I facilities. SC

Comment [A2]: Per Ivar (6/27/11), keep tabs on State Board's IASGP as it may abandon this reference ... in which case this will need to be modified. SC

Comment [A3]: Confirmed the use of Phase II here with Ivar (6/27/11). Alternatively just replace with 40 CFR 122.26(b)(14).

Ivar (6/27/11) stated Phase I facilities captures preproduction plastics transfer and storage facilities.

Per Ivar, get away from tiers and prioritization. Only prioritization method he would consider is based on exposure. SC

Comment [A4]: Taken from State Board's Phase II general permit. SC

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(5) All other commercial or industrial facilities that the Permittee determines may contribute a significant pollutant load to the MS4

ii. Each Permittee shall include the following minimum fields of information for each critical source industrial and commercial facility in its watershed-based inventory or database:

(1) Name of facility

(2) Name of owner/ operator and contact information

(3) Address of facility (physical and mailing)

(4) A narrative description including Standard Industrial Classification (SIC) System/ North American Industry Classification System (NAICS) codes that best describe the industrial activities performed and principal products used at each facility and status of exposure to storm water.

(5) Name of receiving water

(6) Identification of whether the facility is tributary to a CWA § 303(d) listed waterbody segment or waterbody segment subject to a TMDL, where the facility generates pollutants for which the waterbody segment is impaired

(7) Coverage under the IASGP or other individual or general NPDES permits or any applicable waiver issued by the Regional or State Board pertaining to storm water discharges

iii. Each Permittee shall update its inventory of critical sources at least annually. The update shall be accomplished through collection of new information obtained through field activities or through other readily available inter and intra-agency informational databases (e.g., business licenses, pretreatment permits, sanitary sewer connection permits, and similar information).

Comment [A5]: Implies waterbody information but specified below as well. SC

Comment [A6]: (5) Description of BMPs employed. MB

Couldn't they choose to do this as part of inspection records, or do you mean structural treatment controls? SC

c. Inspect Critical Sources

i. **Commercial Facilities**

Mandatory Compliance Inspections: Each Permittee shall inspect all commercial facilities identified in Parts 4.D.2(a)(1), 4.D.2(a)(4), and 4.D.2(a)(5) twice during the 5-year term of the Order, provided that the first mandatory compliance inspection occurs no later than (2 years after Order adoption date). A minimum interval of 6 months between the first and the second mandatory compliance inspection is required. In addition, each Permittee shall implement the activities outlined in the following subparts. At each facility, inspectors shall verify that the operator is implementing the source control BMPs for the corresponding facility type as specified in Parts 4.D.3(a)(1) - 4.D.3(a)(4). The Permittees shall require implementation of additional BMPs where storm water from the MS4 discharges to an environmentally sensitive area (ESA, see Part 6 for definition) or a CWA § 303(d) listed waterbody (see Part 4.D.4(b) below).

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(1) Restaurants - *Scope of Inspection*: Each Permittee shall inspect all restaurants within its jurisdiction to confirm that storm water BMPs are being effectively implemented in compliance with state law, and county and municipal ordinances. The following BMPs shall be implemented, unless the pollutant generating activity does not occur: the Municipal Sidewalk and Street Washing BMPs listed in Attachment 2 of Regional Water Board Resolution 98-08, and the BMPs listed in Table 2 (BMPs at Restaurants).[2]

Comment [A7]: Confirmed with Ivar (6/27/11). There is no need to modify Order to address non-traditional flood control district and their reg mechanisms. SC

Table 2 - BMPs at Restaurants

Pollutant-Generating Activity	BMP Narrative Description	California Stormwater BMP Handbook Industrial and Commercial BMP Identification #
Waste/ Hazardous Materials Storage, Handling and Disposal	Implementation of effective storage, handling and disposal procedures for hazardous materials.	By Permittees
Unauthorized Non-Storm Water Discharges	Effective elimination of non-storm water discharges.	SC-10
Accidental Spills/ Leaks	Implementation of effective spills/ leaks prevention and response procedures.	SC-11
Outdoor Storage of Raw Materials	Implementation of effective source control practices and structural devices.	SC-33
Storage and Handling of Solid Waste	Implementation of effective solid waste storage/ handling practices and appropriate control measures	SC-34
Parking/ Storage Area Maintenance	Implementation of effective parking/ storage area designs and housekeeping/ maintenance practices	SC-43
Storm Water Conveyance System Maintenance	Implementation of proper conveyance system operation and maintenance protocols.	SC-44

Comment [A8]: Confirmed with Ivar (6/27/11): Reference most recent BMPs developed by CASQA throughout. He foresees that watershed based permit would lead to pooled resources and access to CASQA would not be cost prohibitive. SC

(2) Automotive Service Facilities – *Scope of Inspection*: Each Permittee shall inspect all automotive service facilities within its jurisdiction to confirm that storm water BMPs are being effectively implemented in compliance with state law, and county and municipal ordinances. The following BMPs shall be implemented, unless the pollutant generating activity does not occur: the Municipal Sidewalk and

[2] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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Street Washing BMPs listed in Attachment 2 of Regional Water Board Resolution 98-08, and the BMPs listed in Table 3 (BMPs at Automotive Service Facilities).[3]

Table 3 - BMPs at Automotive Service Facilities

Pollutant-Generating Activity	BMP Narrative Description	California Stormwater BMP Handbook Industrial and Commercial BMP Identification #
Unauthorized Non-Storm Water Discharges	Effective elimination of non-storm water discharges.	SC-10
Accidental Spills/ Leaks	Implementation of effective spills/ leaks prevention and response procedures.	SC-11
Vehicle/ Equipment Fueling	Implementation of effective fueling source control devices and practices.	SC-20
Vehicle/ Equipment Cleaning	Implementation of effective equipment/ vehicle cleaning practices and appropriate wash water management practices	SC-21
Vehicle/ Equipment Repair	Implementation of effective vehicle/ equipment repair practices and source control devices.	SC-22
Outdoor Liquid Storage	Implementation of effective outdoor liquid storage source controls and practices.	SC-31
Outdoor Storage of Raw Materials	Implementation of effective source control practices and structural devices.	SC-33
Storage and Handling of Solid Waste	Implementation of effective solid waste storage/ handling practices and appropriate control measures	SC-34
Parking/ Storage Area Maintenance	Implementation of effective parking/ storage area designs and housekeeping/ maintenance practices	SC-43
Storm Water Conveyance System Maintenance Practices	Implementation of proper conveyance system operation and maintenance protocols.	SC-44

[3] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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(3) Retail Gasoline Outlets and Automobile Dealerships – *Scope of Inspection*: Each Permittee shall inspect all RGOs and automobile dealerships within its jurisdiction to confirm that storm water BMPs are being effectively implemented in compliance with state law, and county and municipal ordinances. The following BMPs shall be implemented, unless the pollutant generating activity does not occur: the Municipal Sidewalk and Street Washing BMPs listed in Attachment 2 of Regional Water Board Resolution 98-08, the Stormwater Quality Task Force Best Management Practice Guide for RGOs, and the BMPs listed in Table 4 (BMPs at Retail Gasoline Outlets and Automobile Dealerships).[4]

Table 4 - BMPs at Retail Gasoline Outlets and Automobile Dealerships

Pollutant-Generating Activity	BMP Narrative Description	California Stormwater BMP Handbook Industrial and Commercial BMP Identification #
Unauthorized Non-Storm Water Discharges	Effective elimination of non-storm water discharges.	SC-10
Accidental Spills/ Leaks	Implementation of effective spills/ leaks prevention and response procedures.	SC-11
Vehicle/ Equipment Fueling	Implementation of effective fueling source control devices and practices.	SC-20
Vehicle/ Equipment Cleaning	Implementation of effective wash water control devices.	SC-21
Outdoor Storage of Raw Materials	Implementation of effective source control practices and structural devices.	SC-33
Storage and Handling of Solid Waste	Implementation of effective solid waste storage/ handling practices and appropriate control measures	SC-34
Building and Grounds Maintenance	Implementation of effective facility maintenance practices.	SC-41
Parking/ Storage Area Maintenance	Implementation of effective parking/ storage area designs and housekeeping/ maintenance practices	SC-43

[4] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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(4) Commercial Nurseries and Nursery Centers (Merchant Wholesalers, Nondurable Goods, and Retail Trade) – *Scope of Inspection*: Each Permittee shall inspect all commercial nurseries and nursery centers within its jurisdiction to confirm that storm water BMPs are being effectively implemented in compliance with state law, and county and municipal ordinances. The BMPs listed in Table 5 (BMPs at Nurseries)[5] shall be implemented, unless the pollutant generating activity does not occur.

Table 5 - BMPs at Nurseries

Pollutant-Generating Activity	BMP Narrative Description	California Stormwater BMP Handbook Industrial and Commercial BMP Identification #
Unauthorized Non-Storm Water Discharges	Effective elimination of non-storm water discharges.	SC-10
Outdoor Loading/ Unloading	Implementation of effective outdoor loading/ unloading practices.	SC-30
Outdoor Liquid Storage	Implementation of effective outdoor liquid storage source controls and practices.	SC-31
Outdoor Equipment Operations	Implementation of effective outdoor equipment source control devices and practices.	SC-32
Outdoor Storage of Raw Materials	Implementation of effective source control practices and structural devices.	SC-33
Building and Grounds Maintenance	Implementation of effective facility maintenance practices.	SC-41

ii. **Industrial Facilities**

Each Permittee shall conduct compliance inspections as specified below.

(1) Frequency of Inspections

(A) *Mandatory Compliance Inspections*: Each Permittee shall perform an initial mandatory compliance inspection at all industrial facilities identified in Parts 4.D.2(a)(2) - 4.D.2(a)(5) no later than (2 years after Order adoption date). After the initial inspection, all facilities determined as having exposure of industrial activities to storm water are subject to a second mandatory compliance inspection. A minimum interval of 6

Comment [A9]: Question the RB on whether they want to abandon or modify the Tier 1 and 2 categorizations used in the current LA permit (See above). Ventura did not use this convention and it is included here instead.

Per Ivar, lets strike and build flexibility into option SQMP up front. SC

[5] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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months between the first and the second mandatory compliance inspection is required. A facility need not be inspected more than twice during the term of the Order unless subject to an enforcement action as specified in Part 4.D.4(c)(2) below.

(B) *No Exposure Verification*: Following the first mandatory compliance inspection, a Permittee shall also perform a second mandatory compliance inspection yearly at a minimum of 20% of the facilities determined not to have exposure of industrial activities to storm water at the time of the first mandatory compliance inspection. The purpose of this inspection is to verify the continuity of the no exposure status. Facilities determined as having exposure will be notified that they must obtain coverage under the IASGP. A minimum interval of 6 months between the first and the second mandatory compliance inspection is required.

(C) *Applicable to All Facilities*: A Permittee need not inspect facilities that have been inspected by the Regional Water Board within the previous 24 month interval. However, if the Regional Water Board performed only one inspection, the Permittee shall conduct the second required mandatory compliance inspection.

(2) Scope of Inspection:

Each Permittee shall confirm that each operator:

(A) Has a current Waste Discharge Identification (WDID) number for facilities discharging storm water associated with industrial activity, and that a Storm Water Pollution Prevention Plan (SWPPP) is available on-site; <u>or</u>

(B) Has applied and has a current No Exposure Certification (and WDID number) for facilities subject to this requirement;

(C) Is effectively implementing BMPs in compliance with state law, and county and municipal ordinances. Facilities must implement the source control BMPs identified in the *California Stormwater BMP Handbook, Industrial and Commercial*[6], unless the pollutant generating activity does not occur. The Permittees shall require implementation of additional BMPs where storm water from the MS4 discharges to an environmentally sensitive area (ESA, see

[6] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption, and the source control BMPs can be found in Section 3 of that version. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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Part 6 for definition) or a CWA § 303(d) listed waterbody (see Part 4.D.4(b) below).

d. Ensure Compliance of Critical Sources

i. *BMP Implementation*:

Facilities must implement the source control BMPs identified in the *California Stormwater BMP Handbook, Industrial and Commercial*[7], unless the pollutant generating activity does not occur. In the event that a Permittee determines that a BMP is infeasible at any site, the Permittee shall require implementation of similar BMPs that will achieve the equivalent reduction of pollutants in the storm water discharges. Likewise, for those BMPs that are not protective of water quality standards, Permittees may require additional site-specific controls.

ii. *Environmentally Sensitive Areas (ESAs) and Impaired Waters*:

For critical sources that discharge to MS4s that directly discharge to ESAs or to CWA §303(d) listed impaired waterbodies, the Permittees shall require operators to implement additional pollutant-specific controls to reduce pollutants in storm water runoff that are causing or contributing to exceedances of water quality objectives. If the Regional Water Board has approved a TMDL Implementation Plan for the receiving water, the Permittees shall require operators to take all actions necessary to implement the applicable provisions of the TMDL Implementation Plan.

iii. *Progressive Enforcement*:

Each Permittee shall implement a progressive enforcement policy to ensure that facilities are brought into compliance with all storm water requirements within a reasonable time period as specified below.

(1) Follow-up inspections: In the event that a Permittee determines, based on an inspection conducted, that an operator has failed to adequately implement all necessary BMPs, that Permittee shall take progressive enforcement actions which, at a minimum, shall include a follow-up inspection within 4 weeks from the date of the initial inspection.

(2) Enforcement action: In the event that a Permittee determines that an operator has failed to adequately implement BMPs after a follow-up inspection, that Permittee shall take enforcement action as established through authority in its municipal code and ordinances or through the judicial system.

Comment [A10]: Consider referencing an ERP here SC

[7] The BMPs refer to the current version of the California Stormwater BMP Handbook, Industrial and Commercial. The January 2003 version was current at the time of Order adoption, and the source control BMPs can be found in Section 3 of that version. In accordance with Part 4.A.2, other BMPs may be substituted upon approval by the Executive Officer.

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(3) Each Permittee shall maintain records and make them available on request to the Regional Water Board, including inspection reports, warning letters, notices of violations, and other enforcement records, demonstrating a good faith effort to bring facilities into compliance.

e. Interagency Coordination

i. *Referral of Violations of Municipal Ordinances and California Water Code § 13260:*

A Permittee may refer a violation(s) of its municipal storm water ordinances and California Water Code § 13260 by Industrial and Commercial facilities to the Regional Water Board provided that the Permittee has made a good faith effort of progressive enforcement to achieve compliance with its own ordinances. At a minimum, a Permittee's good faith effort must be documented with:

(1) Two follow-up inspections

(2) Two warning letters or notices of violation

ii. *Referral of Violations of the Industrial Activities Storm Water General Permit (IASGP), including Requirements to File a Notice of Intent or No Exposure Certification:*

For those facilities in violation of municipal storm water ordinances and subject to the IASGP, Permittees may escalate referral of such violations to the Regional Water Board (promptly via telephone or electronically) after one inspection and one written notice of violation (copied to the Regional Water Board) to the operator regarding the violation. In making such referrals, Permittees shall include, at a minimum, the following documentation:

(1) Name of the facility

(2) Operator of the facility

(3) Owner of the facility

(4) WDID Number (if applicable)

(5) Industrial activity being conducted at the facility that is subject to the IASGP

(6) Records of communication with the facility operator regarding the violation, which shall include at least one inspection report

(7) The written notice of violation copied to the Regional Water Board

iii. *Investigation of Complaints Transmitted by the Regional Water Board Staff:*

Comment [A11]: Confirmed with Ivar (6/27/11). Permittees don't all have actual storm water ordinances and we should generalize throughout. Global changes. SC

Comment [A12]: Strike the term good faith effort—vague and unenforceable, and complicates enforcement. Just say that the Permittee must have at a minimum, documented . . .

This term and logic is consistent with EPA's permit improvement guide. Likely copied directly from it. SC

Comment [A13]: 1.Why wait to the end of the quarter? Why do they only have to do one inspection and one followup letter here but two – for failure to file a ROWD? What is t the logic?

Confirmed with Ivar (6/27/11): Ordinance violations likely cover those with immediate threat. SC

RB-AR33016

Each Permittee shall initiate, within one business day,[8] investigation of complaints (other than non-storm water discharges to the MS4) from facilities within its jurisdiction. The initial investigation shall include, at a minimum, a limited inspection of the facility to confirm validity of the complaint and to determine if the facility is in compliance with municipal storm water ordinances and, if necessary, to oversee corrective action.

iv. *Assistance with Regional Water Board Enforcement Actions:*

As directed by the Regional Water Board Executive Officer, Permittees shall assist Regional Water Board enforcement actions by:

(1) Assisting in identification of current owners, operators, and lessees of properties and sites.
(2) Providing staff, when available, for joint inspections with Regional Water Board inspectors.
(3) Appearing to testify as witnesses in Regional Water Board enforcement hearings.
(4) Providing copies of inspection reports and other progressive enforcement documentation.

v. *Participation in a Task Force:*

The Permittees shall participate with the Regional Water Board, and other public agencies on an enforcement task force to communicate concerns regarding special cases of storm water violations by industrial and commercial facilities, and to develop a coordinated approach to enforcement action.

DRAFT

[8] Permittees may comply with the Permit by taking initial steps (such as logging, prioritizing, and tasking) to "initiate" the investigation within that one business day. However, the Regional Water Board would expect that the initial investigation, including a site visit, to occur within four business days.

RB-AR33017

DISSERTATION

EFFECTS OF URBANIZATION ON THE HYDROLOGIC REGIMES AND GEOMORPHIC STABILITY OF SMALL STREAMS IN SOUTHERN CALIFORNIA

PREVIEW

Submitted by

Robert J. Hawley

Department of Civil and Environmental Engineering

In partial fulfillment of the requirements

for the Degree of Doctor of Philosophy

Colorado State University

Fort Collins, Colorado

Fall 2009

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COLORADO STATE UNIVERSITY

July 28, 2009

WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY ROBERT J. HAWLEY ENTITLED EFFECTS OF URBANIZATION ON THE HYDROLOGIC REGIMES AND GEOMORPHIC STABILITY OF SMALL STREAMS IN SOUTHERN CALIFORNIA BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

Ellen E. Wohl

Chester C. Watson

Eric D. Stein

Advisor Brian P. Bledsoe

Department Head Luis A. Garcia

PREVIEW

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ABSTRACT OF DISSERTATION

EFFECTS OF URBANIZATION ON THE HYDROLOGIC REGIMES AND GEOMORPHIC STABILITY OF SMALL STREAMS IN SOUTHERN CALIFORNIA

In southern California streams, altered hydrologic and sediment regimes associated with urbanization (hydromodification) have induced significant morphologic responses such as incision, widening, and planform shifts from single-thread to braided with far-reaching effects to adjacent land and throughout drainage networks. The overarching objective of this dissertation is to improve process-based understanding of these changes such that the risk of future degradation may be mitigated through improved management. Three chapters follow from this fundamental flow of logic: changes in land cover beget changes in flow regimes, leading to increased erosive energy and sediment-transport potential, which, dependent on the relative resistance of the setting, can culminate into substantial changes in channel form.

The purpose of Chapter 1 was to understand the first step in this sequence: how urbanization affects the flow regime. Duration Density Functions (DDFs) were developed as histogram-style cumulative duration curves that represent the full range of geomorphically-significant flows as simple power functions. Using long-term data from 52 U. S. Geological Survey (USGS) gauges, empirical models were fit to both peak flows and DDF parameters (i.e., magnitude and shape) as multivariate functions of statistically-significant spatial variables including total impervious area. With little flow control at the subdivision scale to date, total impervious area became an effective hydrologic

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PREVIEW

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surrogate for urbanization, demonstrating an exponential effect on peak flows, particularly the 1-, 1.5-, and 2-yr events, and increased durations of all sediment-transporting flows. For example, watersheds with ~10% imperviousness typically exhibit a ~5-fold increase in $Q_{1.5}$ and 2 to 3 times as many days of sediment-transporting flows relative to an undeveloped setting. The models developed in Chapter 1 directly informed the hydrologic components of the subsequent chapters, where impervious area was not found to be a significant predictor of geomorphic response when considered independent of setting or sediment transport.

The focus of Chapter 2 was to understand the relative susceptibilities of regional channel types to hydromodification in the context of a 'Screening Tool' that is being developed to help managers assess risk across geomorphic settings. Specifically, Chapter 2 is focused on 1) the general framework of a pre-final version of the susceptibility screening tool, and 2) the development of risk-based analyses of geomorphic thresholds, a central component of key decision nodes in the screening tool. Geomorphic thresholds are real and of great concern in stream management, such that any susceptibility-assessment scheme should account for the proximity to such threshold-based responses. Logistic-regression analyses of braiding, incision, and bank stability directly and probabilistically assess proximity to geomorphic thresholds, and offer a framework for assessing risk that goes beyond expert judgment. Calibrated with local data that were collected in an extensive field campaign, the logistic models were highly significant (i.e., $p < 0.005$ to $p < 0.0001$) and correctly classified unstable states in ~90% of the cases using simple but powerful predictor variables that can be measured at the screening/reconnaissance level. A screening tool that incorporates objective probabilistic-based components is novel relative to previous and more subjective classification

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schemes, such that regionally-diverse agencies and staff can quantitatively assess channel susceptibility with less variable results.

With the objective of developing a process-based understanding of observed channel changes, Chapter 3 presents models that predict relative magnitudes, directions, and risks of channel responses as functions of cumulative sediment-transport capacity ratios (Lr) that contrast 25-yr DDF simulations of urbanized versus undeveloped conditions. Lr was a highly significant term in quantifying channel 'enlargement', whereas logistic regression of Lr in combination with d_{50} suggested that fine-grained systems (i.e., especially $d_{50} \leq 16$ mm) have little capacity to absorb any increases in sediment-transport potential. A regional Channel Evolution Model (CEM) that includes departures from the original CEM of Schumm *et al.* (1984) is also presented along with a modified dimensionless stability diagram (*sensu* Watson *et al.* (1988)) that provides a conceptual framework for assessing relative departure from equilibrium/reference form for both lateral and vertical channel responses.

The overarching conclusion of this dissertation is that urbanization markedly affects the flow regimes of streams in southern California and that the corresponding imbalances in sediment-transport capacity result in substantial geomorphic instabilities across most stream settings. Consequently, mitigation strategies should be tailored to specific stream types and incorporate process-based objectives such as maintaining sediment continuity via duration standards rather than traditional regulations focused exclusively on flow magnitude.

Robert J. Hawley
Department of Civil and Environmental Engineering
Colorado State University
Fort Collins, CO 80523
Fall 2009

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ACKNOWLEDGEMENTS

Throughout this journey I have been blessed with an invaluable support network of faculty, friends, and family. First to my advisor, Dr. Brian Bledsoe, who has been a perennial bulwark since my first bike ride out to the ERC. Through coursework and research, Skype calls from Chile, California budget crises, late registration, future plans, and family surprises, your genuine and steady guidance has been par excellence. Thank you for a first-rate project, uninterrupted funding, masterly reviews, and balanced conversations – I always leave our meetings feeling energized and could not envision a better advisor/student relationship. Cheers.

To my committee members, Drs. Eric Stein, Chester Watson, and Ellen Wohl, I cannot thank you enough for your time and care in steering this dissertation into clear waters. Eric, thank you for keeping me tied to stakeholder goals, for sharing your wealth of local knowledge, resources, and energy, and for flying out for one of our meetings. Chester, your course and pioneering research truly gave me the shoulders of a giant to stand on. Ellen, from our field trip to Pawnee Buttes to lectures, critical-thinking essays and seminars, I feel so much more complete, and at the same time completely humbled to have you on my committee.

Next to Gloria Garza, who is the eternal champion of graduate students. Despite crunched deadlines you morphed these chapters into a 'silver singing river' of a

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manuscript. Through it all, your incredible assistance and cheerful e-mails kept the stress-meter down, and I'm still in awe of how quickly you churned out revisions. I am forever grateful. And to the staff in the CEE office, Laurie Alburn, Linda Hinshaw, and Kathy Stencel, your smiling faces and support from before I was even a student have made me feel so welcome at CSU.

To my CSU and SCCWRP colleagues, particularly Dave Dust, Becky Schaffner, Liesl Tiefenthaler, Greg Lyon, and Jeff Brown, thank you for your tireless work in the field, logistical support, GIS assistance, photography, and for making many weeks in the hot sun a quite enjoyable experience. This wouldn't have been possible without you or the detailed work of the Stillwater Science survey crew, chiefly Scott Dusterhoff and Alexander Wong. And to Dr. Derek Booth, I am very grateful to have had this indirect opportunity to collaborate with you.

In his latest book Outliers (2008), Malcolm Gladwell deduces success to the necessary combination of talent and opportunity. To advisors and mentors from my previous life, Drs. Jim Mihelcic, Kevin Hallinan, Joseph Saliba, Roddy Williams, and Art Parola, thank you for your tremendous support and collaboration that clearly helped to get me in the door.

Speaking of opportunities, I am forever indebted to my parents Jeff and Jeanie. My dad was my first role model and the man who introduced me to a love of rivers, nature, and the importance of methodically looking to the data. My mom was my first teacher, instilling in me a passion for learning, the value of hard work, and love of family. Her warm angelic presence brings tranquility to all that I do. To the rest of my family

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and friends, particularly, Dan, Tiffany, David, Diane, Eric, Em, Chanda, and Lynne, thank you for your love and support.

Finally, to my wife Dr. Laura Kissel Hawley, who is my inspiration, my solace, my Dulcinea. Knowing what you had to go through during residency makes this look easy. Your grace through both life's trials and blessings gives me composure. The care and dignity you afford your patients gives me hope. Your boundless love fills me up, and I spill over. May we follow every dream and always have our time in the hammock.

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DEDICATION

To Laura

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HYDROMODIFICATION EFFECTS ON FLOW PEAKS AND DURATIONS IN SOUTHERN CALIFORNIA URBANIZING WATERSHEDS

Robert J. Hawley
Brian P. Bledsoe
Eric D. Stein

Southern California Coastal Water Research Project

Technical Report 654 - July 2011

RB-AR33042

Hydromodification Effects on Flow Peaks and Durations in Southern California Urbanizing Watersheds

Robert J. Hawley[a]
Brian P. Bledsoe[b]
Eric D. Stein[c]

[a] *Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO (Presently: Sustainable Streams, Louisville, KY)*

[b]*Colorado State University, Department of Civil and Environmental Engineering, Fort Collins, CO*

[c]*Southern California Coastal Water Research Project, Biology Department, Costa Mesa, CA*

Technical Report 654

July 2011

Executive Summary

A critical first step to hydromodification management is quantifying the effects of watershed urbanization on both flow peaks and flow durations. This report provides an analysis of forty-three regional U. S. Geological Survey gauges with records greater than ~20 yrs located in watersheds ranging from 1.3 – 272 km^2. The goal was to quantify effects of hydromodification, and to develop regionally calibrated, empirically derived models that can be applied to ungauged streams throughout southern California. The study watersheds spanned a gradient of urban development and ranged from 0 to 23% total impervious area based on 2001 land use data. With little flow control at the subdivision scale to date, most of the region's impervious area is hydrologically effective, in that it is relatively well-connected to surface-drainage networks. Consequently, total impervious area was an effective hydrologic surrogate for urbanization.

Large increases were observed in instantaneous-peak flows of more frequent return periods (e.g., 1.5 and 2 year storms), with greater than a 5-fold increase in 2-year events (Q_2) observed in a watershed with 20% imperviousness relative to ≤ ~1% imperviousness (Table ES-1). Effects of urbanization decreased for larger, less frequent storms. For example, 20% impervious cover resulted in a 40% increase in 10-year peak flows. Such attenuating influence of urbanization with return period is generally consistent with both theory and previous studies (Bledsoe and Watson, 2001; Hollis, 1975; Sauer *et al.*, 1983). During very large, infrequent events (e.g., Q_{100}) soils become saturated and behave similar to impervious surfaces; therefore, urbanization effects can be difficult to detect.

Table ES-1. Influence of urbanization (as measured by total impervious area) on peak-flow rates.

Flow	Peak Factors[a] for Impervious Extent, Imp_{max}					Factor Range at 20% Impervious	
	1%	5%	10%	15%	20%	Minimum	Maximum
$Q_{1.5}$	x 1.1	1.8	3.2	5.7	9.8	6.3	13.6
Q_2	x 1.1	1.5	2.4	3.6	5.6	3.8	7.3
Q_5	x 1	1.2	1.4	1.6	1.9	1	2.2
Q_{10}	x 1	1	1	1	1	1	1.4
Q_{25}	x 1	1	1	1	1	1	1

[a] 'typical' factors (i.e., median influence factors of all five sets of Q_i equations)

Effects of hydromodification on flow duration were expressed as duration density functions (DDFs), which are genrally defined as the number of days that exceed a given flow. They are conceptually similar to probability density functions for logarithmically-binned mean daily discharges greater than some nominal value, for example 1 to 10 cubic feet per second (0.03 to 0.3 m^3/s), depending on watershed size.

The results of this study show that for a particular watershed size and climatic setting, urbanization resulted in proportionally-longer durations of all geomorphically-effective flows, with a more pronounced effect on the durations of low to moderate flows. For example, an average watershed from the study area with ~15% imperviousness could experience three to four times as many days of moderate flows (~100 cfs) and greater than 2-fold duration increases for even the largest flows (~1,000 cfs) relative to an undeveloped setting (i.e., ~1% imperviousness, Figure ES-1). These empirical findings of decreasing influence of urbanization on flow duration with increasing flow magnitude are consistent with the findings regarding peak flows: urbanization tends to show higher influence on more frequent events, with decreasing influence over the largest, rarest storms.

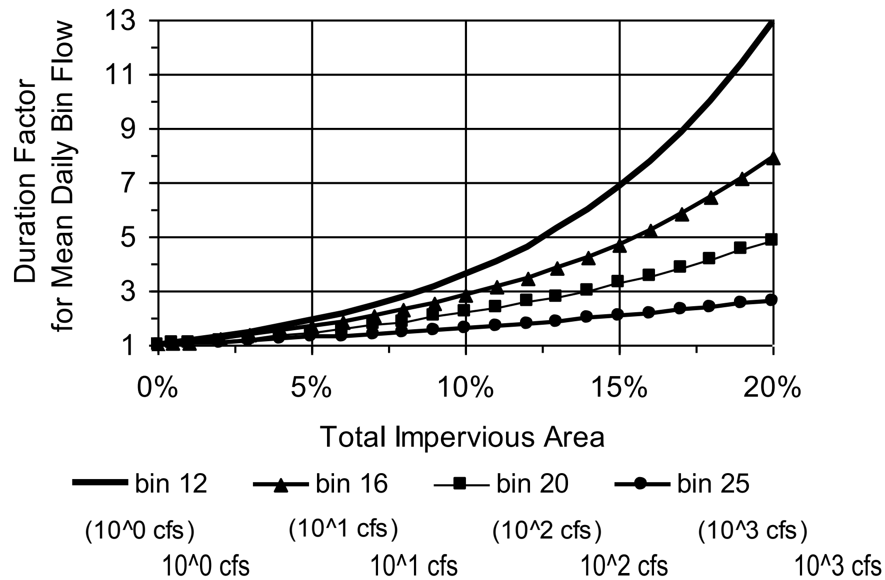

Figure ES-1: Duration factors of respective flow magnitudes across a gradient of Total Impervious Cover based on a 25-year DDF simulations of an average watershed; Average Watershed: A = 25 mi2 and P = 25 in.

The models presented in this report may be used to estimate the effects of unmitigated urbanization on flow peaks and flow durations as a part of regional hydromodification management programs. They could be incorporated into screening tools for hydromodification susceptibility (e.g., Bledsoe *et al.*, 2010). They could also serve as a relatively simple, first step in a modeling tool framework prior to employing more sophisticated modeling techniques such as continuous flow simulations based on different landuse and stormwater management scenarios.

The following report includes methodological background and justifications for the development of a suite of models that predict instantaneous peak flows (as an alternative to the existing USGS regional equations (Waananen and Crippen, 1977)), and duration density functions. The report also includes a summary of landuse and climatic histories, and regional geomorphic relationships such as drainage density vs. annual precipitation and main channel length vs. drainage area. The report concludes with a detailed case study of two gauged watersheds spanning relatively equal periods of pre-urban and post-urban periods, along with a cross-comparison to a proximate reference watershed that remained entirely undeveloped for an identical period of operation. The at-a-station case study, combined with the empirical models, presents a weight of evidence that urbanization has a pronounced and statistically-significant influence on flow magnitudes and durations of southern California stream networks.

Acknowledgements

We would like to thank organizations and individuals who contributed to this project in terms of funding, data collection, and analysis. This research was funded in part by a State of California research grant, for which we are very grateful. Becky Schaffner of SCCWRP was extremely helpful in providing GIS assistance and training. The USGS continues to deliver spatial and hydrologic data to the public domain that are unparalleled in terms of scale and quality. We would like to extend our gratitude to all staff (past and present), and particularly to Scott Patterson of the South Poway Field Office whose time and care in answering questions provided clarity regarding individual gauges. This document is much improved as a result.

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Introduction

By decreasing infiltration and increasing direct runoff, impervious surfaces can create larger peaks, less groundwater recharge, and increased variability, especially if stormwater is routed directly to streams. These fundamental hydrologic interrelations, such as larger peaks and increased flashiness, have been demonstrated regionally (Galster *et al.*, 2006; Konrad and Booth, 2002) and on a national scale using United States Geological Survey (USGS) gauge data (Poff *et al.*, 2006; Sauer *et al.*, 1983). In California, increased peak flows in developed watersheds have been documented by the USGS as early as 1963 (Waananen, 1969). Durbin (1974) reported potential increases in the 2-yr flow (Q_2) of 3- to 6-fold in San Bernardino County, with little effect on higher return intervals such as the 50-yr flow. Rantz (1971) used development extent and percentage of channels sewered to estimate peak factors for the San Francisco Bay area ranging from 1 to 4 for Q_2, and decreasing with larger return intervals (e.g., 1 to 2.5 for Q_{50}).

Such changes in flow, broadly associated with urbanization, are documented as having profound effects on biologic and geomorphic processes, so much so that the U.S. Environmental Protection Agency (EPA) has recently begun to mandate 'hydromodification' regulations (EPA, 2006). Channel instability and complex responses have been associated with urbanization across hydroclimatic regimes (Bledsoe and Watson, 2001; Booth, 1990; Chin, 2006; Chin and Gregory, 2001; Simon and Downs, 1995; Trimble, 1997), while altered flow and sediment regimes affect aquatic life cycles, habitats, food webs, and facilitate colonization by invasive species, among other types of degradation (Poff *et al.*, 2006; Roesner and Bledsoe, 2002; Waters, 1995).

Our recent field investigations in southern California seem to indicate a relatively high geomorphic sensitivity to hydromodification (Hawley, 2009), consistent with previous studies (Coleman *et al.*, 2005) and the semiarid climate in general (Trimble, 1997). The hydrogeomorphic setting (i.e., steep topography, flashy regimes, high-sediment loads, and largely nonresistant bed material) generally compounds risk factors for far-reaching channel responses such as headcutting, extensive mass-wasting, and planform shifts.

An important first step in any hydromodification management program is to quantify the effects of hydromodification on both peak flows and durations (*sensu* Wolman and Miller, 1960). The challenges in quantifying effects are 1) how to determine the most effective flow magnitudes to manage (i.e., which flow magnitudes are most affected by hydromodification); and 2) how to integrate effects on flow duration (i.e., which flow magnitudes perform the most cumulative work on the channel boundary). This report addresses these issues via the following objectives:

1. offer an updated alternative to the USGS (Waananen and Crippen, 1977) regional equations for estimating peak flows of ungauged streams that is calibrated with more recent southern California gage data;
2. develop a physically-based empirical method for estimating long-term cumulative flow duration histograms for ungauged sites; and

3. determine how urbanization affects peak flows and cumulative durations for all geomorphically-important flows by including urban components (if statistically significant) in Objectives 1 and 2.

In filling these knowledge gaps, we offer the following hypotheses:

H_0: urban influence on the magnitudes of peak flows will be highest at the more frequent events and lowest at the longer recurrence intervals;

H_0: the lack of representation of southern California gauges used to develop the USGS national urban equation (Sauer *et al.*, 1983) should result in better performance by models calibrated directly to the region; and

H_0: cumulative durations can be modeled with reasonable accuracies and will be significantly influenced by urbanization.

Research Foundations and Justification

This paper principally builds on the work and ongoing data collection of the USGS. To this day, Waananen and Crippen's (1977) simple power functions of drainage area and mean annual precipitation serve as a primary method of peak-flow estimation in southern California. Limited by an overall lack of gauge data on "streams with drainage areas generally less than 25 mi^2, and particularly less than 10 mi^2," the models came with substantial standard errors and were deemed "generally applicable for streams with drainage areas greater than 10 mi^2" (Waananen and Crippen, 1977).

Given over 30 more years of data, and especially more data on smaller streams, it was prudent to revisit these equations. In this paper, we go beyond the Log-Pearson Type III distribution to a more regionally-appropriate statistical distribution. With several gauges in developed watersheds, urbanization was included in the models using direct measures of total impervious area (TIA). This approach is arguably less subjective and more parsimonious than the USGS national approach to urban flow augmentation (Sauer *et al.*, 1983), which can be time intensive and is subject to user interpretation of "basin development factors" that are typically immeasurable with available Geographic Information System (GIS) data. Moreover, of the 199 gauges used to develop the national equations, few gauges were from semiarid settings, with only one from southern California (San Diego Creek, gauge no. 11048500). Despite largely-different hydrologic behavior relative to much of the rest of the nation, the USGS national equations are currently being applied throughout the region.

Toward Cumulative Durations

Peak flows alone can be useful in understanding potential erosive energy at an individual recurrence interval; however, they have less meaning when considered independent of durations. Whether a large flow lasts for minutes or days, it has substantial implications for cumulative sediment transport.

Moreover, all flows capable of moving sediment have the potential to influence channel form, *sensu* the concept of geomorphic *effectiveness* (Wolman and Miller, 1960).

It follows that when evaluating the potential impacts of urbanization on channel stability, researchers have begun to favor cumulative sediment-transport models based on continuous or cumulative flows over extended periods (e.g., years/decades). In evaluating various flow-control schemes in the Pacific Northwest, Booth and Jackson (1997) touted the potential benefits of 'duration' standards in contrast to 'peak' standards, particularly at flows above the threshold of sediment entrainment. Consideration of all sediment-transporting flows would seem especially important in the semiarid environment known for sporadic sediment movements (Graf, 1981, 1988), extended periods of aggradation/degradation and lagged recovery times (Wolman and Gerson, 1978), and relatively infrequent periods of equilibrium (Bull, 1997). One of the only published approaches to addressing hydromodification in California to date uses flow-duration histograms produced from long-term rainfall-runoff simulations in Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) to compute an 'effective work index' by summing excess shear stress over cumulative flow durations of 50 yrs (Santa Clara, 2004). The corresponding mitigation goal is to design flow control such that cumulative post-developed sediment-transport capacity matches the pre-developed regime. The Sediment Impact Analysis Method (SIAM), publicly available via the U. S. Army Corps of Engineers (USACE) in the Hydrologic Engineering Center - River Analysis System (HEC-RAS) software package, is also designed to use a histogram-style flow-duration curve and can be used to model long-term sediment transport (Mooney, 2007; USACE, 2009).

An alternative to solely using rainfall-runoff models to develop flow-frequency curves is to base them on local gauge data. Using the nearest upstream/downstream gauge (Hey, 1975) or a gauge from a similar watershed, frequency curves have typically been scaled using a nondimensional index such as $Q/Q_{bankfull}$ (Emmett, 1975; Leopold, 1994) or Q/Q_2 (Watson *et al.*, 1997). The advantage of the latter is that the 2-yr flow may be estimated by a USGS regional equation, whereas the bankfull flow is often difficult to define and does not have a consistent return interval across different streams (Biedenharn *et al.*, 2000, 2001; Pickup and Warner, 1976; Williams, 1978). The disadvantage of scaling based on the 2-yr flow is that, at least in southern California, it comes with much poorer accuracies than higher recurrence intervals (Waananen and Crippen, 1977). It may also be difficult to define which gauge(s) is similar enough to the ungauged watershed for direct scaling (e.g., similar topography, basin size, precipitation).

We expand on the Watson *et al.* (1997) approach by developing a statistical model to estimate flow-duration curves for ungauged sites with all regional gauges meeting our selection criteria, such that a synthetic flow-duration histogram is predicted as a function of watershed-scale physical descriptors such as drainage area and precipitation. The resulting *conditional* probability density functions that predict cumulative durations of geomorphically-effective flows in a histogram format are henceforth referred to as Duration Density Functions (DDFs). The logarithmically-distributed histogram bins are represented by power functions (i.e., #days = coef * Q^{exp}) and scaled by the maximum daily flow of record. Given a way to predict the shape (exponent), magnitude (coefficient), and scale (Q_{max}) based on physical parameters, one could predict long-term durations of sediment-transporting flows for any ungauged watershed. More importantly regarding hydromodification, DDFs could simulate the increases in durations of sediment-transporting flows associated with unmitigated urbanization by including a statistically-significant surrogate measure (e.g., TIA) in the model. In this light, DDFs can become a central tool in understanding, modeling, and mitigating the effects of hydromodification in southern California.

Study Domain

Southern California is generally described in this study as the greater Los Angeles/San Diego area within about 100 mi of the Pacific coast, including portions of Ventura, Los Angeles, San Bernardino, Orange, Riverside, and San Diego Counties and ca. 20 to 25 million residents. Mountain ranges to the north (Transverse Ranges) and east (Peninsular Ranges) offer fairly well-defined geologic bounds, with a total relief of up to 11,500 ft (3,500 m) and short travel distances to the ocean on the order of 50 mi (~80 km). The steep slopes promote runoff and produce more hydrologically-efficient watersheds than low-relief settings.

The climate is broadly characterized as Mediterranean, but precipitation and vegetative influences tend to increase with elevation, although there are obvious differences between the west (wetter) and east (drier) slopes of the Peninsular Ranges due to an effective 'rain shadow'. Regional extremes of average annual precipitation range 8 to 40 in/yr (200 to 1,000 mm/yr), while vegetation changes from sparse grasses and chaparral to dense coniferous stands at higher elevations. When rains do fall, they can be intense; the 2-yr 24-hr rainfall ranges ~2 to 6 in. (50 to 160 mm) across the domain.

This leads to a flashy regime with short-lived instantaneous peak flows that are much larger than the corresponding daily means. For example, a 10-yr instantaneous event would typically attenuate to a daily-mean flow on the order of a 2- to 3-yr event, with the former likely ten to twenty times the latter. Systems are predominantly ephemeral and clearly dominated by overland flow with little groundwater storage relative to humid systems. The heterogeneous lithologies have variable infiltration capacities, but differences seem to be overwhelmed during high-intensity storms, although they probably play a role in seepage losses during transmission (Knighton, 1998).

Beyond seasonal patterns, large fluctuations in annual, decadal, and even multi-decadal precipitation result in an active fire regime. Regional fires are often newsworthy for both direct (e.g., property destruction and mass evacuations) and indirect damage (e.g., post-fire landslides and flooding), and the corresponding pulses in both sediment and runoff (Booker *et al.*, 1993; California Forest Service (CaFS), 1951; Gabet and Dunne, 2003; Los Angeles County Flood Control District (LACFCD), 1959; McPhee, 1989). As early as 1947, the CaFS had recorded post-fire peaks two to thirty times as large as pre-fire peak flows for equivalent storms in their experimental forest, with influence decreasing with storm magnitude.

Finally, during field investigations of recently-developed suburban neighborhoods, we saw little evidence of stormwater retention/detention. Developed watersheds often had lined channels (i.e., concrete or riprap) and energy dissipaters at outfalls were occasionally present. Large regional basins and dammed reservoirs do exist; however, flow controls in watersheds less than ~40 mi^2 (~100 km^2) were largely lacking. With the understanding that unmitigated urbanization largely increases flow variability, and that streams in southern California are inherently flashy, we hypothesize that the effects of urbanization may be especially pronounced.

Methods

Gauge data are made publicly available by the USGS, which adheres to strict quality assurance/quality control procedures prior to publishing flows as accepted/approved. To ensure comparable quality in processing and analysis, we developed the following methods. Some of the methods include a limited presentation and discussion of preliminary 'results' that informed model design and/or were less central to the overall conclusions of this research. For example, regarding peak flows, it was necessary to decide on a distribution prior to the building of statistical models. Gauge-selection criteria, below, describes how we tested several distributions and which was selected to use in model design.

The following sub-sections summarize the methodological process by which we arrived at final models and conclusions. First, we systematically-selected regional gauges and processed their peak-flow data. Next, we developed a method for processing and representing all daily-mean flows via cumulative histogram-based functions. Methods were then considered for objectively representing urbanization extent. Next, informed by literature and a theoretical understanding of surface-drainage network hydrology, an expansive array of spatially-based variables was populated for inclusion in the analyses. Lastly, analytical methods are presented including a cross-validation procedure that guided final model design.

Unit Disclaimer

Acknowledging the general preference of International System (SI) units among the scientific community, we felt it was beneficial to develop these equations in U.S. Customary System (or English) units for more direct comparisons to the U. S. Geological Survey (Waananen and Crippen, 1977) equations. Without becoming overly cumbersome, we try to offer SI units in parentheses and some figures are expressed in SI units.

Gauge-Selection Criteria

Our first step was the systematic selection of regional gauges for model development. The focus was on watersheds less than ~100 mi^2 (250 km^2), primarily due to the fact that most of the region's larger streams have been affected by dams and diversions. We excluded gauges that were artificially influenced by flow diversions to isolate only the effects of urbanization relative to the undeveloped, free-flowing setting.

We strove for a balance between a large representation of sites and gauges with sufficiently long records. Short records increase the likelihood of misrepresenting the true flow regime, while overly-conservative record-length requirements would eliminate the bulk of gauges. For example, only nineteen of the gauges within the study domain had records of 50 yrs or more; however, there were forty-nine gauges with records greater than 20 yrs. There was a natural break in the record lengths of the candidate gauges at ca. 15 yrs (two gauges at 18 yrs with one gauge at 14 yrs and the balance less than ca. 8 yrs). With limited urban/semi-urban gauges (i.e., only eight gauges > 2.5% imperviousness), the fact that the 14-yr record was in a partially urban watershed (imperviousness = 2.7% in 2001) supported its inclusion. This totaled fifty-two gauges with a spatial distribution depicted in Figure 1. A summary of selected gradients such as drainage area and record length is provided in Table 1 (a comprehensive dataset may be obtained by contacting the corresponding author). These gradients also serve as bounds to the applicable ranges of our models.

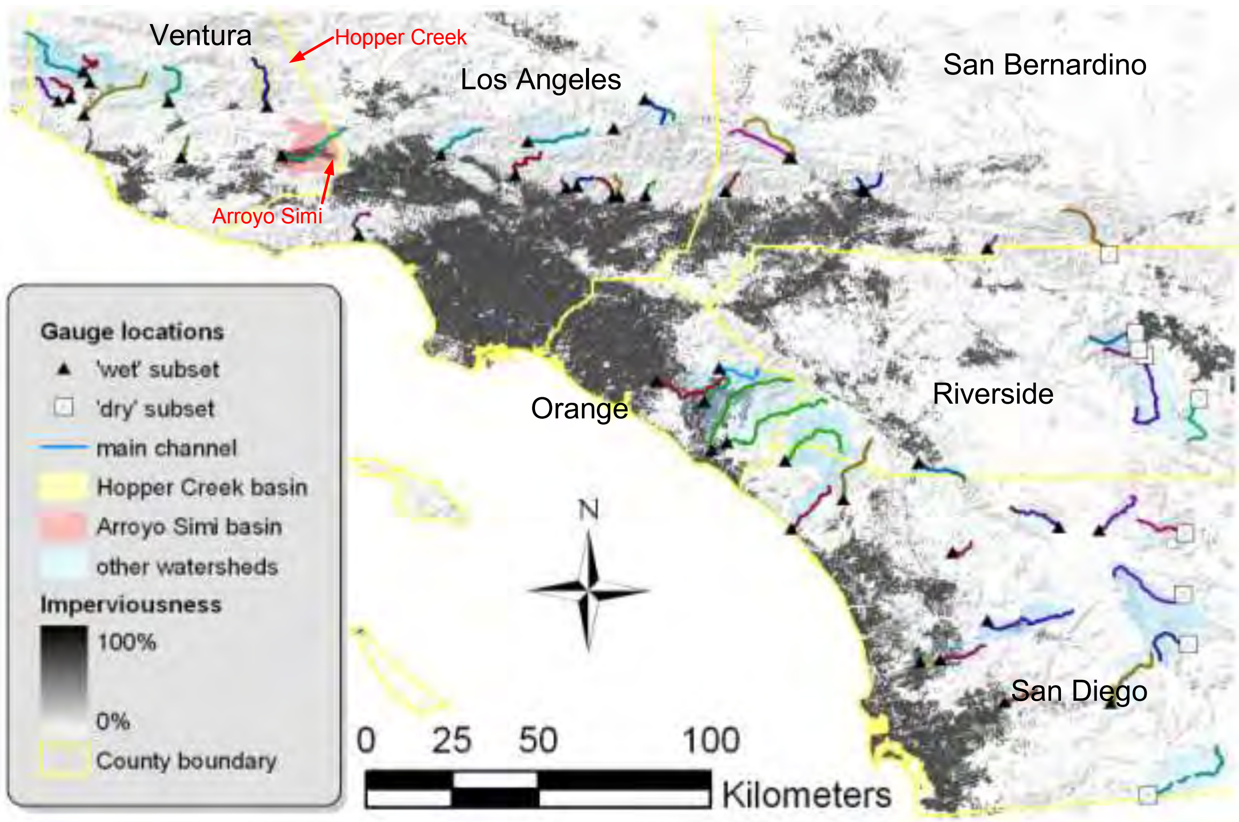


Figure 1. Locations of gauges used in equation development ('wet' subset) with corresponding watershed and main channel, overlaid by a gradient of imperviousness and county boundaries, with rural (Hopper) and urban (Arroyo Simi) case study gauges.

Table 1. Selected[a,b] gradients of the forty-three USGS gauged watersheds used to develop models (i.e., model-application bounds), and the nine hydrogeomorphically-distinct gauges[c] that were withheld from models.

	USGS GAUGE IDENTIFICATION					FLOW RECORD			ROAD DENSITY		IMPERVIOUSNESS			PRECIPITATION		HYDROGEOMORPHIC					
Variable	Name	Number	Lati-tude	Longi-tude	HUC8	Begin	End	Total[d]	2007	Avg[e]	2001	Max[e]	Avg[e]	Mean Annual[f]	2-yr 24-hr[g]	Drainage Area[h]	Drainage Density[i]	Average Basin Eleva-tion[j]	Average Channel Slope[j]	Average Surface Slope[k]	Valley Slope at Gauge[l]
Abbreviation	Gauge	No	Lat	Long	HUC 8	Begin	End	YrsPeak	Rdnsty07	RdnstyAv	Impv01	ImpMax	ImpAv	P	P224	DA	DD	ElvAvg	SlpChn	SlpSurf	SlpVly
Units			(decimal degrees)	(decimal degrees)		(calendar yr)	(calendar yr)	(yrs)	(km/km^2)	(km/km^2)				(mm)	(mm)	(km^2)	(km/km^2)	(m)			
Forty-three gauges included in model development																					
1	AGUACALIENTECNR WARNERSPRINGS	11031500	33.2886	-116.6531	18070303	1961	1987	27	0.48	0.27	0.1%	0.1%	0.1%	434	64	49.5	1.26	1,184	4.0%	30%	0.8%
2	ALISOCAELTORO	11047500	33.6261	-117.6842	18070301	1930	1980	50	6.80	1.83	20.3%	8.1%	1.4%	408	73	22.6	0.96	261	2.2%	18%	1.3%
3	ARROYOSECONRPASADENA	11098000	34.2222	-118.1767	18070105	1910	2008	94	0.99	0.55	0.5%	0.5%	0.4%	803	131	41.7	1.79	833	4.6%	53%	3.3%
4	ARROYOSIMINRSIMI	11105850	34.2731	-118.7869	18070103	1933	1983	50	4.08	1.97	10.0%	8.6%	4.9%	447	86	180.0	1.42	417	1.9%	23%	0.8%
5	ARROYOTRABUCOASAN JUANCAPISTRANO	11047300	33.4983	-117.6650	18070301	1970	2008	23	5.35	3.95	18.8%	18.8%	14.2%	462	79	140.7	1.13	357	2.1%	25%	0.9%
6	BIGROCKCNRVALYERMO	10263500	34.4208	-117.8386	18070106	1923	2008	84	0.67	0.36	0.4%	0.5%	0.4%	781	126	59.4	1.07	1,626	7.9%	50%	3.2%
7	BUCKHORNCNRVALYERMO	10263900	34.3431	-117.9203	18090206	1960	1966	37	0.14	0.02	0.2%	0.2%	0.2%	889	150	1.4	1.22	2,228	20.2%	31%	21.1%
8	CAJONCNRKEENBROOK	11063000	34.2669	-117.4564	18070203	1920	1982	58	1.86	0.85	1.4%	1.3%	0.8%	495	114	104.9	1.02	1,125	3.4%	25%	2.3%
9	COYOTECREEKNEAR OAKVIEW	11117600	34.4167	-119.3697	18070101	1958	1988	30	0.51	0.31	0.0%	0.0%	0.0%	715	129	34.2	1.39	548	7.9%	39%	3.9%
10	CUCAMONGACNRUPLAND	11073470	34.1794	-117.6281	18070203	1929	1975	48	0.23	0.01	0.0%	0.0%	0.0%	908	159	25.0	1.60	1,448	17.8%	59%	10.9%
11	DELUZCNRFALLBROOK	11044900	33.3697	-117.3217	18070302	1951	2005	18	1.47	1.00	0.3%	0.3%	0.3%	529	60	122.8	1.18	242	2.0%	26%	0.1%
12	ETWINCNRARROWHEAD SPRINGS	11058500	34.1792	-117.2647	18070203	1919	2008	87	0.63	0.31	0.7%	0.7%	0.5%	848	129	22.6	1.73	954	11.6%	45%	5.2%
13	FISHCNRDUARTE	11084500	34.1658	-117.9233	18070106	1916	1979	62	1.01	0.49	0.1%	0.1%	0.1%	840	130	16.5	1.71	701	9.7%	51%	2.2%
14	HONDABARRANCANRSOMIS	11107000	34.2689	-119.0489	18070103	1954	1963	18	1.41	0.96	0.3%	0.3%	0.3%	468	76	6.1	2.15	233	3.9%	23%	2.4%
15	HOPPERCREEKNEARPIRU	11110500	34.4008	-118.8256	18070102	1930	1983	49	0.53	0.04	0.0%	0.0%	0.0%	557	110	61.6	1.64	595	4.6%	42%	1.1%
16	KEYSCTRIBAVALLEYCENTER	11040200	33.2292	-117.0358	18070303	1970	1991	14	3.71	2.70	2.7%	2.7%	2.5%	571	78	19.9	1.28	454	1.7%	8%	1.4%
17	LASFLORESCNROCEANSIDE	11046100	33.2922	-117.4558	18070301	1951	2008	41	0.64	0.43	0.8%	0.9%	0.7%	383	54	68.2	1.63	134	1.6%	20%	0.7%
18	LITTLEDALTONCNR GLENDORA	11086500	34.1675	-117.8375	18070106	1939	1971	33	1.61	1.06	0.1%	0.1%	0.1%	735	121	7.1	1.19	665	10.3%	48%	6.0%
19	LITTLESANGORGONIOCNR BEAUMONT	11056500	34.0292	-116.9453	18070203	1948	1985	36	1.57	1.14	0.5%	0.5%	0.4%	801	120	4.6	1.55	1,736	16.8%	45%	8.6%
20	LITTLESANTAANITACNR SIERRAMADRE	11100500	34.1869	-118.0431	18070105	1916	1979	46	0.72	0.03	0.1%	0.1%	0.1%	888	142	4.8	1.34	981	18.6%	56%	11.1%
21	LITTLETUJUNGACNRSAN FERNANDO	11096500	34.2744	-118.3717	18070105	1928	1973	45	1.63	0.73	1.0%	0.8%	0.7%	581	98	53.7	2.56	641	4.6%	36%	1.7%

Forty-three gauges included in model development (continued)

Variable	Name	Number	Latitude	Longitude	HUC8	Begin	End	Total[(d)]	2007	Avg[(e)]	2001	Max[(e)]	Avg[(e)]	Mean Annual[(f)]	2-yr 24-hr[(g)]	Drainage Area[(h)]	Drainage Density[(i)]	Average Basin Elevation[(j)]	Average Channel Slope[(j)]	Average Surface Slope[(k)]	Valley Slope at Gauge[(l)]
	USGS GAUGE IDENTIFICATION					FLOW RECORD			ROAD DENSITY		IMPERVIOUSNESS			PRECIPITATION		HYDROGEOMORPHIC					
Abbreviation	Gauge	No	Lat	Long	HUC 8	Begin	End	YrsPeak	Rdnsty07	RdnstyAv	Impv01	ImpMax	ImpAv	P	P224	DA	DD	ElvAvg	SlpChn	SlpSurf	SlpVly
Units			(decimal degrees)	(decimal degrees)		(calendar yr)	(calendar yr)	(yrs)	(km/km^2)	(km/km^2)				(mm)	(mm)	(km^2)	(km/km^2)	(m)			
22	LONEPINECNRKEENBROOK	11063500	34.2664	-117.4631	18070203	1920	2007	77	1.27	1.13	0.4%	0.4%	0.4%	568	136	39.3	1.31	1,357	6.6%	34%	4.4%
23	LOSCOCHESCNRLAKESIDE	11022200	32.8361	-116.8994	18070304	1983	2008	24	3.89	3.78	9.1%	9.1%	8.9%	366	58	31.7	1.13	288	2.5%	17%	1.6%
24	LOSPENASQUITOSCNR POWAY	11023340	32.9431	-117.1208	18070304	1964	2008	43	4.71	3.42	20.1%	20.1%	14.2%	353	53	108.9	1.23	287	2.6%	18%	1.3%
25	LOSPENASQUITOSCBL POWAY CNRPOWAY	11023330	32.9492	-117.0692	18070304	1969	1993	23	4.10	2.83	17.2%	15.2%	12.2%	361	54	80.9	1.21	319	3.6%	18%	0.8%
26	NFMATILIJA	11116000	34.4925	-119.3056	18070101	1928	1983	50	0.44	0.15	0.1%	0.1%	0.1%	826	122	41.1	1.89	772	7.7%	44%	3.8%
27	PECHANGACNRTEMECULA	11042631	33.4642	-117.1239	18070302	1987	2007	20	1.18	1.07	1.6%	1.6%	1.4%	448	66	34.7	1.31	605	4.8%	22%	0.8%
28	ROGERSCNRAZUSA	11084000	34.1653	-117.9056	18070106	1917	1962	45	0.82	0.28	0.1%	0.1%	0.1%	815	125	17.3	1.59	526	6.2%	54%	3.6%
29	SANANTONIOCACASITAS SPRINGS	11117500	34.3803	-119.3036	18070101	1949	1983	34	2.76	1.74	1.2%	1.2%	1.1%	605	122	132.4	1.47	380	2.8%	30%	1.4%
30	SANDIEGOCATCULVERDRNR IRVINE	11048500	33.6817	-117.8086	18070204	1949	1985	36	4.90	2.01	23.4%	14.9%	6.4%	366	64	107.7	1.13	144	1.2%	11%	0.7%
31	SANJUANCNRSANJUAN CAPISTRANO	11046500	33.5189	-117.6242	18070301	1928	1969	41	0.97	0.37	2.3%	0.3%	0.3%	467	75	273.9	1.37	343	1.8%	28%	1.4%
32	SANMATEOCNRSAN CLEMENTE	11046300	33.4708	-117.4722	18070301	1952	2008	30	0.98	0.75	0.1%	0.1%	0.1%	515	70	209.5	1.13	404	2.2%	28%	0.7%
33	SANTAANACNROAKVIEW	11117800	34.4236	-119.3403	18070101	1958	1988	30	0.93	0.69	0.1%	0.1%	0.1%	768	135	23.3	1.50	604	9.2%	41%	3.0%
34	SANTAANITACNRSIERRA MADRE	11100000	34.1917	-118.0164	18070105	1916	1970	54	0.73	0.21	0.1%	0.1%	0.1%	889	143	25.1	1.54	944	14.1%	54%	8.1%
35	SANTAMARIACNRRAMONA	11028500	33.0522	-116.9447	18070304	1912	2008	68	2.92	2.15	2.5%	2.5%	2.1%	496	64	147.3	1.00	574	1.5%	11%	0.4%
36	SANTAPAULACNRSANTA PAULA	11113500	34.4133	-119.0814	18070102	1927	2007	72	0.87	0.53	0.1%	0.1%	0.1%	774	136	99.5	1.44	903	8.9%	40%	2.8%
37	SANTIAGOCAMODJESKA	11075800	33.7128	-117.6442	18070203	1961	2007	46	0.39	0.22	0.2%	0.2%	0.2%	596	93	33.7	1.26	683	5.1%	47%	1.7%
38	SWEETWATERRNRDE SCANSO	11015000	32.8347	-116.6222	18070304	1905	2008	73	1.47	0.97	0.3%	0.3%	0.2%	697	105	117.3	1.22	1,223	1.9%	21%	2.0%
39	TOPANGACNRTOPANGABCH	11104000	34.0644	-118.5861	18070104	1930	1979	49	3.47	2.26	1.4%	1.4%	1.1%	564	98	46.6	1.66	250	2.5%	30%	3.8%
40	TUJUNGACBMILLCNRCOLBYRANCH	11094000	34.3092	-118.1444	18070105	1948	1971	24	0.64	0.30	0.2%	0.2%	0.2%	667	123	168.0	1.43	1,242	4.5%	37%	2.4%
41	VENTURARNRMEINERSOAKS	11116550	34.4650	-119.2889	18070101	1959	1988	27	0.25	0.07	0.1%	0.1%	0.1%	856	132	192.1	1.91	774	4.3%	46%	1.1%
42	WATERMANCANYON CREEKNR ARROWHEADSPRINGS	11058600	34.1858	-117.2722	18070203	1921	1985	65	2.40	1.54	1.5%	1.5%	1.1%	905	128	12.5	0.96	890	10.6%	45%	7.6%
43	WFSANLUISREYRNR WARNERSPRINGS	11033000	33.2967	-116.7589	18070303	1913	1986	30	0.43	0.18	0.0%	0.0%	0.0%	780	98	66.0	1.15	1,164	4.3%	24%	1.5%

Variable	USGS GAUGE IDENTIFICATION					FLOW RECORD			ROAD DENSITY		IMPERVIOUSNESS			PRECIPITATION		HYDROGEOMORPHIC					
Variable	Name	Number	Lati-tude	Longi-tude	HUC8	Begin	End	Total[d]	2007	Avg[e]	2001	Max[e]	Avg[e]	Mean Annual[f]	2-yr 24-hr[g]	Drainage Area[h]	Drainage Density[i]	Average Basin Eleva-tion[j]	Average Channel Slope[j]	Average Surface Slope[k]	Valley Slope at Gauge[l]
Abbreviation	Gauge	No	Lat	Long	HUC 8	Begin	End	YrsPeak	Rdnsty07	RdnstyAv	Impv01	ImpMax	ImpAv	P	P224	DA	DD	ElvAvg	SlpChn	SlpSurf	SlpVly
Units			(decimal degrees)	(decimal degrees)		(calendar yr)	(calendar yr)	(yrs)	(km/km²)	(km/km²)				(mm)	(mm)	(km²)	(km/km²)	(m)			
Nine gauges withheld from models[c]																					
44	*ANDREASCNRPALM SPRINGS*	*10259000*	*33.7600*	*-116.5492*	*18100200*	*1948*	*2008*	*59*	*0.00*	*0.00*	*0.0%*	*0.0%*	*0.0%*	*386*	*72*	*23.4*	*1.41*	*1,001*	*14.9%*	*51%*	*7.9%*
45	*BORREGOPALMCNR BORREGOSPRINGS*	*10255810*	*33.2789*	*-116.4292*	*18100200*	*1950*	*2004*	*52*	*0.21*	*0.04*	*0.0%*	*0.0%*	*0.0%*	*317*	*48*	*56.4*	*1.36*	*1,043*	*7.5%*	*41%*	*12.7%*
46	*CAMPOCNRCAMPO*	*11012500*	*32.5911*	*-116.5247*	*18070305*	*1936*	*2008*	*71*	*1.47*	*1.09*	*0.5%*	*0.5%*	*0.4%*	*430*	*60*	*218.5*	*0.82*	*938*	*1.9%*	*12%*	*2.2%*
47	*DEEPCNRPALMDESERT*	*10259200*	*33.6311*	*-116.3914*	*18100200*	*1962*	*2008*	*46*	*0.58*	*0.43*	*0.7%*	*0.7%*	*0.6%*	*281*	*58*	*78.8*	*1.16*	*1,337*	*7.8%*	*30%*	*12.0%*
48	*MISSIONCNRDESERTHOT SPRINGS*	*10257600*	*34.0111*	*-116.6272*	*18100200*	*1967*	*2008*	*40*	*0.10*	*0.00*	*0.1%*	*0.1%*	*0.1%*	*519*	*99*	*91.8*	*1.51*	*1,475*	*7.0%*	*45%*	*4.4%*
49	*PALMCYNCNRPALM SPRINGS*	*10258500*	*33.7450*	*-116.5347*	*18100200*	*1930*	*2008*	*73*	*0.44*	*0.21*	*0.3%*	*0.3%*	*0.2%*	*297*	*57*	*241.3*	*1.63*	*932*	*4.2%*	*26%*	*2.2%*
50	*SANFELIPECNRJULIAN*	*10255700*	*33.1186*	*-116.4344*	*18100200*	*1958*	*1983*	*25*	*1.08*	*0.76*	*0.4%*	*0.3%*	*0.3%*	*445*	*65*	*230.8*	*1.46*	*864*	*1.8%*	*24%*	*4.8%*
51	*TAHQUITZCNRPALM SPRINGS*	*10258000*	*33.8050*	*-116.5583*	*18100200*	*1947*	*2008*	*59*	*0.00*	*0.00*	*0.0%*	*0.0%*	*0.0%*	*562*	*92*	*44.1*	*1.43*	*1,563*	*15.0%*	*41%*	*6.4%*
52	*VALLECITOCNRJULIAN*	*10255850*	*32.9861*	*-116.4194*	*18100200*	*1963*	*1983*	*20*	*0.58*	*0.38*	*0.2%*	*0.2%*	*0.2%*	*400*	*67*	*102.4*	*1.58*	*988*	*5.0%*	*30%*	*2.2%*
Gradients of the forty-three gauged watersheds used in model development (and model application bounds)					min	1905	1962	14	0.14	0.01	0.0%	0.0%	0.0%	353	53	1.4	0.96	134	1.2%	8%	0.1%
					mean	1940	1989	44	1.78	1.06	3.3%	2.7%	1.8%	633	103	71.1	1.41	745	6.2%	34%	3.3%
					max	1987	2008	94	6.80	3.95	23.4%	20.1%	14.2%	908	159	273.9	2.56	2,228	20.2%	59%	21.1%

[a] Table includes all USGS gauges in the study domain with watersheds less than ~250 km², flow records greater than ~15 yrs, and no upstream dams/diversions.

[b] Gaps in U.S. Department of Agriculture (USDA) geospatial soil coverages precluded the inclusion of soil characteristics in the analysis; however, a representative sample of regional watersheds ranged from 100% Natural Resources Conservation Service (NRCS) Type D to 100% NRCS Type B and up to 10% Type A soils with undeveloped NRCS Curve Numbers that ranged 77 to 88 with a mean of 83.4.

[c] The nine gauges in Hydrologic Unit Code (HUC) 18100200 and 18070305 were excluded from model development due to their significantly ($p < 0.05$) different hydrogeomorphic setting on the east slope of the Peninsular Range.

[d] Total years of annual maximum instantaneous peak records as recorded and made available by the USGS (i.e., not necessarily equal to "End" minus "Begin" due to intermittent records at several gauges).

[e] Average and maximum road density and impervious values based on integration of spatial extent over the gauge records using three to four measures of spatial extent in time, delineated from historical USGS quadrangle maps and contemporary geospatial coverages from USGS and CalAtlas in a GIS.

[f] Mean annual precipitation integrated over the watershed using USGS shapefile developed using regional precipitation data from 1900 to 1960.

[g] Total precipitation volume over 24-hr duration with a probability of occurrence once every 2 yrs, spatially integrated over the watershed using NRCS shapefile developed using regional precipitation data from 1961 to 1990.

[h] Contributing watershed area delineated in a GIS using the USGS HUC boundaries and a 10-m National Elevation Dataset (NED).

[i] Drainage density developed using total stream length in basin as delineated in a GIS using the USGS National Hydrography Dataset (NHD) developed at a 1:24,000 scale.

[j] Average basin elevation and channel slope measured after USGS protocol using points at 10 and 85% of the main-channel distance from gauge to basin divide.

[k] Average surface slope of the entire watershed using clipped NED model from USGS.

[l] Representative valley slope over reach at gauge l

The gauges had relatively-normal distributions of variables such as record length, precipitation, and surface slope, although drainage area and density showed a small positive skew. Imperviousness, however, had a highly-positive skew of 2.2. As of 2001, only fifteen gauges had watersheds with more than 1% TIA, while only six were greater than 10% imperviousness.

Another notable spatial trend was that eight gauges located in the eastern-most portion of the domain and one gauge in the far southeast at the Mexican border ('dry' subset Figure 1) lie in what is effectively a rain shadow. Stratified by USGS 8-digit Hydrologic Unit Codes (HUCs) of 18100200 or 18070305, the so-called 'dry' gauges were subject to less mean-annual precipitation as well as different types of events (i.e., local convective thunderstorms in addition to winter frontal storms). Hawley (2009) demonstrated significantly-different hydrologic behavior in the 'dry' subset, so much so that models were developed by using a discontinuous 'dummy' variable. In order to develop more targeted models for the balance of the gauges, we excluded the 'dry' subset in this study, making the final sample size forty-three and our models not applicable for watersheds east of the Peninsular Ranges (i.e., HUCs 18100200 and 18070305).

Instantaneous Peak Flows

Procedures were developed to populate recurrence-interval flows for the 1-, 1.5-, 2-, 5-, 10-, 25-, 50-, and 100-yr events from peak-flow data as recorded by the USGS. Their method seemed to be a hybrid of an annual-maximum and partial-duration approach, with an average of one record per calendar/water year, but cases of same-year peaks and occasional gaps during dry years. If a gauge was online during a no-flow year and a corresponding peak of 0 was not already recorded, the record was augmented to standardize the sample size at all gauges, populating an annual-maximum series. This was required on seven gauges and had clear implications on Q_1; however, it had little effect on higher recurrence intervals. For example, recurrence probabilities such as $Q_{1.5}$ and Q_2 generally had several similar flows near those rankings such that a shift would still result in a flow from the same range (e.g., 349 versus 331 cubic feet per second (cfs) for $Q_{1.5}$ and 570.5 versus 571 cfs for Q_2 at Arroyo Seco). Even less effect would be seen at the higher flows (i.e., p = 1:25 versus 1:24 is effectively equivalent as representative of the 25-yr flow).

Other cases of record gaps included years with the date and/or stage of the peak but no flow. Interpolations based on USGS-rating relationships were used to estimate a reasonable flow for that date based on equivalent gauge heights and/or daily-mean flows. This was performed at eight gauges, representing less than 20% of the total. The interpolated flows were not used to determine a flow for a specific return interval; rather, they were simply used as placeholders in the plotting-position rankings.

Next, flows were proportionally ranked to determine recurrence probabilities via the Weibull plotting position (Chow, 1964; Yevjevich, 1972). Several commonly-used probability distributions were then tested to represent the flow-frequency relationship at each gauge, including the normal, lognormal (LN), exponential, and gamma. Because a central component of this paper is an updated alternative to the USGS 1977 regional equations, we also considered the Log-Pearson Type III (LP3), a log-transformed three-parameter gamma distribution that has been the standard USGS flow-frequency method since 1967 (U. S. Water Resources Council, 1967). Distributions were fit by minimizing residual squares between recorded and modeled flows (i.e., method of moments) giving proportional weight to the larger flows; whereas, the reverse procedure would dampen the significance of larger flows by minimizing residuals among recurrence probabilities. With easily-invertible distributions (e.g., normal, LN, and gamma) we fit flows directly to recurrence probabilities, whereas distributions that could not be solved analytically when inverted required alternative solutions (e.g., weighted skew factor (G) for the LP3 method).

Despite application in previous studies, the LP3 performed relatively poorly due to the flashy regimes and the corresponding effect on the skew factor. Even by following the recommended weighting scheme (U. S. Water Resources Council, 1981), the large number of gauges with years of very low or no flow typically converted a highly-positive skew in arithmetic space to a negative skew after the log-transformation. As discussed by Chow *et al.* (1988), this imposes an artificial upper bound on the data. Attempts to account for the low/zero flows within the confines of the LP3 method via the addition of correction factors both large (log (Q + 100 cfs)) and small (log (Q + 0.1 cfs)) were regularly outperformed by a simple regression of flow (Q_i) as a function of log-transformed recurrence interval {ln(i)} (Figure 2).

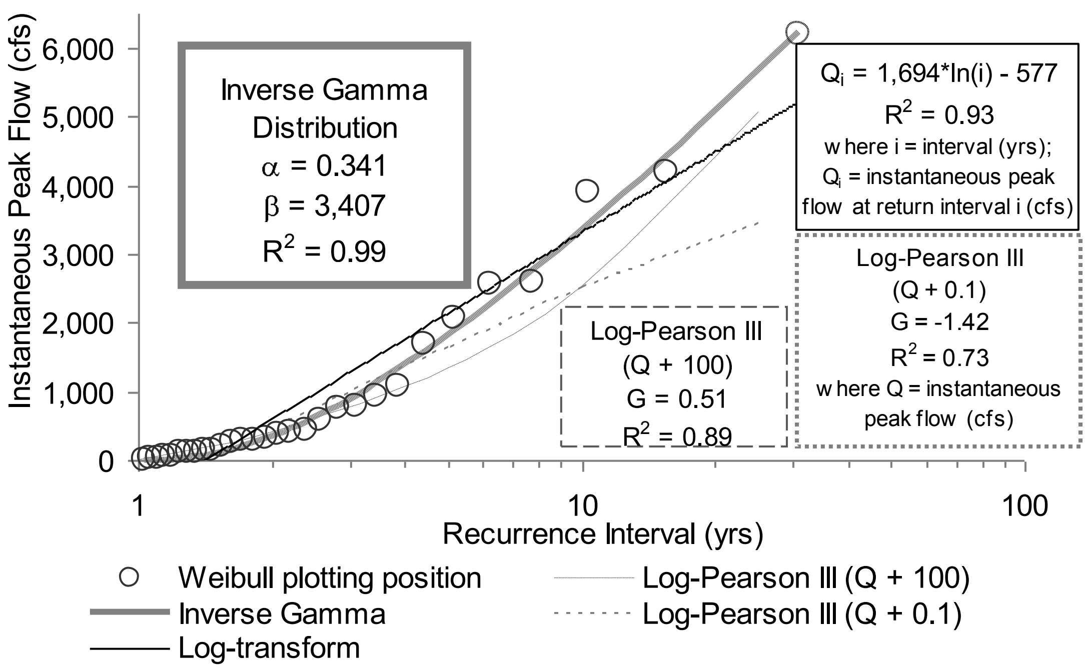


Figure 2. Flow versus recurrence interval of 30-yr record at USGS gauge no. 11033000, West Fork San Luis Rey River near Warner Springs, California, with Log-Pearson Type III adjusted (Q + 0.1) and (Q + 100) and inverse gamma distributions, and log-transform function.

Among all tested distributions, the inverse gamma with parameters α and β was superior in every case in terms of homoscedasticity of residuals and R^2 (e.g., mean and median R^2 0.95 and 0.97, respectively, with only three cases < 0.90). Bounded by zero by definition, the gamma function is ideal for modeling skewed distributions without the need for a log transformation (Chow *et al.*, 1988) – befitting for the flashy ephemeral regimes of southern California. Gamma-distribution flows were used to develop models for flows greater than or equal to the 5-yr interval, while the Weibull plotting position was used for the 1-, 1.5-, and 2-yr events due to nominal interpolation gaps over the smaller ranges given the relatively-large record lengths.

Long-Term Cumulative Durations

Although peak flows are important in understanding erosive energy at a given return interval, flow durations offer a much more complete understanding of the cumulative sediment-transport potential. Accordingly, we developed procedures to mathematically represent all daily-mean flows on record with cumulative duration curves. First, daily-mean flows were binned via a histogram procedure analogous to the initial steps of an effective-discharge calculation after Biedenharn *et al.* (2000, 2001). Histogram bins were scaled by the maximum daily-mean flow on record (Q_{max}) rather than an instantaneous peak flow (e.g., Q_2 after Watson *et al.* (1997)) for two reasons. First, as described in detail later, Q_{max} values could be predicted with much greater accuracies than the highly variable Q_2. Second, scaling with Q_{max} ensured consistent temporal scales for the duration analyses because daily-mean discharges were the only long-term records widely available (i.e., opposed to shorter intervals such as 1 hr or 15 min) and the two time scales were not transferable or even scalable. That is, the ratio of peak to daily mean was not consistent across return periods, sites, or even equivalent flows at the same site. For example, two equivalent 10-yr peak flows recorded at the same gauge could have corresponding daily-mean flows that differed by a factor of two in rural settings, and up to three in urban settings, potentially attributable to the spatial extent, intensity, or even timing of the event.

Regarding the selection of the type and number of bins for our models, the truly limiting factor in sediment-distribution curves – the ultimate application of our models – is ensuring a relatively-continuous flow-frequency distribution such that no bins are populated by 0 days of occurrence (Biedenharn *et al.*, 2000, 2001). Although arithmetic bins are statistically more prudent, the extreme flashiness of ephemeral streams in southern California made logarithmic bins the only practical way to represent flow frequency without discontinuities. The following equation was used to size logarithmically-equivalent bins after Raff *et al.* (2004):

$$H_{B\text{-}log} = \{\ln(Q_{max}) - \ln(Q_{min})\} / (N_B - 1) \qquad \textbf{Eq. (1)}$$

where:

$H_{B\text{-}log}$ = bin size of logarithmically-spaced histogram bins;
Q_{max} = maximum flow of record;
Q_{min} = minimum flow of record; and

N_B = number of bins.

For consistency across all gauges toward development of a regional equation, we set Q_{min} equal to 0.01 cfs at all sites, the lowest non-zero daily-mean flow reported by any gauge. Bins 1 through N_B were then populated by the total number of days of occurrence at flow rates within the respective bins. Lower and upper bounds of each logarithmically-spaced bin were determined using the following equations after Raff *et al.* (2004):

$$B_{lwr-log} = e^{\{\ln(Q_{min}) + (B-2)*H_{B-log}\}}$$ **Eq. (2)**

$$B_{upr-log} = e^{\{\ln(Q_{min}) + (B-1)*H_{B-log}\}}$$ **Eq. (3)**

where:

$B_{lwr-log}$ = lower logarithmically-spaced bound of bin number (B);
$B_{upr-log}$ = upper logarithmically-spaced bound of bin number (B); and
B = bin number (i.e., 1 to N_B, where N_B = total number of bins).

Setting N_B equal to 25 provided a reasonable balance of resolution (small bin sizes) and continuous frequency distributions. All but three gauges, Buckhorn (6 yrs), Honda Barranca (9 yrs), and Keys C (14 yrs), had daily-flow records long enough to sufficiently populate 25 bins. Little San Gorgonio, despite having a long enough record (37 yrs), was skewed by an extreme flow resulting in 3 of the top 6 bins being empty with the remaining three only having 1 day of occurrence. An additional three gauges (Cucamonga, Pechanga, and Waterman) each had 1 bin populated with 0 days of occurrence, but because the adjacent bins were amply populated, we could 'borrow' 0.5 days from each adjacent bin to convert the 0-day bin into a 1-day bin. Of the original forty-three gauges, this resulted in thirty-nine that could be included in the DDF models.

In order to represent the histograms in a concise, transferable format, the next step was to convert them into *conditional* Probability Density Functions (PDFs) by fitting power functions to the centroids of the bins representing the geomorphically-effective range of flows. Again looking toward application, with a high likelihood of under-predicting sediment transport due to data intervals of days rather than minutes (Watson *et al.*, 1997), further bias was avoided by fitting the DDFs to the arithmetic-bin centroids, as opposed to the logarithmic centroids. This positioned each centroid on a slightly higher flow than the otherwise geometric centroid (e.g., 806 cfs versus 774 cfs for bin 21 at San Antonio, or 8,119 cfs versus 7,793 cfs for bin 25). Given that sediment transport increases non-linearly with flow, such a scheme would better approximate the composite transport of the individual flows within the bin.

The next consideration was which bins would be important to represent for sediment transport. Their distributions were relatively continuous over bins 12-25, and particularly continuous over bins 16-25, such that they could be well-represented with simple power functions. Fortuitously, those bins that could be well-fit coincided with the same ranges that would be important for sediment transport. From preliminary analyses it was apparent that streams characterized by threshold behavior (i.e., bankfull dimensionless shear stress (τ_{*BF}) ~0.03 to 0.06) would be sufficiently represented with a 16-25 scheme, while live-bed channels (i.e., τ_{*BF} ~1 to 10+) would require the broader range. As demonstrated by Hawley (2009), cumulative sediment transport became relatively insignificant below bin 12, despite cases of entrainment at lower flows.

Figure 3 offers an example of a typical DDF fit of bins 16-25 at the San Antonio gauge. Overlaid in Figure 3 is the De Luz gauge as an example of one of the poorer fits (i.e., eight gauges with $R^2 < 0.95$, three gauges < 0.90). By depicting two gauges with relatively similar watersheds, Figure 3 also alludes to the significance of the gauge-record length. DDFs scaled nonlinearly with years of duration, primarily attributable to the extreme flashiness and inter-year variability in precipitation. Longer gauge records have higher probabilities of experiencing an extreme precipitation event, corresponding to nonlinear increases in flows and durations.

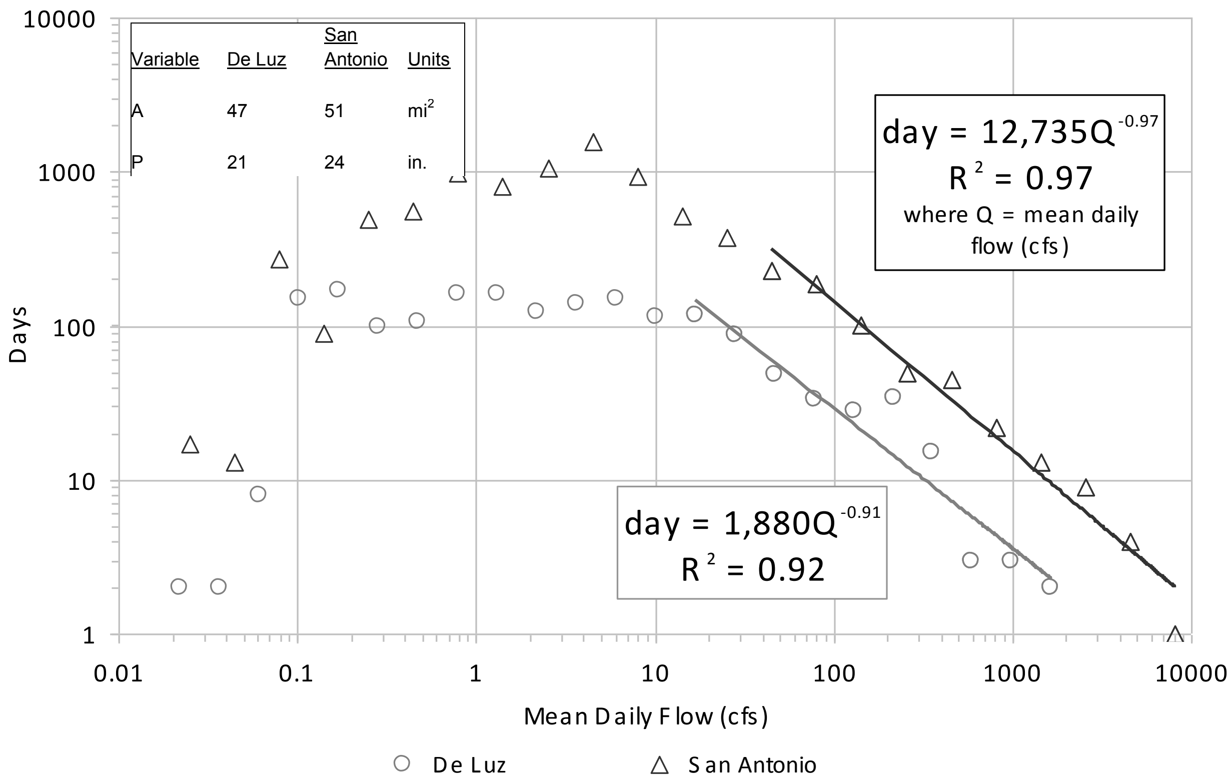


Figure 3. DDFs of gauges De Luz and San Antonio fitted to centroids of logarithmically distributed histogram bins 16-25 with selected variables of drainage area (A), average annual precipitation (P), and record length (Yr).

The 16-25 scheme with the coefficient and exponent parameters termed d1 and d2, respectively, showed largely-homoscedastic residuals (Figure 3) at the risk of not capturing all sediment-transporting bins in live-bed channels (bin 16 of San Antonio = 45 cfs). The second scheme, termed day1 and day2, regressed bins 12-25 to more conservatively include all significant sediment-transporting flows (e.g., bin 12 at San Antonio = 4.5 cfs). However, as one could envision with De Luz (Figure 3), the disadvantage in including bins 12-15 is that it resulted in more heteroscedastic residuals at some gauges. R^2 values were also slightly worse, with eleven gauges less than 0.95 and five gauges less than 0.90. The general form of the power functions used in the respective schemes is:

$days_{@Q} = d1 * Q^{d2}$ (bins 16-25, i.e., τ_{*BF} ~0.03 to 0.06) **Eq. (4)**

$days_{@Q} = day1 * Q^{day2}$ (bins 12-25, i.e., τ_{*BF} ~1 to 10+) **Eq. (5)**

where:

$days_{@Q}$	=	number of days of occurrence at flow rate (Q);
Q	=	arithmetic average of daily-mean flows corresponding to the lower- and upper-bin boundaries defined by Eqs. (2) and (3), respectively (cfs);
d1	=	coefficient for power function fit to bins 16-25;
d2	=	exponent for power function fit to bins 16-25;
day1	=	coefficient for power function fit to bins 12-25;
day2	=	exponent for power function fit to bins 12-25; and
τ_{*BF}	=	dimensionless shear-stress ranges at approximate 'bankfull' flow range (i.e., on the order of Q_{10}) corresponding to threshold (0.03 to 0.06), and live-bed (1 to 10+) behavior.

With the outlined methods for processing daily-mean flows, DDFs were fit to all gauges to populate a matrix of their respective components (i.e., Q_{max}, d1/day1, d2/day2). The dataset was used to develop models of each DDF component as multivariate functions of statistically-significant watershed descriptors, offering an objective method for estimating flows and cumulative durations at ungauged locations.

Measures of Urbanization

An investigation focused on understanding the influence of urbanization on flow regimes should dedicate great care to measuring its extent. With the goal of objectively representing urbanization in both space and time, we first looked to what other researchers have used to characterize it, including but not limited to:

- % impervious area (Booth, 1991, 2000; Espey and Winslow, 1974; Galster *et al.*, 2006; Leopold, 1968; Sauer *et al.*, 1983),
- % developed (Galster *et al.*, 2006; Rantz, 1971),
- % served by storm sewers (Leopold, 1968; Rantz, 1971),
- % paved (Hollis, 1975),

- road density (Konrad and Booth, 2002),
- population density (Konrad and Booth, 2002; Sauer *et al.*, 1983), and
- numerical indices, e.g., function of channel conditions, stormwater connectivity, etc. (Espey and Winslow, 1974; Sauer *et al.*, 1983).

Measures have ranged from qualitative groupings (e.g., rural versus urban) to fully-continuous variables (e.g., % impervious). One of the more widely used approaches is to employ the USGS National Urban Equations developed by Sauer *et al.* (1983). The second most significant variable in the seven-parameter approach is the Basin Development Factor (BDF), which is a somewhat subjectively-assigned composite index (0 to 12) of channel improvements, channel linings, storm drains/sewers, and curb and guttered streets.

We had several goals regarding the quantification of urbanization in our equations. First, despite being an empirical approach, assurance of fidelity to hydrologic processes was desired. Next, measures should be readily quantifiable via publically-available GIS data (i.e., no subjectivity or field investigations necessary). Third, the variable should be a continuous metric wherever possible (e.g., % impervious) rather than taking the form of a categorical variable such as high, medium, and low. Finally, because urbanization is not constant through time, we needed to be able to measure changes in spatial extent over the gauge records.

Arguably, the measure of urbanization that is most rooted in theory and most important hydrologically is imperviousness (Novotny, 2003). Impervious surfaces diminish infiltration potential, eliminate interception storage of plant surfaces, and decrease surface roughness relative to soil/vegetated surfaces, all of which acts to increase direct surface runoff and and the rate at which it flows. However, it is whether an impervious surface is *connected* to the drainage network that determines if the potential effects are transferred downstream. Effective Impervious Area (EIA) is defined as impervious surfaces that are directly connected to the downstream drainage system, consequently excluding any areas draining to pervious surfaces (Booth and Jackson, 1997). Although it is more representative of process than TIA, EIA can be arduous to measure. The two metrics have been correlated on regional scales such as for Denver, Colorado (Alley and Veenhuis, 1983), and western Washington (Dinicola, 1989); however, large differences in stormwater regulations throughout the country both in space and time suggest that the application of such relations to other regions would be imprudent. Fortunately for this research (although unfortunately for receiving streams), stormwater at the subdivision scale in southern California has largely gone unmitigated to date. This makes TIA generally much more representative of EIA than in other regions. Additionally, TIA is readily quantifiable in GIS via the USGS national impervious raster from 2001, meeting both criteria of being objectively quantifiable and largely representative of process.

Other important physical descriptors of urbanization are alterations of the hydrologic network via storm sewers, channelization/lining, or artificial surface storage. The latter has a diminishing effect on peak flows, while the other network adjustments can amplify peaks via decreased roughness and often shorter/steeper flow paths. Unfortunately, no public domain GIS layers were available to quantify storm sewers; therefore, it was decided to measure both road density and impervious area as potential surrogates. The USGS National Hydrography Dataset (NHD) offered measures of known artificial-channel adjustments in existing stream networks (e.g., 'artificial path', 'canalditch', 'connector', or 'pipeline'). Quantifications of such artificial stream-network links were included, although they did not prove to be statistically significant in preliminary models.

As such, impervious area and road density were used as the primary measures of urbanization. State of California (Cal-Atlas) road vectors from 2000 and 2007, along with a USGS impervious raster (2001), provided contemporary measures. The 2000 vector file was clipped to match georeferenced historical USGS topographic quadrangle maps, providing two additional snapshots of road density in time (typically ranging between the 1950s to 1980s). An example at one of the most urban gauges, Arroyo Trabuco (gauge no. 11047300), is presented in Figure 4, along with 2001 impervious levels. Knowing which roads were not constructed at respective points in time provided the basis for clipping-out associated impervious areas from the 2001 raster file such that changes in imperviousness through time could also be estimated. This procedure was performed for each watershed greater than 1% impervious area in 2001 (15 gauges), with the expectation that watersheds with less than 1% impervious area in 2001 would show little change in development through time. As a check to see how urban measures changed in a rural setting, the historical procedure was performed on one gauge with 0.4% impervious area in 2001 (Lone Pine, gauge no. 11063500).

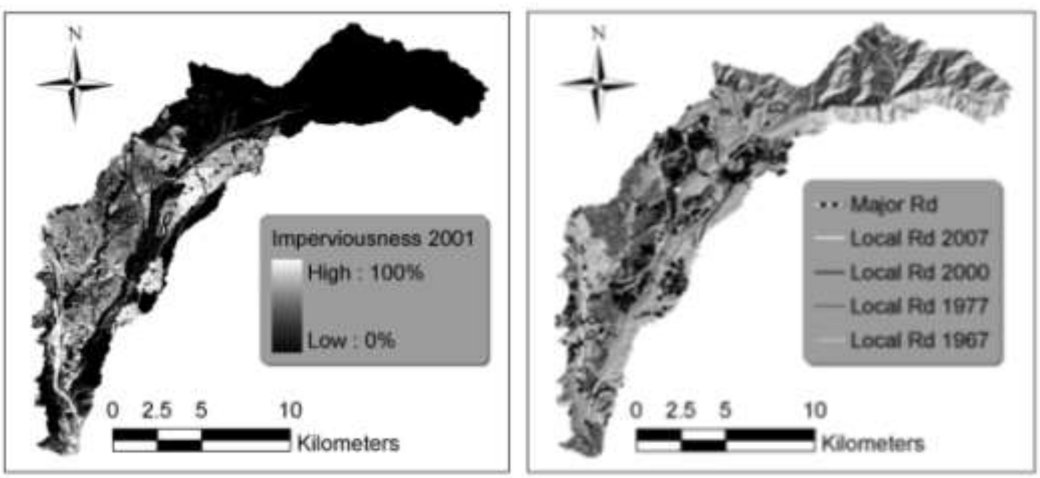


Figure 4. 2001 imperviousness and road vectors tracked through time per USGS historic quadrangle maps and current Cal-Atlas shapefiles at Arroyo Trabuco (Orange County, California, near intersection of Interstates 5 and 405).

It was apparent from the historical analysis that both road density and imperviousness tended to progress relatively linearly during development phases (Figure 5) such that the trapezoidal rule was sufficient to integrate mean values over the record. The gauges with the five highest integrated road densities (i.e., > 4 mi/mi^2) were covered by measured values of road density over their entire flow record. However, it was necessary to develop procedures to estimate measures of urbanization at gauges with records extending beyond the earliest measured values (e.g., pre-1950s). Given that the earliest measured values indicated relatively undeveloped/rural settings, Hawley (2009) was able to co

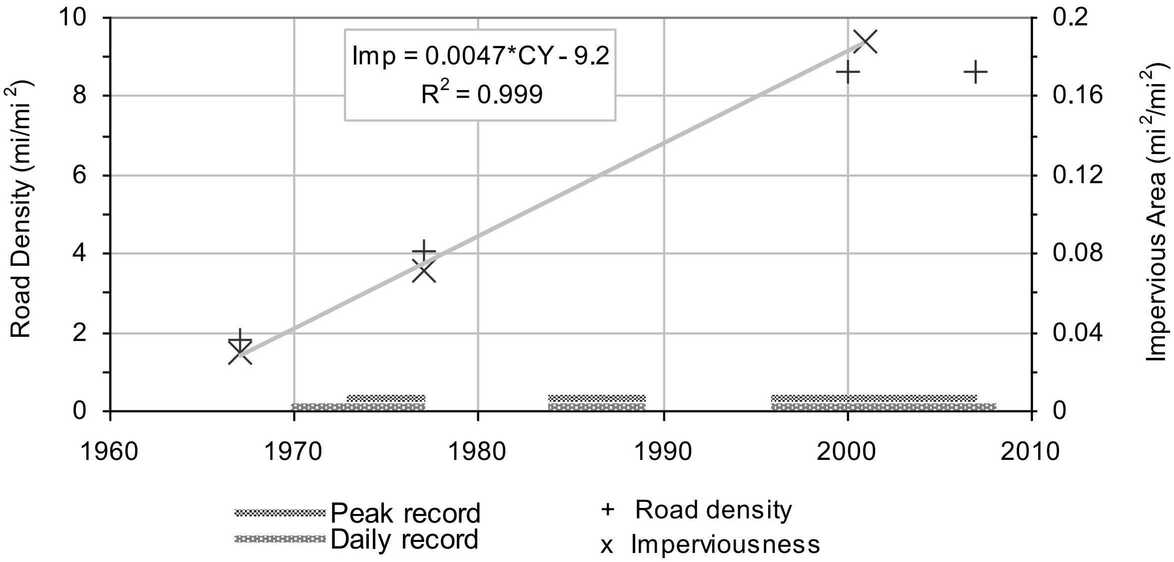


Figure 5. Imperviousness and road density through time at Arroyo Trabuco, overlaid by active gauge years and linear regression of imperviousness (Imp) as a function of calendar year (CY) from 1967 to 2001.

After tracking the progression of urbanization in great detail, several time-integrated measures were quantified of both road density and impervious area for testing in the models. Those that proved to be most consistently significant (i.e., $p < 0.05$) in preliminary models are indicated in **bold**:

- Imperviousness (TIA)
  - **Average spatial extent** (i.e., aerial extent of total imperviousness tracked through time and integrated over gauge record)
  - **Maximum spatial extent** (i.e., aerial extent of total imperviousness during last year of gauge record)
  - Fraction of record > (i.e., amount of time out of total years of record greater than xx% impervious area)
    - 1.5%
    - **5%**

- **7.5%**
- 10%
- 15%

- Road Density
    - Average spatial extent
    - Maximum spatial extent
    - Fraction of record >
        - 2 mi/mi^2
        - 4 mi/mi^2
        - 5 mi/mi^2
        - 6 mi/mi^2
        - 8 mi/mi^2

One potential explanation for the discrepancy in statistical significance between impervious area and road density is that TIA is a better surrogate for EIA than road density given such little stormwater mitigation to date. Furthermore, although the road density and imperviousness tend to be linearly correlated (e.g., Figure 5) at individual sites, they are *exponentially* correlated across all sites. As evident in Figure 6, a relatively-undeveloped gauge in a rural setting could have road densities up to 4 mi/mi^{2}and still have minimal amounts of impervious area (i.e., ~1.5%), while a gauge in a developing watershed with just 50% higher road density could have over seven times as much impervious area (i.e., 6 mi/mi^{2}relative to 10% imperviousness). This exponential relation masks potentially-critical differences in imperviousness in the early phases of development when ~2 mi/mi^{2}could represent less than 0.1% TIA in a rural basin or greater than 2% in a developing basin. The correlation is also misrepresentative in highly urbanized basins, as the relationship seems more linear than exponential above ~6 mi/mi^2. Such a complex, discontinuous relationship between road density and TIA would make it difficult for a continuous model to use one measure as a surrogate for the other.

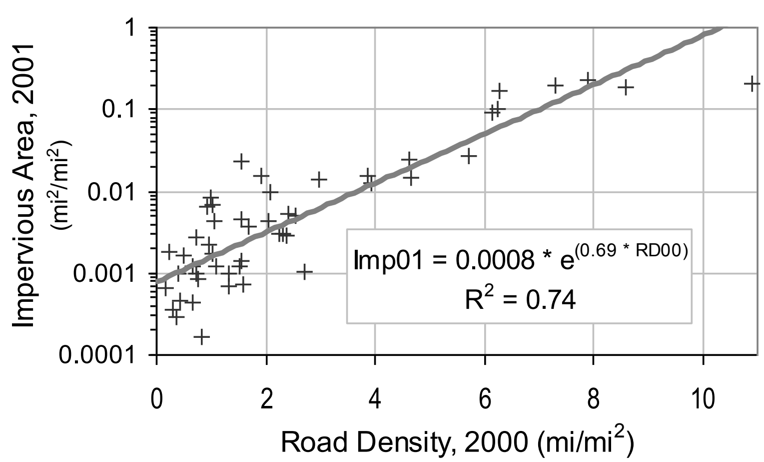


Figure 6. Exponential correlation between impervious area in 2001 (Imp01) and road density in 2000 (RD00) across all sites.

Other Physically-Based Metrics

One way to avoid specious conclusions in empirical studies is to develop multiple competing hypotheses (Schumm, 1991). It is not enough to infer causation by observing higher flows in urban settings. To be truly exhaustive, alternatives should be offered such as: were the urban gauges set in steeper watersheds, were they active during exceptional precipitation years, etc.? A matrix of readily-quantifiable hydrogeomorphic metrics was populated across varying temporal and spatial scales (Table 2) to test the influence of a multitude of potentially competing factors. GIS data (see Reference section) were acquired from public-domain sources such as the USGS, U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), and State of California geospatial clearinghouse (Cal-Atlas). Empty fields in some USDA polygons precluded a complete analysis of Natural Resources Conservation Service (NRCS) soil types; however, most source data were complete. Two sources of average annual precipitation were available. The USGS layer (1900 - 1960) was of slightly coarser spatial grain than the NRCS (1961 - 1990) shapefile, but because the 1977 USGS equations for southern California were developed with the former, both precipitation coverages were tested in the models. General resolution of these data was such that their precision was typically on the order of 1% of the measurement (e.g., 10-m National Elevation Dataset (NED) over 1 km of channel).

Table 1. Summary of variables tested in models with corresponding significance.

	Variable [(a)]	Units	Definition (equation)	GIS Source/Scale
spatial (x and y)	**A**	mi^2	drainage area	HUC and NED/10m
	Stm	mi	total stream length	NHD/ 1:24,000
	DD	mi/mi^2	drainage density (DD = Stm/A)	
	L	mi	length of main channel from gauge to basin divide	
	Shp	mi/mi^2	main-channel length divided by drainage area, i.e., shape (Shp = L/A)	
	W_{vly}	ft	valley width, measured from base of hillslope at gauge location	
	Ord	-	order – Strahler (1952) stream order	
	Arf_{Stm}	-	artificial fraction of total stream length, i.e., code ≠ 460	NHD
	Arf_{Mn}	-	artificial fraction of main channel	
topographic (x, y, and z)	Rlf	ft	total relief along main channel (elevation at divide minus elevation at gauge)	
	Elev	ft	average basin elevation, i.e., average of elevations at 10% and 85% of main-channel length measured from gauge to divide	
	Gage	ft	elevation at gauge	
	S_{chn}	ft/mi	average slope of main channel via elevations at 10% and 85% points	
	Vly	ft/mi	valley slope at gauge measured across geomorphically-continuous valley ~10% of main-channel length or ~1,500 ft (500 m)	
	Srf	ft/ft	average surface slope of watershed	

	Variable [a]	Units	Definition (equation)	GIS Source/Scale
precipitation	**P**	in.	average annual precipitation (area-weighted)	USGS (1900 - 1960)
	Pnrcs	in.	average annual precipitation (area-weighted)	NRCS (1961 - 1990)
	P224	in.	2-yr 24-hr precipitation volume (area-weighted)	NRCS
	IP	-	precipitation intensity relative to annual average (IP = P224/Pnrcs)	
	LAhst	-	relative difference from long-term precipitation average of 15.07 in. recorded at LA during gauged years	(1878 - 2006)
	$LAwt_{yr}$	-	number of exceptionally 'wet' precipitation years (50% > LA average, i.e., > 22.6 in.) during gauge record	
	$LAwt_{rt}$	-	relative number of exceptionally 'wet' precipitation years (50% > LA average) during gauge record divided by gauge record	
	SDhst	-	relative difference from long-term precipitation average of 9.96 in. recorded at SD during gauged years	(1850 - 2005)
	$SDwt_{yr}$	-	number of exceptionally 'wet' precipitation years (50% > SD average, i.e., > 14.9 in.) during gauge record	
	$SDwt_{rt}$	-	relative number of exceptionally 'wet' precipitation years (50% > SD average) during gauge record divided by gauge record	

[a] Variables: primary in **bold**, secondary in *italics*, and no statistical signficance is plain text

ArcMap software by Environmental Systems Research Institute (ESRI), including extensions such as 'spatial analyst', was used to optimize GIS measurements such as delineating watersheds and flow paths. Automated results from NED processing were cross-checked with existing shapefiles such as USGS HUC boundaries and NHD flowlines to verify estimates of drainage area, drainage density, etc.

Figure 7 depicts the inter-annual, decadal, and multi-decadal trends in regional precipitation as recorded at the two long-term precipitation gauges in Los Angeles (LA) and San Diego (SD). It includes the number of active gauges as well as number of gauges above specified levels of road density, suggesting that the more urban period of record (post ~1970) potentially had larger volumes of precipitation than the pre-urban period. By looking at records of individual gauges, Figure 8 shows some of the more urban records were active during wetter years; however, the most urban gauge (Arroyo Trabuco) was active during one of the driest composite climates on record. As such, we included the relative difference between mean-annual precipitation during flow records, along with the number of exceptionally wet years (50% > mean), in the models.

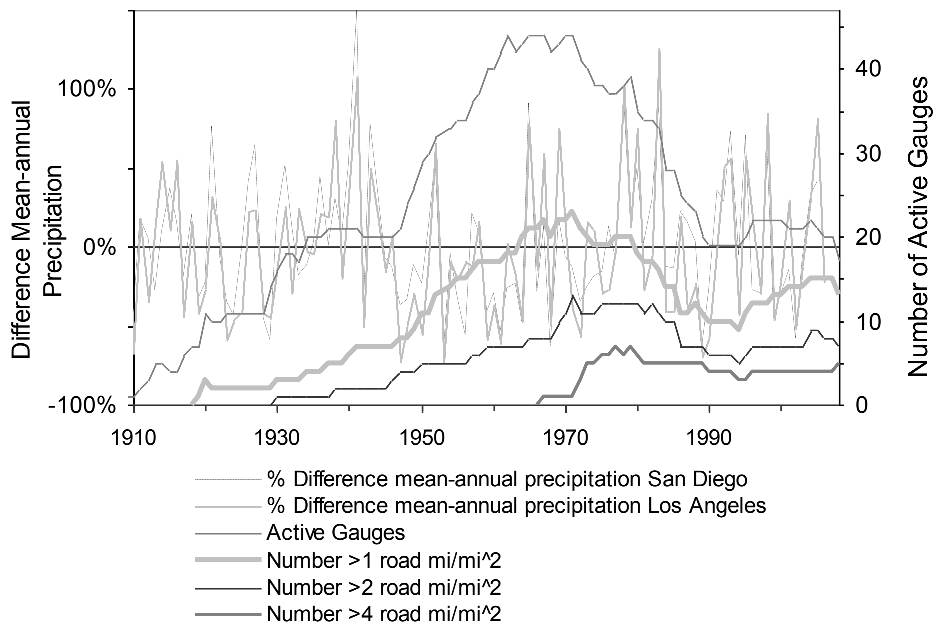


Figure 7. Inter-annual precipitation variability recorded at Los Angeles and San Diego overlaid with number of active gauges and number of gauged watersheds exceeding specified road-density levels (indicating increasing urbanization).

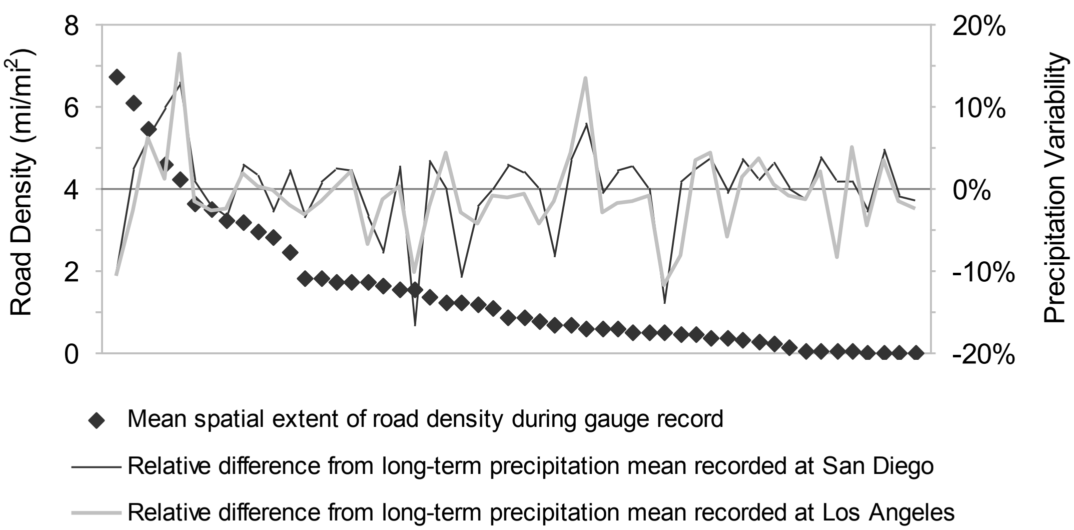


Figure 8. Mean spatial extent of road density overlaid by relative difference from long-term mean-annual precipitation recorded at Los Angeles and San Diego during gauge records.

Watershed configurations and drainage patterns varied throughout the study domain from linear to circular and parallel to dendritic, respectively. The slight departure in the overall trend of main-channel length (length of longest stem from gauge traced to drainage divide) as a function of drainage area from Hack's (1957) relationship is less notable than the variance within the sample (Figure 9), particularly important because one of the most exceptionally-linear watersheds (Arroyo Trabuco, 37 km to 140 km^2) was also one of the most urbanized. To represent these potentially-significant differences, the parameter 'Shp' was added as an alternative independent variable, defined as main-channel length/area.

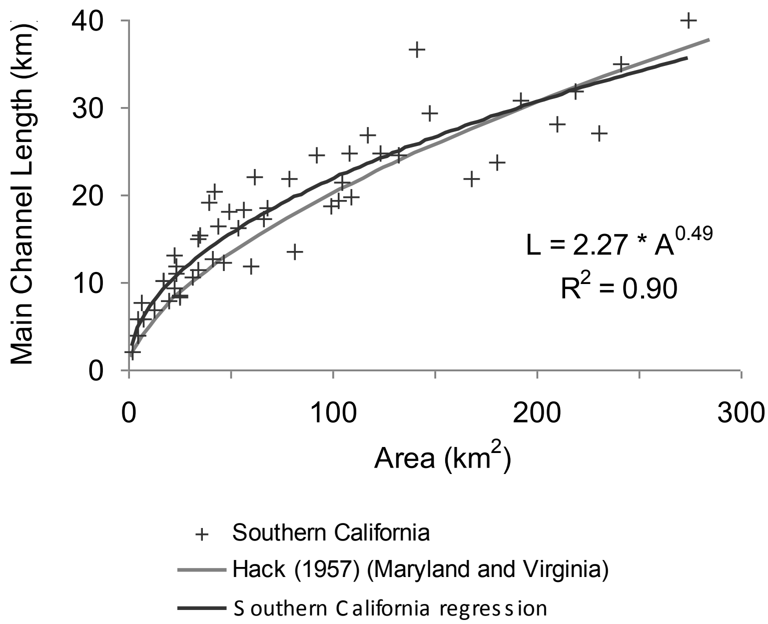


Figure 9. Main-channel length to basin divide (L) versus drainage area (A): southern California and the Hack (1957) relationship from Maryland and Virginia.

Consistent with Gregory (1976), drainage density was positively correlated to mean-annual precipitation in the semiarid regime and negatively correlated in the more humid setting (Figure 10). Additional parameters not explicitly accounted for in the models were vegetative cover, soil type/depth, and bedrock permeability due to incomplete spatial data; however, vegetation density may be implicitly captured in a discontinuous/threshold manner via mean-annual precipitation – one of the process-based explanations to the pattern in Figure 10. Other potentially contributing, but admittedly inter-correlated, factors which exhibited similarly-shaped patterns with drainage density included the 2-yr 24-hr precipitation, average surface slope, and average basin elevation. Two additional variables that showed scattered, slightly-positive correlations with drainage density were total basin relief and the 2-yr 24-hr precipitation volume standardized by the mean-annual precipitation.

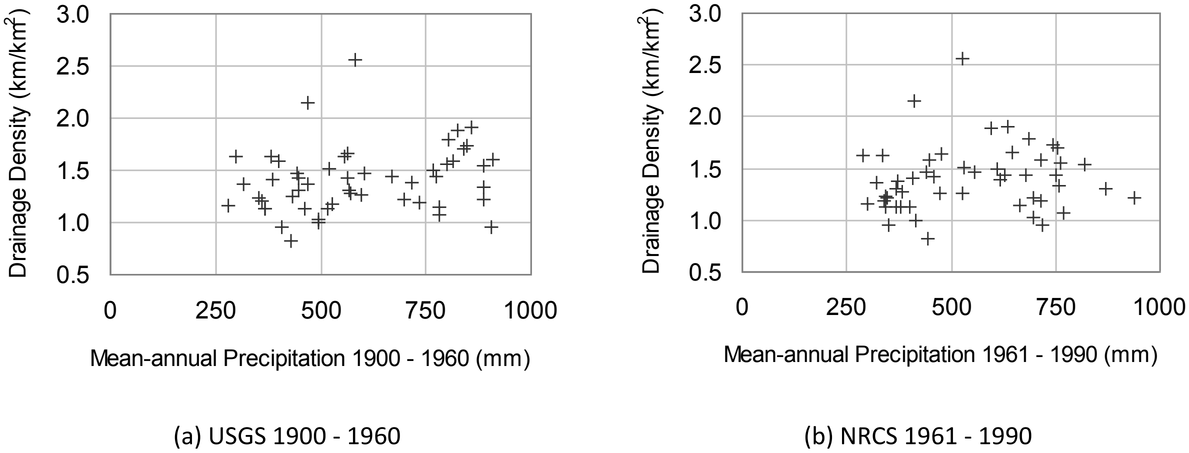


Figure 10. Drainage density versus area-averaged mean-annual precipitation.

Analytical Methods and Model Design

Beyond representing physical processes with appropriate quantitative variables, it was also important to guide their combination in model design to obviate potential collinearity issues. The objectives of the modeling were 2-fold: 1) to represent process by determining which variables were most significant in predicting flow magnitudes and durations, and 2) to determine which combinations and forms of these critical variables resulted in the most optimally-fit models for application. To guide the selection process, a cross-validation step was performed prior to final model design in which every fourth gauge (sorted alphabetically) was withheld resulting in a 33/10 calibration/validation split.

Multivariate power functions via regression analysis have been widely used by the USGS in developing regional equations for recurrence-interval flows (Jennings *et al.*, 1994). Logarithmic transformations of primary variables (e.g., Q, A, and P) in the southern California dataset created relatively constant residual variance, such that our analyses continue in this tradition. We used Statistical Analysis Software (SAS) to perform ordinary least squares regression. Hundreds of iterations of models were run with various withholding schemes using forward, backward, and best subset selection to determine the most consistently-significant parameters and candidate models for final testing. Due to sample variance, some variables were tested in multiple forms (e.g., exponential and power) and varied units (e.g., slope in ft/ft or ft/mi), expanding the range of variables from which the models could select.

Because unguided model selection often resulted in collinear variables and/or multiple forms of the same variable, our basic model framework was to test combinations of up to one variable from distinct process-based categories to preclude collinear variables from competing to represent the same process within the same model. Regarding peak-flow equations, the models selected from the following categories:

- watershed/network size: drainage area (A) or total stream length (Stm);
- spatial efficiency: shape (Shp) or drainage density (DD);
- precipitation: mean annual (P), 2-yr 24-hr volume (P_{224}), or 2-yr 24-hr relative to mean annual (IP);
- topographic efficiency: average slope of watershed surface (Srf), average channel slope (S_{chn}), valley slope at site (Vly), and total relief along main channel (Rlf);
- imperviousness (TIA): average imperviousness over record (Imp_{av}), maximum imperviousness of record (Imp_{max}), fraction of record length greater than 5% impervious (Imp_5), and fraction of record length greater than 7.5% impervious (Imp_7).

Identical steps were taken in designing equations for the component variables of DDFs (i.e., Q_{max}, d1/day1, and d2/day2). Beyond the process-based categories discussed above, a probabilistic category was added with candidate variables that increased the likelihood of having an extremely large/long event. This included the number of years of gauge record (Yr), the relative difference from long-term precipitation average recorded at LA during gauged years (LA_{hst}), and the number of active gauge years that were exceptionally 'wet', that is, 50% greater than the long-term mean recorded at LA ($LAwt_{yr}$ and $LAwt_{rt}$).

Finally, due to the fact that DDFs essentially pivot around Q_{max}, it was clear that their shape (i.e., d2 or day2) would best be explained by direct measures of their magnitude (d1 or day1) and scale (Q_{max}). All else being equal, a larger DDF magnitude would correspond to a steeper (more negative) slope, while a larger scale (Q_{max}) would tend to correspond to a flatter (less negative) curve. As such, d1/day1 and Q_{max} were included in some of the d2/day2 models to evaluate the performance benefits relative to the risk of compounding prediction errors on the application side. Instantaneous peak flows were also tested as a substitute for daily Q_{max}, with Q_{10} being the best candidate for final models due to performance in predicting d2/day2, as well as regularly having the best prediction accuracies among all instantaneous Q_i in preliminary models.

Model forms that were congruent with hydrologic theory and had high performance in the cross-validation phase were selected for final model calibration. Model performance was measured via several indicators such as a high significance of individual variables (typically $p < 0.05$), high Adjusted R^2 (Adj. R^2) and/or minimum corrected Akaike Information Criterion (AIC_c), and homoscedastic residuals across both calibration and validation data. We assessed model performance, including standard diagnostics, in both logarithmic and arithmetic space. Outliers were identified using standard diagnostics (e.g., Cook'D, Rstudent residual, etc.); however, to be withheld from the model there needs to be supporting *a priori* evidence and/or compelling physically-based justification (e.g., the hydrogeomorphically-distinct 'dry' subset of gauges east of the Penninsular Range discussed above). In general, we attempted to follow the guideline of ca. 10 observations per predictor variable, such that models from the cross-validation phase typically had only three to four independent variables (i.e., per thirty-three samples) allowing for exceptions in cases of high performance/statistical significance.

Results

The presentation of results is divided into three subsections: 1) cross-validation summary, 2) peak-flow equations, and 3) DDF models. Because competing models often performed similarly, we include five to six models for each dependent variable. This reduces the risk of giving too much weight to one model/variable as they are all physically based, and there is generally no clear basis for choosing one model over a similarly performing alternative. It also better represents the range of influence of urbanization in that different proportions of the variance are explained depending on what other statistically-significant variables are included.

Cross-Validation Summaries and Individual Variable Performance

Cross-validation models of Q_i and DDF components are summarized in Tables 3(a) and 3(b), respectively. Measures of watershed size (Stm, A) and precipitation (P, P_{224}) accounted for the most variance across all return-interval flows. Measures of imperviousness accounted for up to one quarter of the variance of the 1-yr flow, with decreasing significance for higher flows (e.g., partial R^2 ~0.10, 0.06, 0.02 for 1.5-, 2-, and 5-yr flows, respectively). At higher return intervals (i.e., $\geq Q_{10}$), the size of the watershed accounted for so much of the variance that few additional terms were statistically significant (i.e., $p < 0.05$), resulting in high performance using relatively-simple models. For example, for return intervals 10, 25, 50, and 100, R^2 in arithmetic space ranged from 0.7 to 0.9 for both calibration and validation subsamples using the following equations:

$Q_i = f(A, P)$

$Q_i = f(Stm, P)$

$Q_i = f(Stm, P_{224})$ (see Figure 11 for cross-validation performance at Q_{25})

Table 2. Summary of cross-validated models.

(a) For instantaneous peak flows ($n_{calibration} = 33$, $n_{validation} = 10$)

Dependent Variable	Urbanization Significant ($p < 0.05$) in Validated Model?	Best Predictor Variables [(a)]	Average Calibration Standard Error[(b)]	Average Validation Standard Error[(b)]
Q1.5	✓	A, Strm (0.2); P, P_{224}, IP, (0.2); Imp_{max} (0.1)	80%	100%
Q2	✓	A, Strm (0.4); P, P_{224}, IP (0.1); Imp_{max} (0.06)	80%	80%
Q5	✓	A, Strm (0.7); P, P_{224}, IP (0.1); Imp_{max} (0.02)	60%	70%
Q10	p = 0.12	A, Strm (0.8); P, P_{224}, IP (0.05)	40%	50%
Q25		A, Strm, (0.8); P, P_{224}, IP (0.07)	30%	50%
Q50		A, Strm (0.8); P, P_{224}, (0.08)	30%	50%
Q100		A, Strm (0.7); P, P_{224} (0.1)	40%	60%

Table 3. Continued

(b) For DDFs

Dependent Variable	n Calibration	n Validation	Urbanization Significant ($p < 0.05$) in Validated Model?	Best Predictor Variables [(a)]	Average Calibration $R^{2\,(c)}$	Average Validation $R^{2\,(c)}$
Qmax	33	10		A, Strm (0.6); P, P_{224} (0.2)	0.8	0.8
d1	29	9	✓	A (0.1); P (0.2); Yr (0.5); Imp_x (0.05)	0.7	0.9
day1	30	9	✓	A (0.1); P (0.2); Yr (0.5); Imp_x (0.1)	0.7	0.7
d2	30	9	p = 0.06	Q_{10} (0.3); d1 (0.5)	0.9	0.9
day2	30	9	✓	Q_{10} (0.3); day1 (0.5)	0.9	0.8

[(a)] Corresponding partial R^2 in parentheses

[(b)] Standard Error of estimate reported from arithmetic space as a percentage of the sample mean

[(c)] R^2 reported from arithmetic space

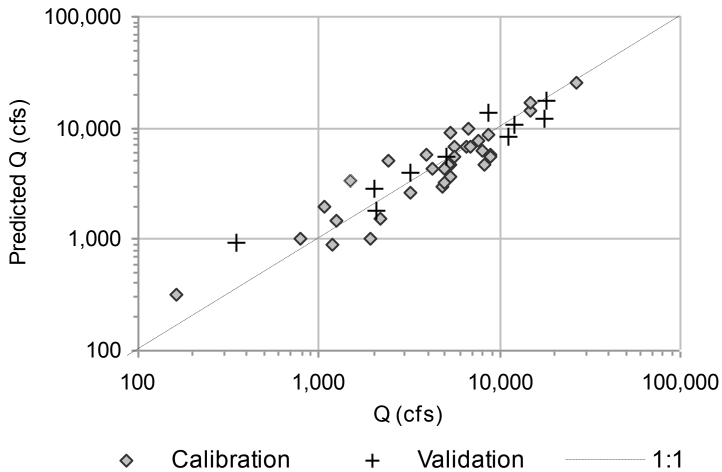


Figure 11. Cross-validation performance of $Q_i = f$(Stm, P_{224}) for 25-yr return interval (predicted Q_{25} versus actual) with 1:1 'perfect-fit' line overlaid.

However, the diminishing predictive power of watershed scale (i.e., A and Stm) with storm frequency (e.g., partial R^2 for A ~0.7 at Q_5 versus ~0.2 at $Q_{1.5}$) explained why equations with more classes of hydrologic variables generally performed better than simpler models for return intervals less than 5 yrs. That is, with decreasing volumes of precipitation, the efficiency with which a drainage network concentrated and conveyed runoff became increasingly significant in predicting peak flow. Although hundreds of models were tested, the form that performed best during cross validation in terms of arithmetic space R^2, AIC, SE, and least patterned residuals for $Q_{1.5}$ and Q_2 was:

$Q_i = f(\text{Stm, Shp, IP, Vly, Imp}_{max})$

Imperviousness could account for up to 25% of variability in the 1-yr flow, but other terms had little predictive power. Largely attributable to the fact that fifteen of the forty-three gauges had entire years of no flow (i.e., $Q_1 = 0$), models showed poor overall performance and unacceptably-patterned residuals. Consequently, no Q_1 equations were advanced to final calibration.

Based on performance across all remaining return intervals (i.e., 1.5, 2, 5, 10, 25, 50, and 100), five base-models were selected for final calibration. A summary of the cross-validated models is presented in Table 3(a).

Recall that DDFs have three components: Q_{max} (scale), d1 or day1 (magnitude), and d2 or day2 (shape). Process-based categories such as scale and precipitation explained most of the variance of Q_{max} (partial R^2 of 0.6 and 0.2, respectively). Record length (Yr) was the next most significant variable in forward selection, explaining 3 to 4% of the variance. The most significant measure of network spatial efficiency was DD (2 to 3% of the variance) when used in combination with A, P or P_{224}, and Yr. Other measures of spatial and topographical efficiency were insignificant ($p >> 0.05$) except in models where precipitation was intentionally withheld, which resulted in poorer overall performance. This suggested that the measures were acting more as a surrogate for precipitation. Finally, urbanization was insignificant in predicting the maximum daily-mean flow on record, consistent with the models of the rarest and largest peak flows (i.e., $\geq Q_{25}$).

Forward selection of DDF magnitude parameters typically identified the following form, with corresponding partial R^2 in parentheses:

d1: Yrs (0.52), A (0.05 - 0.06), P (0.14), Imp_x (0.04 - 0.06)

day1: Yrs (0.46), A (0.07 - 0.09), P (0.18), Imp_x (0.10 - 0.11), S_{chn} (0.02 - 0.03)

One of three similarly performing impervious descriptors (i.e., Imp_x representing Imp_{av}, Imp_5, or Imp_7) was typically the third variable added during forward selection for 'day1', while it was generally the fourth best explanatory variable for 'd1'. Exponential forms of the impervious terms consistently explained more variance than the power form.

Models of day1 with S_{chn} had improved calibration accuracy but reduced validation performance compared to the base model (i.e., A, P, Yrs, and Imp_x). Adding both Srf (0.03 - 0.04) and DD (0.02 - 0.03) to the base model improved both calibration and validation performance. Despite reservations about including six independent variables with only thirty calibration observations, the fact that all variables were significant ($p < 0.05$) supported their inclusion. One model of d1 had modest performance with no urban term (A, DD, Srf, Yrs) during calibration, but had substandard performance with the valiadation data across all measures (i.e., R^2, Adj. R^2, SE, AIC, and AIC_c). It was selected for final model calibration in order to compare performance of urban models against the best non-urban model.

A substantial outlier was identified during the calibration/validation phase of d1. In this case, there was significant *a priori* rationale to consider excluding the Ventura River gauge near Meiners Oaks, California (gauge no. 11116550), because the DDF itself was poorly fit (worst R^2 at 0.79) with unacceptably-patterned residuals. Withholding the outlier resulted in substantial changes to the parameter values, increased the significance of urbanization and drainage area (partial R^2 of 0.04 to 0.07 and 0.12, respectively), and improved overall model performance. Similar to the expanded day1 models, d1 as a function of A, P, DD, Srf, Yrs, and Imp_x resulted in improved performance in the validation data and less heteroscedastic residuals.

The shape of the DDFs (d2 or day2) was highly influenced by its magnitude (Q_{max}) and scale (d1 or day1). Models that intentionally withheld such measures were not only poorly fit (best Adj. R^2 0.57 for d2), but had severely patterned residuals. Conversely, models that included d1 (partial R^2 0.54) and Q_{max} (partial R^2 0.28), or Q_{10} (partial R^2 0.32) as an alternative to Q_{max}, accounted for up to 90% of the total variance. Inclusion of these variables was necessary to achieve high model performance ($R^2 > 0.6$).

Another significant outlier (Little Dalton near Glendora, California) was identified during d2 cross validation; however, there was no concurring *a priori* evidence to withhold the gauge from the models. Two similarly performing models were identified during calibration in the following forms:

$$d2 = f(Q_{10}, d1, Yrs, Imp_x)$$

$$d2 = f(Q_{10}, d1, Yrs, P_x)$$

The model with P or P_{224} in place of Imp_x performed slightly better during calibration (Adj. R^2 0.90 versus 0.88); however, had larger errors and more patterned residuals in validation (R^2 0.83 versus 0.93, Standard Error (SE) 14% versus 9%). Both were selected for final calibration, along with a three-term equation that substituted Slp_{chn} for Yrs and P, which performed slightly worse in both calibration and validation, but all terms were significant at the $p < 0.05$ level.

Likewise with the calibration of day2, Q_{10} and day1 explained most of the variance (0.31 and 0.51, respectively), with Q_{max} explaining 26% of the variance in the place of Q_{10}. Models that intentionally excluded those variables could barely explain the total variance that 'day1' could explain individually. Standard diagnositics revealed unacceptably-patterned residuals when plotted against Q_{10}. The shape, which slightly resembled the trend of drainage density versus precipitation (Figure 10), became less pronounced when Imp_x was included in the model. They were most evenly distributed by including P_{224}, Yr, and Elev in place of imperviousness, but the five-variable model for day2 performed the poorest with the validation data (R^2 0.56 versus 0.86 for day2 = f(day1, Q_{10}, Yrs, Imp_{av})). This was despite the fact that each variable in the five-variable model was significant at the 0.05 level during calibration and the model on the whole accounted for more variance (i.e., 91% versus 85%). As such, both models were selected for final calibration.

In summary, for each dependent variable, cross validation produced five to twelve reasonably performing candidate models that were advanced to final calibration; the best performing models are presented herein. A central finding was that measures of imperviousness were highy significant ($p < 0.05$) in predicting instantaneous peak flows at return intervals less than or equal to 5 yrs. Additionally, urbanization was highly significant in predicting the magnitude of DDFs ($p < 0.05$ in nineteen of twenty models, $p < 0.001$ in nine of twenty models). This was particularly true for the day1 (partial R^2 ~0.10) scheme that includes more bins with low/moderate flows (bins 12-25) as opposed to the d1 (partial R^2 ~0.05) scheme which is more skewed toward the highest flows (bins 16-25). DDF shape (d2 or day2) was less explained by urbanization ($p < 0.10$ in four of fourteen models), other than through the indirect influence of DDF magnitude, which explained greater than 50% of the variance of its shape.

Peak-Flow Equations

Five equations are presented for each return-interval flows. By using the same equation formats for all recurrence intervals, it is apparent how the most influential variables change with return period. In general, there seems to be a behavior change around the 2- and 5-yr events, transitioning from a high influence of drainage efficiency, rainfall intensity, and imperviousness to a greater dependency on watershed size such as area and total stream length.

The equations have varied forms; however, the final equation (Eq. (10)) is intentionally presented as a revision to the USGS 1977 equations that were functions of only A and P. We added an exponential term for Imp_{max} because it models the effects of urbanization in a simple continuous form (i.e., $Imp_{max} \rightarrow 0$, urban term $\rightarrow 1$, equation $\rightarrow$ rural equation). We present each equation with the corresponding variable definitions (in Table 2); and parameters, units, and performance measures (in Tables 4(a) through 4(j)) for each return interval. ***In these equations, uppercase terms indicate variables and lowercase nomenclature indicates the corresponding β parameter from the regression. Bold font draws attention to terms with varied units.***

Equation (6) is presented with corresponding parameters, units, and performance measures in Table 4(a):

$$Q_i = e^{(Incpt)} * Stm^{stm} * e^{(shp*Shp)} * IP^{ip} * Vly^{vly} * e^{(impmax*Impmax)} \qquad \textbf{Eq. (6)}$$

where:

- Q_i = instantaneous peak flow at return interval i yrs (cfs);
- Stm = total stream length in basin (mi);
- Shp = length of main channel (traced to basin divide) divided by total drainage area (mi/mi^2);
- IP = P_{224}/P_{nrcs}, i.e., 2-yr 24-hr volume/average annual volume: NRCS 1961 - 1990 (in/in);
- Vly = valley slope at gauge as measured across a geomorphically-continuous valley setting (i.e., relatively continuous valley width lacking major tributary confluences) up to a length of ~10% of main-channel length or ~1,500 ft (ft/mi);

and

Imp$_{max}$ impervious area as **fraction** of total drainage area **(mi^2/mi^2)**.

Table 3. Corresponding parameters, units, and performance measures for equations.

(a) For Eq. (6)

Return Period (yrs)	Incpt (-)	stm (mi)	shp (mi/mi^2)	ip (-)	vly (ft/mi)	imp_{max} (-)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
1.5	8.19	0.286	-1.03	3.49	0.448	9.21	0.53	68%	445	stm 0.32
2	7.99	0.376	-0.891	2.87	0.337	6.68	0.61	62%	487	stm 0.12, shp 0.07
5	8.86	0.647	-0.380	2.57	0.099	2.54	0.80	49%	591	shp 0.25, vly 0.37, imp_{max} 0.11
10	7.83	0.717	-0.344	1.77	0.137	0	0.86	39%	628	shp 0.19, vly 0.10
25	7.08	0.783	-0.282	1.31	0.197	0	0.84	39%	680	shp 0.31
50	6.82	0.811	-0.255	1.12	0.223	0	0.82	42%	714	shp 0.40
100	6.68	0.831	-0.236	0.99	0.241	0	0.80	45%	742	Ip 0.10, shp 0.46

(b) For Eq. (7)

Return Period (yrs)	Incpt (-)	a (mi^2)	dd (mi/mi^2)	p224 (in.)	imp_{max} (%)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
1.5	-0.799	0.630	1.36	1.80	0.763	0.46	94%	471	dd 0.07
2	0.411	0.694	1.14	1.48	0.579	0.55	82%	508	dd 0.07
5	2.83	0.840	0.957	0.713	0.240	0.74	59%	604	imp_{max} 0.05
10	3.61	0.865	0.804	0.778	0.096	0.84	41%	633	imp_{max} 0.29
25	4.22	0.884	0.701	0.825	0	0.85	32%	659	
50	4.41	0.891	0.699	0.910	0	0.85	31%	687	
100	4.56	0.897	0.699	0.968	0	0.84	32%	712	

(c) For Eq. (8)

Return Period (yrs)	Incpt (-)	stm (mi)	p224 (in.)	imp_{max} (-)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
1.5	-0.188	0.628	1.81	13.1	0.48	83%	459	
2	0.837	0.689	1.46	9.91	0.56	74%	499	
5	3.00	0.835	0.678	3.99	0.74	56%	599	imp_{max} 0.05
10	3.62	0.859	0.748	1.70	0.84	40%	629	imp_{max} 0.26
25	4.16	0.876	0.781	0	0.86	32%	660	
50	4.34	0.884	0.864	0	0.85	31%	686	
100	4.50	0.889	0.921	0	0.84	33%	712	

Table 4. Continued

(d) For Eq. (9)

Return Period (yrs)	Incpt (-)	a (mi^2)	p_{224} (in.)	elv (ft)	imp_{max} (-)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
1.5	6.08	0.586	3.07	-0.960	10.8	0.57	67%	442	
2	6.99	0.656	2.71	-0.939	7.59	0.68	63%	486	
5	8.22	0.821	1.54	-0.733	0	0.80	47%	584	
10	7.45	0.850	1.55	-0.546	0	0.88	34%	615	
25	7.06	0.870	1.57	-0.426	0	0.87	32%	662	
50	6.95	0.879	1.58	-0.375	0	0.86	34%	695	
100	6.90	0.886	1.59	-0.340	0	0.84	37%	724	

(e) For Eq. (10)

Return Period (yrs)	Incpt (-)	a (mi^2)	p (in.)	imp_{max} (-)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
1.5	-2.03	0.592	1.55	11.6	0.37	85%	461	
2	-0.644	0.667	1.29	8.61	0.47	76%	501	
5	2.137	0.838	0.773	3.23	0.70	59%	603	P 0.08, Imp_{max} 0.17
10	2.90	0.868	0.767	0	0.81	45%	637	
25	2.68	0.891	1.01	0	0.83	37%	673	
50	2.63	0.902	1.11	0	0.82	37%	700	
100	2.62	0.909	1.19	0	0.81	38%	724	

(f) For Q_{max} (scale) equations for DDFs Eqs. (11) through (13)

Eq. Number	Incpt (-)	a (mi^2)	stm (mi)	yr (yrs)	dd (mi/mi^2)	p (in.)	p224 (in.)	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-exceptions (p > 0.05)
11	-2.24	0.979	-	0.341	-	1.79	-	0.80	51%	632	
11	1.44	0.966	-	0.288	-	-	1.65	0.81	49%	629	Yr 0.10
12	-2.35	0.974	-	0.362	0.687	1.63	-	0.81	48%	629	DD 0.10
12	1.06	0.960	-	0.315	0.624	-	1.50	0.81	46%	625	DD 0.13, Yr 0.07
13	-2.30	-	0.958	0.381	-	1.54	-	0.82	48%	628	
13	0.900	-	0.942	0.341	-	-	1.40	0.82	45%	623	

Table 4. Continued

(g) For d1 Eqs. (14) and (15)

Imperviousness Variable	Incpt	a	p	yr	dd	srf	imp_x	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-values for Imp_x
	(-)	(mi^2)	(in.)	(yrs)	(mi/mi^2)	(-)	(-)				
Imp_{av}	-15.6	0.891	4.89	1.65	-	-	10.2	0.81	173%	830	0.016
Imp_5	-16.2	0.920	5.01	1.70	-	-	1.42	0.82	170%	829	0.005
Imp_7	-16.8	0.945	5.13	1.74	-	-	1.82	0.84	167%	827	< 0.001
Imp_{av}	-12.9	1.07	3.74	1.64	-1.39	4.43	9.15	0.84	131%	813	0.020
Imp_5	-13.6	1.09	3.90	1.69	-1.38	4.23	1.28	0.85	128%	811	0.006
Imp_7	-14.2	1.11	4.05	1.73	-1.37	4.18	1.69	0.87	123%	808	< 0.001

(h) For d2 Eqs. (16) and (17)

Imperviousness or Precipitation Variable	Incpt	β_{Q10}	β_{d1}	β_{yr}	β_{Px}	β_{impx}	Adjusted $R^{2\,(d)}$	Standard Error [(b)]	AIC_c [(c)]	p-values for Imp_x or P_x
	(-)	(cfs)	(days, cfs)	(yrs)	(in.)	(-)				
Imp_{av}	-1.91	0.193	-0.128	0.123	-	1.02	0.89	8.1%	-187	0.011
Imp_5	-1.95	0.195	-0.130	0.130	-	0.124	0.89	8.1%	-186	0.012
Imp_7	-1.97	0.198	-0.131	0.136	-	0.139	0.89	8.1%	-187	0.011
P	-1.33	0.183	-0.111	0.097	-0.172	-	0.90	7.9%	-188	0.005
P_{224}	-1.76	0.190	-0.116	0.125	-0.170	-	0.91	7.6%	-192	<0.001

(i) For day1 Eqs. (18) and (19)

Imperviousness Variable	Incpt	a	p	yr	dd	srf	imp_x	Adjusted $R^{2\,(a)}$	Standard Error [(b)]	AIC_c [(c)]	p-values for Imp_x
	(-)	(mi^2)	(in.)	(yrs)	(mi/mi^2)	(-)	(-)				
Imp_{av}	-12.9	0.676	3.71	1.85	-	-	13.8	0.75	92%	709	0.002
Imp_5	-13.3	0.706	3.75	1.92	-	-	1.79	0.76	89%	707	< 0.001
Imp_7	-13.6	0.727	3.78	2.00	-	-	2.08	0.77	85%	702	< 0.001
Imp_{av}	-9.55	0.905	2.25	1.84	-1.56	5.54	12.7	0.81	66%	686	0.001
Imp_5	-10.1	0.924	2.37	1.90	-1.57	5.31	1.63	0.82	65%	685	< 0.001
Imp_7	-10.4	0.945	2.40	1.93	-1.59	5.32	1.92	0.83	67%	687	< 0.001

Table 4. Continued
(j) For day2 Eqs. (20) and (21)

Imperviousness or Precipitation Variable	Incpt (-)	β_{Q10} (cfs)	β_{day1} (days, cfs)	β_{yr} (yrs)	β_{Px} (in.)	β_{impx} (-)	Adjusted $R^{2\,(d)}$	Standard Error (b)	AIC_c (c)	p-values for Imp_x or P_x
Imp_{av}	-1.60	0.166	-0.138	0.129	-	0.720	0.85	9.1%	-188	0.060
Imp_5	-1.63	0.169	-0.139	0.134	-	0.089	0.85	9.1%	-188	0.058
Imp_7	-1.65	0.170	-0.140	0.140	-	0.106	0.85	9.1%	-188	0.044
P	-1.22	0.157	-0.123	0.102	-0.098	-	0.84	9.2%	-187	0.096
P_{224}	-1.40	0.154	-0.111	0.107	-0.167	-	0.87	8.3%	-195	0.013

(a) Adjusted R^2 reported from geometric space
(b) Standard Error of estimate expressed as percentage of sample mean in arithmetic space
(c) Corrected AIC reported from arithmetic space
(d) Adjusted R^2 reported from arithmetic space (for linear models)

Equation (7) is presented with corresponding parameters, units, and performance measures in Table 4(b):

$$Q_i = e^{(Incpt)} * A^a * DD^{dd} * P_{224}^{p224} * Imp_{max}^{impmax} \qquad \textbf{Eq. (7)}$$

where:

A = total contributing drainage area (mi^2);

DD = drainage density computed by total stream length divided by drainage area (mi/mi^2);

P_{224} = 2-yr 24-hr precipitation volume: NRCS (in.);

Imp_{max} expressed as **percentage** of total drainage area **(mi^2/mi^2) * 100%**; and

$Imp_{max} \geq 1\%$ or else term is dropped.

Equation (8) is presented with corresponding parameters, units, and performance measures in Table 4(c):

$$Q_i = e^{(Incpt)} * Stm^{stm} * P_{224}^{p224} * e^{(impmax*Impmax)} \qquad \textbf{Eq. (8)}$$

where:

Imp_{max} expressed as **fraction** of total drainage area **(mi^2/mi^2)**.

Equation (9) is presented with corresponding parameters, units, and performance measures in Table 4(d):

$$Q_i = e^{(Incpt)} * A^a * P_{224}^{p224} * Elv_{bsn}^{elv} * e^{(impmax*Impmax)} \qquad \textbf{Eq. (9)}$$

where:

Elv_{bsn} = average elevation between the 10 and 85% points along the main channel from outlet to divide (feet above mean sea level); and

Imp_{max} expressed as **fraction** of total drainage area **(mi^2/mi^2)**.

Equation (10) is presented with corresponding parameters, units, and performance measures in Table 4(e):

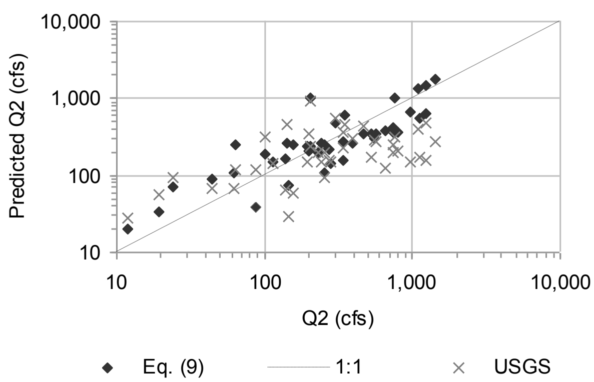
$$Q_i = e^{(Incpt)} * A^a * P^p * e^{(impmax*Impmax)} \quad \textbf{Eq. (10)}$$

where:

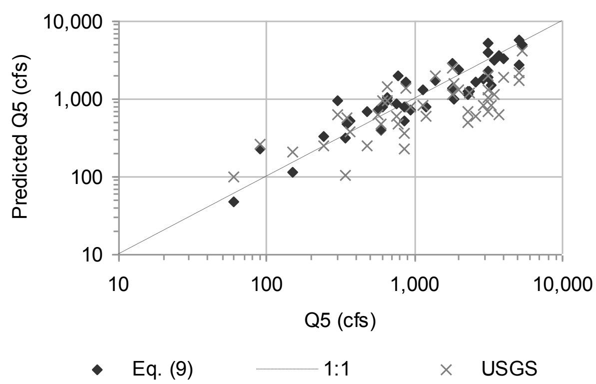
P = average annual precipitation, USGS: 1900 - 1960 (in.); and

Imp_{max} impervious area as **fraction** of total drainage area **(mi^2/mi^2)**.

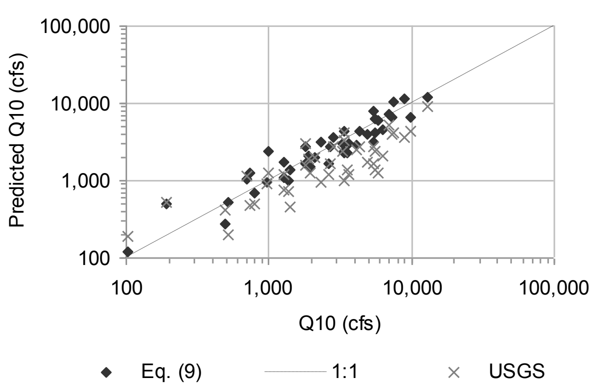
Model performance generally increases up to Q_{10}, with relatively consistent precision at higher return intervals. Performance of Eq. (9) relative to the USGS rural (1977) and urban (1983) equations is depicted in Figures 12 and 13, respectively. The disparity between our models and the USGS models decreases with increasing return period (Table 5).

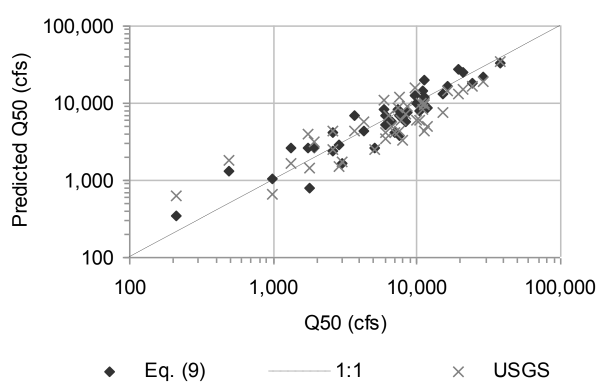


(a) at Q2



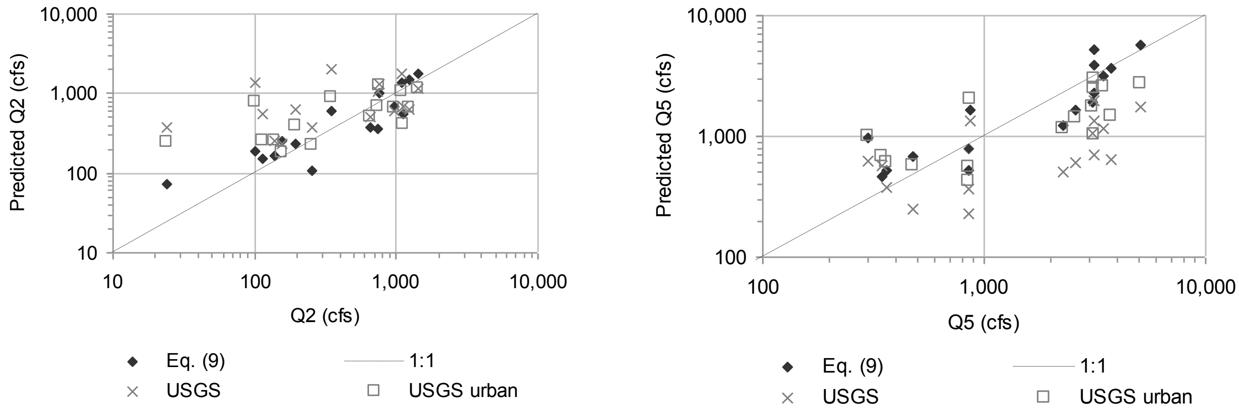
(b) at Q5





(c) at Q10 **(d) at Q50**

Figure 12. Comparison of performance between Eq. (9) and USGS rural (1977).



(a) at Q2 **(b) at Q5**

Figure 13. Comparison of performance between Eq. (9) and USGS urban (1983) in most urbanized watersheds.

Table 4. Comparison of Q_i model performance with USGS rural (1977) and urban (1983) equations using Standard Error values from arithmetic space.

Return Period (yrs)	Standard Error of Estimate as % of Sample Mean (arithmetic space)					USGS 1977	USGS 1983
	Eq. (6)	Eq. (7)	Eq. (8)	Eq. (9)	Eq. (10)	Rural	Urban
1.5	68%	94%	83%	67%	85%	-	-
2	62%	82%	74%	63%	76%	104%	91%
5	49%	59%	56%	47%	59%	80%	80%
10	39%	41%	40%	34%	45%	67%	78%
25	39%	32%	32%	32%	37%	51%	70%
50	42%	31%	31%	34%	37%	43%	64%
100	45%	32%	33%	37%	38%	40%	60%

Given the longer records and a focus on smaller watersheds, our models generally outperform the USGS equations (Table 5). It should be noted that the SE for the USGS urban equation is substantially influenced (perhaps unduly) by the large number of predictor variables (seven) relative to the sample size. However, direct comparisons of unadjusted metrics such as R^2 or Sum of Squared Errors (SSE) demonstrated better performance by our equations in every case relative to the USGS urban equations. The single case where our equations were outperformed by the USGS rural equations was Eq. (6) at the 100-yr flow, which is included because it was one of the best performing equations at $Q_{1.5}$ through Q_{10}.

Duration Density Functions

Power functions (Eqs. (4) and (5)) are used to predict durations of bin flows as scaled by Q_{max} using Eq. (1). Two forms of the power function cover different ranges of bins (i.e., bins 16-25 with d1 and d2 or bins 12-25 using day1 and day2). Models for each are presented with Q_{max} followed by d1 and d2, followed in turn by day1 and day2.

Models of Q_{max} (cfs) that were advanced from cross validation performed comparatively well during final calibration in both geometric and arithmetic space. The only notable change was that DD and Yr became less significant, with p-values greater than 0.05 in some cases. Final models are presented with corresponding parameters, units, and performance measures in Table 4(f):

$$Q_{max} = e^{Incpt} * A^{a} * P_x^{px} * Yr^{yr} \quad \textbf{Eq. (11)}$$

$$Q_{max} = e^{Incpt} * A^{a} * P_x^{px} * Yr^{yr} * DD^{dd} \quad \textbf{Eq. (12)}$$

$$Q_{max} = e^{Incpt} * Stm^{stm} * P_x^{px} * Yr^{yr} \quad \textbf{Eq. (13)}$$

where:

Q_{max} = maximum mean 24-hr flow (cfs);

Yr = length of mean-daily flow record (yrs);

P_x = P or P_{224} (as specified in Table 4(f)), where:

P = mean annual precipitation 1900 - 1960 (USGS) (in.); and

P_{224} = 2-yr 24-hr precipitation volume (NRCS) (in.).

A substantial outlier was identified during the cross-validation phase of d1, and confirmed during final calibration *across all model forms.* Consistently outside of the 95% confidence interval for model predictions, studentized residuals ranged from -2.5 to -4, while other points generally fell within -2 to 2. The 'best' case for its inclusion was model d1 = f(A, DD, Srf, Yrs, Imp_{av}), with a Cook's D of 0.39 and an RStudent residual of -3.0, corresponding to a two-sided p-value of 0.005. Because the coefficient of the DDF was suspected to be atypically low *a priori*, a one-sided p-value could be justified (i.e., 0.0026). However, Cook's D and the Rstudent residual were usually far worse, ranging up to 1.0 and -5.1, respectively, in model d1 = f(A, P, Yrs, Imp_7), corresponding to a two-sided p-value of 0.00001, which clearly justified its removal during final calibration.

The base model d1 = f(A, P, Yr, Imp_x), performed relatively well in geometric space; however, arithmetic space performance was significantly improved by adding Srf and DD. Given that the expanded model offered slightly more homoscedastic residuals and all variables were significant ($p < 0.05$) during both cross validation and final calibration, we include it as an alternative to the four-term model. Equations are presented with corresponding parameters, units, and performance measures in Table 4(g). The relatively-large standard errors in arithmetic space are somewhat misleading because the appropriate scales are geometric, varying over three orders of magnitude (300 - 360,000).

$$d_1 = e^{(incpt)} * A^{a} * P^{p} * Yr^{yr} * e^{(impx * Impx)}$$ **Eq. (14)**

$$d_1 = e^{(incpt)} * A^{a} * P^{p} * Yr^{yr} * DD^{dd} * e^{(srf * Srf)} * e^{(impx * Impx)}$$ **Eq. (15)**

where:

Srf = average surface slope of watershed (m/m); and

Imp_x = Imp_{av}, Imp_5, or Imp_7 (as specified in Table 4(g)), where:

Imp_{av} =average impervious extent over record as a fraction of total drainage area **(mi^2/mi^2)**;

Imp_5 =fraction of record greater than 5% TIA **(yr/yr)**; and

Imp_7 =fraction of record greater than 7.5% TIA **(yr/yr)**.

As during the cross-validation phase, the majority of the variance in d2 was explained by d1, Q_{10}, and Yr (in that order). In the fourth position, both impervious and precipitation terms accounted for similar proportions of the variance, while no additional variables were significant. Performance measures such as R^2 and SE slightly favored the models that included precipitation in the place of imperviousness. In contrast, however, residuals relative to predicted values were more equitably distributed by including imperviousness.

With similar performance across several measures, alternatives of the linear base model (d2 = f(Q10, d1, Yr)) developed in arithmetic space are presented, with corresponding parameter values and performance measures in Table 4(h).

$$d_2 = Incpt + \beta_{Q10} * \ln(Q_{10}) + \beta_{d1} * \ln(d1) + \beta_{yr} * \ln(Yr) + \beta_{impx} * Imp_x \quad \textbf{Eq. (16)}$$

$$d_2 = Incpt + \beta_{Q10} * \ln(Q_{10}) + \beta_{d1} * \ln(d1) + \beta_{yr} * \ln(Yr) + \beta_{Px} * \ln(P_x) \quad \textbf{Eq. (17)}$$

where:

Q_{10} = 10-yr instantaneous peak flow (cfs); and

d1 = coefficient of DDF calibrated in ‘days’ and ‘cfs’.

As with d1, models of day1 explained the most variance and had greatest homoscedasticity using the exponential forms of imperviousness as opposed to power forms. Standard diagnostics showed similar performance with each impervious measure (i.e., Imp_{av}, Imp_7, and Imp_5), justifying the inclusion of all three forms. The six-term model performed the best in both cross validation and final calibration, with all terms significant ($p < 0.05$) and the greatest homoscedasticity. Furthermore, the case could be made that this form of model offers a more complete representation of the effect of urbanization. That is, imperviousness is still predicted to have an exponential effect on days of occurrence even after accounting for the wide range of other theoretically-important, relatively-significant variables. As such, we include them as alternatives to the more heuristic four-term models. Day1 equations are presented with corresponding parameters, units, and performance measures in Table 4(i). The smaller (arithmetic space) standard errors in comparison to d1 are more attributable to the smaller day1 range (100 to 60,000) than substantial improvements in performance:

$$day_1 = e^{(incpt)} * A^{a} * P^{p} * Yr^{yr} * e^{(impx * Impx)}$$ **Eq. (18)**

$$day_1 = e^{(incpt)} * A^{a} * P^{p} * Yr^{yr} * DD^{dd} * e^{(srf * Srf)} * e^{(impx * Impx)}$$ **Eq. (19)**

Day2 had three consistently significant predictor variables: Q_{10}, day1, and Yr. The placeholder for the fourth variable was tested with all remaining independent variables; however, similar to the d2 models, the best performance was achieved with measures of imperviousness or precipitation. Residual patterns relative to Q_{10} were less pronounced than during cross validation, with impervious models slightly more patterned than those that included precipitation measures. Equation formats are presented with corresponding parameters, units, and performance measures in Table 4(j):

$$day_2 = Incpt + \beta_{Q10} * \ln(Q_{10}) + \beta_{day1} * \ln(day1) + \beta_{yr} * \ln(Yr) + \beta_{impx} * Imp_x$$ **Eq. (20)**

$$day_2 = Incpt + \beta_{Q10} * \ln(Q_{10}) + \beta_{day1} * \ln(day1) + \beta_{yr} * \ln(Yr) + \beta_{Px} * \ln(P_x)$$ **Eq. (21)**

where:

Q_{10} = 10-yr instantaneous peak flow (cfs); and

day1 = coefficient of DDF calibrated in ‘days’ and ‘cfs’.

Implications and Discussion

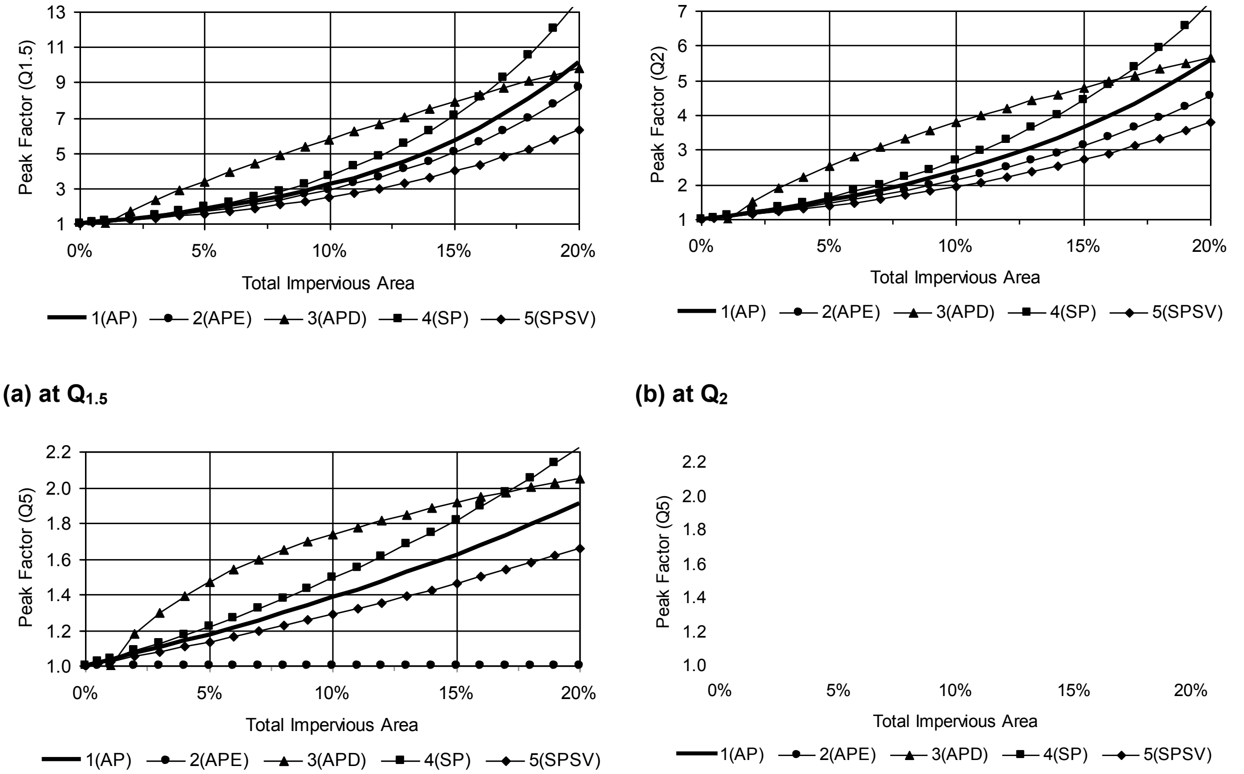
The models predict higher peak flows (especially for ≤ Q_5), and longer durations across all sediment-transporting flows in urban watersheds. As an example, we applied them to a hypothetical watershed with average conditions, controlling for everything but imperviousness. Beyond model application, case studies are presented of two gauges whose records spanned periods of relatively undeveloped and developed periods, offering support to the broader statistical models. Finally, recall that the models were developed using gauges ranging in drainage area from 0.5 to 105 mi^2 with 0 to 26% TIA (Table 1); therefore, the equations should not be applied to watersheds outside of those bounds. Regarding DDFs, models were calibrated with gauges that had a positively-skewed range of ~20 to 95 yrs with a mean of ~45 and standard deviation of ~20. In application, we recommend simulations within one standard deviation of the mean (i.e., ~25 to 65 yrs, convenient for the typical engineering time frame of ~50 yrs).

Effects of Urbanization Predicted by Models

Large increases were found in instantaneous-peak flows of more frequent return periods relative to a rural setting of ≤ ~1% imperviousness. The effects of urbanization decreased with larger, less frequent storms. For example, median peak factors for a watershed with 20% imperviousness were ~10x, ~6x, and ~2x for the 1.5-, 2-, and 5-yr flows, respectively (Figure 14). Such attenuating influence of urbanization with return period is generally consistent with both theory and previous studies (Bledsoe and Watson, 2001; Hollis, 1975; Sauer *et al.*, 1983), including studies specific to California (Rantz, 1971) and southern California (Durbin, 1974). Fundamental hydrology suggests that during very large, infrequent events (e.g., Q_{100}) soils have become saturated and behave similar to impervious surfaces.

The peak factors presented here are generally larger than those from previous studies. For example, Hammer (1972) and Hollis (1975) suggested that the 1.5- to 2-yr flows could double or triple at 10 to 20% imperviousness, and Bledsoe and Watson (2001) found peak factors ranging 1.5 to 4 dependent on regional setting. At those same impervious ranges and flow intervals, median-peak factors from the models ranged 3 to 10, with the maximum projected increase of 7x at Q_2 and 14x at $Q_{1.5}$ with 20% imperviousness. Though such increases may seem extreme, they are not the largest that have been reported (e.g., Urbonas and Roesner (1993)). The flashiness of the setting combined with limited flow-control practices suggest that peak factors of southern California could be larger than in other regions, although the relatively small basin sizes from this study may also play a factor in the higher peak factors.

Models of 1-yr flows performed poorly overall and are not reported, but the influence of urbanization was nevertheless unequivocal. Despite fifteen of the forty-three gauges having a Q_1 of 0 cfs (range 0 to 236, median 1.8, and mean of 14 cfs) the four most urban gauges (Imp_{av} 9 to 14%) accounted for the four largest 1-yr flows (i.e., 236, 102, 49, and 26 cfs) over records of 23 to 43 yrs.



(a) at $Q_{1.5}$ (b) at Q_2

(c) at Q_5 (d) at Q_{10}

Model Key: 1 = f(A, P, Imp_{max}) 2 = f(A, P_{224}, Elv, Imp_{max}) 3 = f(A, P_{224}, DD, Imp_{max}) 4 = f(Stm, P_{224}, Imp_{max}) 5 = f(Stm, IP, Shp, Vly, Imp_{max})

Figure 14. Peak factors for instantaneous peak flows as a function of TIA for all five calibrated peak flow models: (a) at Q1.5, (b) at Q2, (c) at Q5, (d) at Q10.

Finally, regarding peak-flow models, the fact that Imp_{max} accounted for more variance than other impervious measures such as Imp_{av}, Imp_5, or Imp_7, shows the ease at which the most developed portion of a gauge record can overwhelm the undeveloped peak flows, especially for the more frequent return intervals. It may suggest the potential for a statistically-significant influence at higher return intervals (e.g., Q_{10}) in the future as gauges have more time to record large precipitiation events at those impervious levels.

Regarding the DDF curves, gauge data to date did not show urbanization as statistically significant in explaining their scale (Q_{max}), but it had an exponential effect on the magnitude (d1 and day1, i.e., number of days), with a linear effect on d2 and day2 (shape). The combined effect tends to magnify durations of the moderate flows slightly more than durations of the largest flows. Figure 15 presents a 25-yr simulation of an average watershed across rural and urban scenarios using both models (i.e., d1/d2, bins 16-25 and day1/day2, bins 12-25) demonstrating relatively good agreement. Differing only by levels of imperviousness (i.e., Imp_{av} 12% versus 0.5%), the urban setting showed a 3-fold increase in the number of expected days at 50 cfs, with a 2- to 2.4-fold increase at 850 cfs (Table 7).

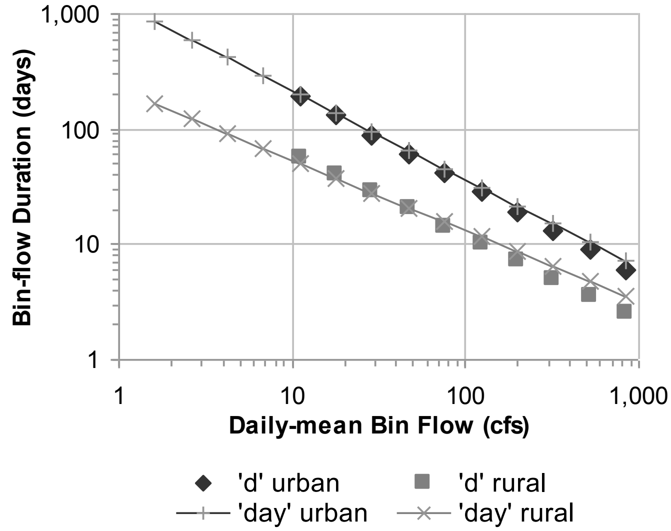


Figure 14 – DDFs of 25-yr simulations of equivalent watersheds in rural and urban settings

Table 5 – Summary of 25-yr DDF simulation for 'dry', rural, and urban scenarios in an average[(a)] watershed

	Variable	Rural	Urban	Ratio (Urban/Rural)
key values for DDF model input	Imp_{av}	0.5%	12%	
	Q_{max} (cfs)	1,040	1,040	1
	Q_{10} (cfs)	2,470	2,730	1.1
d1/d2 model	d1	326	1,330	4.1
	d2	-0.72	-0.80	1.1
	days @ ~10 cfs (bin 16)	57	194	3.4
	days @ ~50 cfs (bin 19)	20	61	3.0
	days @ ~125 cfs (bin 21)	10	28	2.8
	days @ ~320 cfs (bin 23)	5.0	13	2.6
	days @ ~850 cfs (bin 25)	2.5	6.1	2.4
day1/day2 model	day1	221	1,260	5.7
	day2	-0.61	-0.77	1.3
	days @ ~10 cfs (bin 16)	51	199	3.9
	days @ ~50 cfs (bin 19)	21	66	3.1
	days @ ~125 cfs (bin 21)	12	31	2.7

days @ ~320 cfs (bin 23)	6.4	15	2.3
days @ ~850 cfs (bin 25)	3.6	7.2	2.0

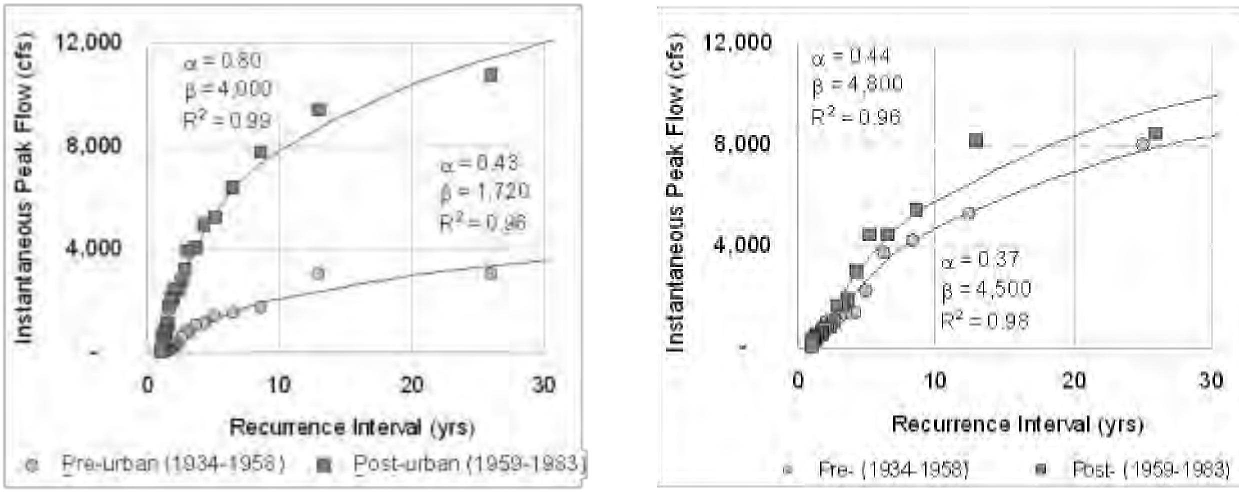
[(a)] 'average' watershed (A ~30 mi^2, P ~14 in., DD ~1.9 mi/mi^2, Srf ~18%)

Alternative urban scenarios predict similarly disproportionate increases in durations. For example, 5% imperviousness would increase durations of bin 16 by ~1.5 and bin 25 by ~1.3, while 15% imperviousness would result in ~4.1 and ~2.4-fold increases, respectively. These empirical findings of decreasing influence of urbanization on flow duration with increasing flow magnitude are consistent with the findings regarding peak flows: urbanization tends to show higher influence on more frequent events, with decreasing influence over the largest, rarest storms.

In conclusion, the fact that Imp_{av}, Imp_7, and Imp_5 outperformed Imp_{max} in DDF models suggests that it may take longer for urbanization to show an effect on the cumulative durations of all flows than to appreciably affect instantaneous peaks at small return intervals. Relatively low measures of imperviousness (i.e., < ~5%) did not show as strong of a statistically-significant influence on durations as on peak flows; however, above 5% and especially above 7.5% there was an unmistakable influence. From this, we are not suggesting that above 5 or 7.5% imperviousness all watersheds behave identically, but rather that it is more difficult for the models to discern differences in durations below those thresholds with current data.

1.1.1 At-a-station effects of urbanization

Two gauges (Arroyo Simi in Ventura County and San Diego Creek in Orange County) spanned equal periods of relatively undeveloped and developing/developed states such that they could be divided into 'pre-urban' and 'post-urban' samples. The paired data showed a marked influence across all peaks and durations of record. For example, Arroyo Simi, depicted in Figure 16(a), had more than a 10-fold difference in the 2-yr flow (2,040 cfs versus 174 cfs), while the 25-yr flow was over three times as large at 10,700 cfs relative to 3,000 cfs. Figure 15(b) summarizes the record at the rural gauge of Hopper Creek spanning the same time frame. By comparison, peak flows differed by an average of only 20% across the two periods in the rural setting, and are likely attributable to the variability in the inter-period precipitation.



1934-1958: Imp_{av} = 2.6%, Imp_{max} = 4.7%
1959-1983: Imp_{av} = 7.3%, Imp_{max} = 8.6%

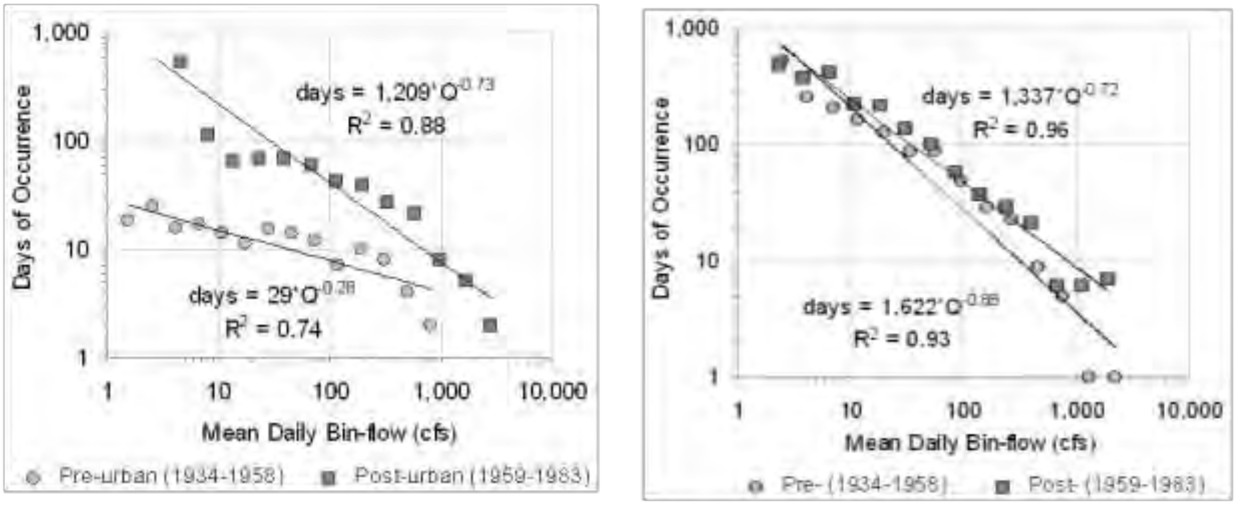
1934-1958: Imp_{av} and Imp_{max} = 0.0%
1959-1983: Imp_{av} and Imp_{max} = 0.0%

(a) recorded at Arroyo Simi during the pre-urban and post-urban periods

(b) recorded at Hopper Creek covering the same periods with no urbanization

Figure 16 – Instantaneous-peak flow relative to recurrence interval, with fitted gamma distributions

The long-term durations of daily-mean flows were also clearly affected by the change in land use at Arroyo Simi and San Diego. Figure 17(a) presents the respective DDFs of Arroyo Simi, recording both higher flows and longer durations for the urban regime. The maximum daily discharges over the 24.5-yr periods were 1,000 and 3,610 cfs, respectively, with the undeveloped regime incurring only 4 days at 500 cfs and 2 days at 800 cfs, while the post-developed regime had 21 days at 600 cfs and 8 days at 1,000 cfs. Additionally, 5 days at 1,700 cfs and 2 days at 2,900 cfs were recorded during the post-urban period, with no days of comparable flows in the pre-urban period. Presuming sediment is entrained by these higher flows, the post-developed regime had on average four to five times as many days of sediment-transporting flows as the pre-developed case, with an additional 7 days of flows that far exceeded the maximum flow in the undeveloped setting.



(a) at Arroyo Simi during the pre-urban and post-urban periods

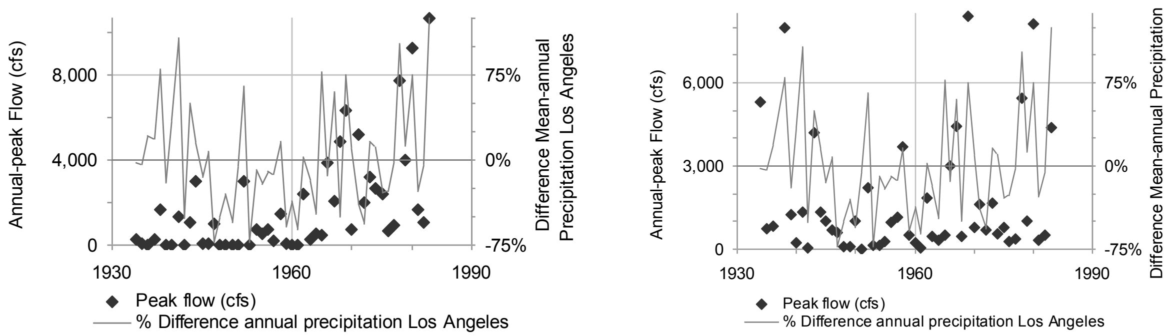
(b) at Hopper Creek covering the same periods with no urbanization

Figure 15 – Cumulative-duration histogram centroids, with fitted DDFs

In contrast, bin flows and durations during the same two periods at the undeveloped gauge were relatively similar. Figure 17(b) presents the nearly overlaid DDFs of Hopper Creek, with all but the two largest bins differing by an average of only 50%. The latter period experienced 6 days at 1,100 cfs and 7 days at 1,900 cfs, while the earlier period only had 1 day at each of the corresponding bins of 1,300 and 2,200 cfs. Even so, the maximum-daily flow was actually largest in the 'pre-' period (2,770 cfs versus 2,400 cfs).

In summary, the rural gauge had a small vertical shift in the DDF between the two periods with slightly more days of similar flows. However, the urban gauge showed dramatic shifts in the DDF both vertically and laterally. At both San Diego and Arroyo Simi, Q_{max} increased by a factor of 3 to 4, while durations of corresponding bin flows increased by factors of 3 to 6 from the undeveloped to urban portions of the records.

We considered potential differences in climate as a competing hypothesis as opposed to urbanization as the primary cause of increased flows and durations between the two periods. As seen in Figure 18(a), the pre-urban period of Arroyo Simi (1934 - 1958) begins with relatively wet years and trends downward, while the post-urban period (1959 - 1983) begins in a relative drought and trends upward. Although the higher peak flows in the respective periods generally correspond with exceptionally wetter years, precipitation alone clearly can not explain the somewhat flat trend in peak flows during the pre-urban period and the largely upward trend during the post-urban period. In contrast, the relative similarity among the highest peaks between the same two periods at the rural gauge of Hopper Creek (Figure 17(b)) and better correlation with the higher precipitation years adds support for causation between urbanization and the latter-period extreme flows recorded at Arroyo Simi.



(a) recorded at Arroyo Simi (urban during second half of record)

(b) recorded at Hopper Creek (rural)

Figure 16 – Annual peak flows overlaid with relative difference in mean-annual precipitation at the Los Angeles weather station

By tracking urbanization through time via impervious cover, the positive trend in peak flows at Arroyo Simi is much better explained (Figure 19). Indeed, multivariate at-a-station regression can explain up to 60% of the variance in annual-peak flows at Arroyo Simi by including imperviousness and annual precipitation as recorded at Los Angeles, with imperviousness highly significant ($p < 0.0001$) and accounting for 30 to 40% of the total variance.

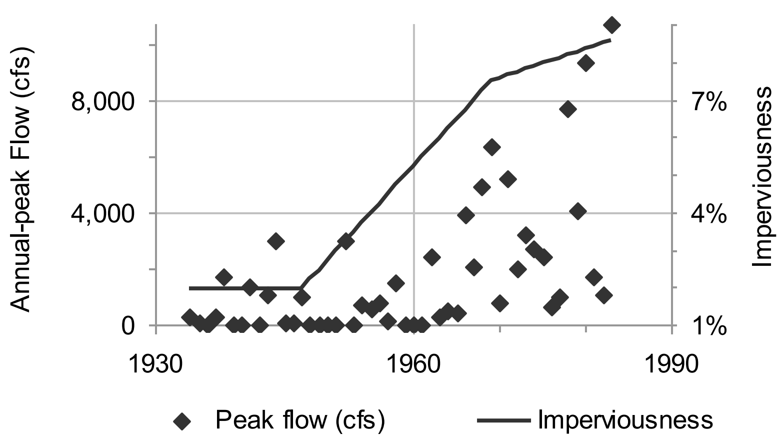


Figure 17 – Annual peak flows recorded at Arroyo Simi overlaid with interpolated percentage of impervious cover in the watershed as tracked via historic USGS quadrangle maps

As indicated in Table 8, the urban records did correspond to periods of slightly higher precipitation in terms of the annual precipitation at the Los Angeles weather station and number of exceptionally wet and dry years. However, these climatic differences alone cannot explain the dramatic differences in flows and durations. The post-urban period of Arroyo Simi has nine flows larger than the largest instantaneous-peak flow from the pre-urban period. In the case of San Diego, there were five flows higher than the maximum from the pre-urban regime. By comparison, the rural gauge at Hopper Creek had only two flows during the latter period that were higher than the highest peak from the first half of the record and they differed by only 5% (i.e., 8,400 and 8,120 cfs versus 8,000 cfs). Also recall that the rural gauge recorded a higher Q_{max} and only slightly less (50%) days of equivalent flows during the earlier period, compared with 3- to 5-fold duration increases at the urban gauges with substantially larger values of Q_{max}.

Table 6 – Comparison of flows, durations, climate, and imperviousness over the pre-urban and post-urban periods of Arroyo Simi (Ventura County) and San Diego Creek (Orange County)

	Variable/ Value	Arroyo Simi (Ventura County)			San Diego Creek (Orange County)		
		Pre-urban 1934 - 1958	Post-urban 1959 - 1983	Post/ Pre	Pre-urban 1950 - 1967	Post-urban 1968 - 1985	Post/ Pre
peak flows	Return Interval (yrs)	Flow Pre (cfs)	Flow Post (cfs)	Ratio	Flow Pre (cfs)	Flow Post (cfs)	Ratio
	1	-	14	∞	-	448	∞
	1.5	19	891	> 40	726	1,233	1.7
	2	174	2,040	12	907	1,937	2.1
	5	1,278	5,138	4.0	1,932	6,363	3.3
	10	2,059	7,790	3.8	2,910	8,192	2.8
	25	3,305	11,237	3.4	4,025	11,625	2.9
	50	4,301	13,877	3.2	4,866	14,237	2.9
	100	5,326	16,536	3.1	5,704	16,859	3.0
durations	~ Mean Daily Flow (cfs)	Days Pre (#)	Days Post (#)	Ratio	Days Pre (#)	Days Post (#)	Ratio
	100	7	42	6.0	9	37	4.1
	200	10	39	3.9	6	32	5.3
	400	8	27	3.4	8	26	3.3
	600	4	21	5.2	3	9	3.0
	800	2	8	4.0	-	10	∞
	1,700	-	5	∞	-	6	∞
	2,900	-	2	∞	-	-	∞
extreme flows and Los Angeles precipitation[(a)]	Variable (unit)	Pre (varied units)	Post (varied units)	Ratio	Pre (varied units)	Post (varied units)	Ratio
	mean annual precip. (in)	15.0	15.7	1.04	13.4	16.0	1.2
	'wet' years (#)	3	6	2	3	4	1.3
	'high' peaks (#)	2	10	5	1	6	6.0
	'dry' years (#)	4	3	0.75	4	1	0.25
	'low' peaks (#)	18	8	0.44	11	5	0.45
impervious-ness	Spatial Extent During Period	TIA Pre (%)	TIA Post (%)	Ratio	TIA Pre (%)	TIA Post (%)	Ratio
	maximum	4.7	8.6	1.8	3.2	14.9	4.5
	mean	2.6	7.2	2.8	3.2	9.7	2.9

[(a)] 'wet' and 'high' correspond to years/events 50% greater than the respective means, while 'dry' and 'low' indicate years/events 50% lower than the mean

The differences in flows and durations between undeveloped and developed periods at the same gauges and the relative similarity during the same periods at the rural gauge add to the weight of evidence that such changes are largely attributable to urbanization. In fact, these differences observed at individual gauges were larger than what is predicted in the models, particularly in terms of Q_{max}. The effects of urbanization captured in the models may have been dampened by the widespread variability across all sites, most of which were still relatively undeveloped. As more years of data are gathered at urban gauges, the models could be further refined to account for urbanization with a more equitable sampling of urban data.

Summary and Conclusions

The overarching objective of this paper was to understand the effects of urbanization on the magnitude and duration elements of flow regimes (i.e., 'hydromodification') in southern California. In doing so, updated alternatives to the USGS regional equations were developed for peak flows, which outperformed both rural (Waananen and Crippen, 1977) and urban (Sauer *et al.*, 1983) models in twenty-nine out of thirty cases in terms of Standard Error, Adj. R^2, etc. The difference was particularly substantial for more frequent return periods (e.g., Adj. R^2 in arithmetic space ~ 0.7 to 0.8 versus < 0.4 at Q_{10}).

Additionally, our models documented changes in the significance of individual variables with return period, reflecting shifts in physical processes. For example, at more frequent events, the efficiency with which a drainage network concentrated and conveyed runoff became increasingly significant in predicting peak flow, while the predominant variables at less frequent events were measures of watershed size and precipitation volume. This may point to different model forms for different return intervals, for example using Eq. (6) to estimate flows less than or equal to Q_5, and Eq. (8) or (10) for Q_{10} and higher.

Beyond peak flows, we developed a method for estimating long-term cumulative durations at ungauged sites. DDFs expand on previous approaches to histogram-style duration curves in that their magnitude, shape, and scale are based on watershed physical properties rather than scaling based on a nearby gauge and a single flow. Most importantly regarding hydromodification, both the peak flow and DDF models account for urbanization using measures of total impervious area, which were statistically significant ($p < 0.05$), particularly for peak flows $\leq Q_2$ and the magnitude (coefficient) component of DDFs, resulting in longer durations across all flows greater than some nominal value (e.g., 1 to 10 cfs).

Multivariate regression controlling for other potentially-significant hydro-climatic variables (e.g., drainage area, mean annual rainfall, surface slope, etc.) correlated urbanization to higher peaks and longer durations of all geomorphically-significant flows. These effects were also documented at individual gauges whose records spanned both pre-urban and post-urban periods. Moreover, these effects were not linear. Although several metrics, units, and equation forms were tested for modeling the effects of urbanization, the form that was most powerful was typically the exponential of total imperviousness as a fraction of the drainage area. That is, flow magnitudes and durations associated with identical watersheds differing only by measures of imperviousness (e.g., ~1% and ~10%) would be disproportionately larger. In terms of peaks, differences would be most substantial at the more frequent events (e.g., ~3.2 x $Q_{1.5}$, ~2.4 x Q_2, and ~1.4 x Q_5). Regarding durations of daily-mean flows, ~2 to 4 times as many days of *all* sediment-transporting flows would be predicted, with the largest increases occurring at more frequent events and smaller but significant increases at the most infrequent events.

Such changes in the hydrologic regime can have far-reaching effects on receiving channels in terms of cumulative erosive energy and channel stability. Particularly for channels considered highly susceptible to hydromodification (e.g., live-bed unconfined systems), significant changes in channel form such as incision, widening, or planform shifts are anticipated if land-cover conversions from pervious to impervious go unmitigated. The relatively-dramatic responses in channel form that have been observed throughout the region are better explained in the context of such equally compelling changes in flow rates and durations of sediment-transporting events. The physically-based, empirically-calibrated hydrologic models presented here may become important tools in developing a process-based understanding of hydromodification effects on fluvial systems in southern California.

Future Work

The logical next step is to apply these hydrologic models to sites where geomorphic data have been collected to evaluate whether changes in flows correspond to sediment discontinuities that in turn correlate to channel degradation. For example, can risk-based models of channel stability be developed using these hydrologic models as a starting point?

Future work could also focus on the refinement of the DDF models developed in this paper. For example, we were limited to daily-mean flow data for these analyses, but one could follow up with the USGS in a subsequent study to see if any of the gauges have 15-min or hourly data over their entire record (i.e., twenty of the fifty-two gauges were 'real-time' sites offering 15-min data for the last 60 days but only daily data over extended records). If one could acquire the finer resolution data for enough sites, they could repeat the histogram procedure in the hope of developing a scaling factor for the DDFs in this paper.

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RB-AR33110

International Stormwater Best Management Practices (BMP) Database Pollutant Category Summary Statistical Addendum:

TSS, Bacteria, Nutrients, and Metals

Prepared by
Geosyntec Consultants, Inc.
Wright Water Engineers, Inc.

Under Support From
Water Environment Research Foundation
Federal Highway Administration
Environment and Water Resources Institute of the
American Society of Civil Engineers

July 2012

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The BMP Database ("Database") was developed as an account of work sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (USEPA) (collectively, the "Sponsors"). The Database is intended to provide a consistent and scientifically defensible set of data on Best Management Practice ("BMP") designs and related performance. Although the individuals who completed the work on behalf of the Sponsors ("Project Team") made an extensive effort to assess the quality of the data entered for consistency and accuracy, the Database information and/or any analysis results are provided on an "AS-IS" basis and use of the Database, the data information, or any apparatus, method, or process disclosed in the Database is at the user's sole risk. The Sponsors and the Project Team disclaim all warranties and/or conditions of any kind, express or implied, including, but not limited to any warranties or conditions of title, non-infringement of a third party's intellectual property, merchantability, satisfactory quality, or fitness for a particular purpose. The Project Team does not warrant that the functions contained in the Database will meet the user's requirements or that the operation of the Database will be uninterrupted or error free, or that any defects in the Database will be corrected.

UNDER NO CIRCUMSTANCES, INCLUDING CLAIMS OF NEGLIGENCE, SHALL THE SPONSORS OR THE PROJECT TEAM MEMBERS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, OR CONSEQUENTIAL DAMAGES INCLUDING LOST REVENUE, PROFIT OR DATA, WHETHER IN AN ACTION IN CONTRACT OR TORT ARISING OUT OF OR RELATING TO THE USE OF OR INABILITY TO USE THE DATABASE, EVEN IF THE SPONSORS OR THE PROJECT TEAM HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

The Project Team's tasks have not included, and will not include in the future, recommendations of one BMP type over another. However, the Project Team's tasks have included reporting on the performance characteristics of BMPs based upon the entered data and information in the Database, including peer reviewed performance assessment techniques. Use of this information by the public or private sector is beyond the Project Team's influence or control. The intended purpose of the Database is to provide a data exchange tool that permits characterization of BMPs solely upon their measured performance using consistent protocols for measurements and reporting information.

The Project Team does not endorse any BMP over another and any assessments of performance by others should not be interpreted or reported as the recommendations of the Project Team or the Sponsors.

Acknowledgements

Report Preparation[1]

Primary Authors:
- Marc Leisenring, P.E., Geosyntec Consultants, Inc.
- Jane Clary, Wright Water Engineers, Inc.
- Paul Hobson, Geosyntec Consultants, Inc.

Reviewers:
- Eric Strecker, P.E., Geosyntec Consultants, Inc.
- Jonathan Jones, P.E., D.WRE, Wright Water Engineers, Inc.
- Marcus Quigley, P.E., D.WRE, Geosyntec Consultants, Inc.

Project Information

WERF Project Director:
Jeff Moeller, P.E., Water Environment Research Foundation

Principal Investigators:
Eric Strecker, P.E., Geosyntec Consultants, Inc.
Jonathan Jones, P.E., D.WRE, Wright Water Engineers, Inc.

Project Steering Committee:
Susan Jones, P.E., Federal Highway Administration
Christopher Kloss, P.E., Office of Water/Office of Science & Technology, U.S. Environmental Protection Agency
Brian Parsons, P.E., Environmental and Water Resources Institute of American Society of Civil Engineers
Marcel Tchaou, Ph.D., P.E., P.H., MBA, Federal Highway Administration Office of Project Development and Environmental Review
Courtney Thompson, American Public Works Association

Project Subcommittee:
Michael E. Barrett, Ph.D., P.E., D.WRE, Center for Research in Water Resources, University of Texas
Bob Carr, P.E., O'Brien and Gere
David R. Graves, CPESC, Environmental Science Bureau, New York State Dept. of Transportation
Gregory E. Granato, U.S. Geological Survey
Jesse Pritts, P.E., Engineering and Analysis Division Office of Water/Office of Science & Technology, U.S. Environmental Protection Agency

[1] Contact Jane Clary (clary@wrightwater.com) or Marc Leisenring (mleisenring@geosyntec.com) with questions regarding this summary.

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INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org

1 INTRODUCTION

In 2010, the Water Environment Research Foundation (WERF), Federal Highway Administration (FHWA), and the American Society of Civil Engineers' Environmental and Water Resources Institute (EWRI) co-sponsored a comprehensive stormwater best management practice (BMP) performance analysis technical paper series relying on data contained in the International Stormwater BMP Database (BMPDB).[2] This series, published in 2011, included papers for solids, bacteria, nutrients, and metals, with each paper summarizing the regulatory context of the constituent category, primary sources, fate and transport processes, removal mechanisms, and statistical summaries of BMP performance for data contained in the BMPDB. This report is an update of the statistical summaries provided in that series to include the data from over 50 new studies added to the database in late 2011 after the publication of the series. This report is not intended to replace the discussion of the previous technical papers because only the statistical summaries are included here. Constituents summarized in this report are listed in Table 1.

Table 1. Constituents Summarized by Pollutant Category

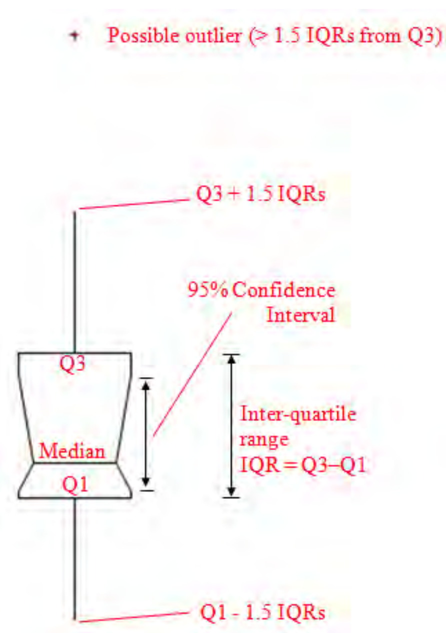
Pollutant Category	Summarized Constituent
Solids	Total suspended solids (TSS)
Bacteria	Fecal coliform *Escherichia coli* (*E. coli*) Enterococcus
Metals	Arsenic (total and dissolved) Cadmium (total and dissolved) Chromium (total and dissolved) Copper (total and dissolved) Iron (total and dissolved) Lead (total and dissolved) Nickel (total and dissolved) Zinc (total and dissolved)
Nutrients	Total phosphorus Orthophosphate Dissolved phosphorus Total nitrogen Total Kjeldahl nitrogen (TKN) Nitrate plus nitrite (NOx)

[2] The BMP Database is a long-term project that began in 1994 through the vision of members active in the Urban Water Resources Research Council of ASCE and the leadership of EPA. Funded for many years by EPA, the project is now supported by a coalition of partners including WERF, FHWA, EWRI and the American Public Works Association (APWA). The technical reports can be downloaded from www.bmpdatabase.org/BMPPerformance.htm.

2 CATEGORY-LEVEL BMP ANALYSIS

An overview of BMP performance for the analyzed constituents is provided in the subsections 2.1 to 2.4 below. The analyses were based upon the distributions of effluent water quality for individual events by BMP category, thereby providing greater weight to those BMPs for which there are a larger number of data points reported. In other words, the performance analysis presented in this technical summary is "storm-weighted," as opposed to "BMP weighted."[3] This update does not include BMP weighted analyses (i.e., analyses of individual study site central tendencies).

Figure 1. Box Plot Key



The BMP categories included in this analysis are grass strips, bioretention, bioswales, composite/treatment train BMPs, detention basins (surface/grass-lined), green roofs, manufactured devices, media filters, porous pavement, retention ponds (surface pond with a permanent pool), wetland basins (basins with open water surface), and wetland channels (swales and channels with wetland vegetation). Note that for bacteria, manufactured devices are broken down into three subcategories: disinfection devices (Manufactured Device – D), inlet insert/filtration (Manufactured Device – F), and physical settling/straining devices (Manufactured Device – P).[4] The effectiveness and range of unit treatment processes present in a particular BMP may vary depending on the BMP design. Several other BMP categories and sub-classes are included in the database, but these have been excluded from this analysis due to limited data sets available for meaningful categorical comparisons. To be included in this category-level summary, at least three BMPs must be included in the BMP category, with each BMP having effluent data for at least three storms. A variety of additional screening criteria are applied for purposes of category-level analysis to make sure that the data sets and BMP designs are reasonably representative, as documented in the "Monitoring Station" table of the BMP Database, which can be downloaded from www.bmpdatabase.org. Poor performance of a BMP is not a reason for data exclusion.

In the subsections below, side-by-side box plots for the various BMPs measurements have been generated using the influent and effluent concentrations from the studies. For each BMP

[3] There are several viable approaches to evaluating data in the BMP Database. Two general approaches that have been presented in the past (Geosyntec Consultants and Wright Water Engineers, 2008) are the "BMP-weighted" and "storm-weighted" approaches. The BMP-weighted approach represents each BMP with one value representing the central tendency and variability of each individual BMP study, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data set. The storm-weighted approach has been selected for this memorandum as it provides a much larger data set for analysis.

[4] A separate technical summary for manufactured devices (Geosyntec and Wright Water Engineers, 2012) was also released in July 2012 providing a more detailed analysis of manufactured device subcategories based on unit treatment processes. See www.bmpdatabase.org to download this analysis.

category, the influent box plots are provided on the left and the effluent box plots are provided on the right. A key to the box plots is provided in Figure 4.

In addition to the box plots, tables of influent/effluent medians, 25th and 75th percentiles, and number of studies and data points are provided, along with 95% confidence intervals about the medians. The median and interquartile ranges were selected as descriptive statistics for BMP performance because they are non-parametric (do not require distributional assumptions for the underlying data set) and are less affected by extreme values than means and standard deviations. Additionally, the median is less affected by assumptions regarding values below detection limits and varying detection limits for studies conducted by independent parties over many years. However, confidence intervals about the median can still be affected by outliers if simple substitution is used. Therefore, a robust regression-on-order statistics (ROS) method as described by Helsel and Cohn (1988) was utilized to provide probabilistic estimates of non-detects before computing descriptive statistics. Despite use of this robust method, conclusions regarding BMP performance should carefully consider the influence of large percentages of non-detects. The number of influent and effluent non-detects should be reviewed before making conclusions, particularly for dissolved metals where non-detects are most prevalent. For more information on the influence of non-detects on dissolved metals data in the BMP Database, see the discussion in the Metals Technical Summary (Wright Water Engineers and Geosyntec, 2011), accessible at www.bmpdatabase.org).

Confidence intervals in the figures and tables were generated using the bias corrected and accelerated (BCa) bootstrap method described by Efron and Tibishirani (1993). This method is a robust approach for computing confidence intervals that is resistant to outliers and does not require any restrictive distributional assumptions. Due to random sampling that is conducted as part of this method, insignificant variations in the results may occur and is the cause of any inconsistencies between the values in the attachments and the tables presented below. Comparison of the confidence intervals about the influent and effluent medians can be used to roughly identify statistically significant differences between the central tendencies of the data. However, non-parametric hypothesis tests, such as the Mann-Whitney rank sum test or the Wilcoxon signed-rank test, can provide additional and more robust results for evaluating significant differences between medians. The Mann-Whitney test applies to independent data sets, whereas the Wilcoxon test applies to paired data sets (Helsel and Hirsch, 1992). Results of these tests are provided in the attached statistical summary reports for TSS, bacteria, metals, and nutrients. In some cases, the Mann-Whitney and Wilcoxon hypothesis test results produce conflicting conclusions regarding statistically significant differences. Such cases are more likely to occur where there are imbalances in the number of influent and effluent samples for a particular data set since the Mann-Whitney test operates on the entire data set, whereas the Wilcoxon test only operates on data pairs.

In the summary tables which follow, effluent values in **bold green** indicate the upper 95% confidence interval of the effluent median is less than the lower 95% confidence interval of the influent median. Effluent values in ***red bold italics*** indicate the lower 95% confidence interval of the effluent median is greater than the upper 95% confidence interval of the influent median. BMP categories with summary statistics in grey indicate that there are less than three studies with either influent or effluent data available – these statistics should be used with caution due to

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the limited data available. In some cases, the retention ponds and wetland basin categories have been combined into a single category to provide more than three studies. Values with no color italic emphasis indicate the influent and effluent intervals overlap.

Be aware that for some BMP types, a statistically significant difference between influent and effluent concentrations may not be present, but the effluent concentrations achieved by the BMP are relatively low and may be comparable to the performance of other BMPs that have statistically significant differences between inflow and outflow. For example, data sets that have low influent concentrations and similarly low effluent concentration (i.e., clean water in = clean water out) may not show statistically significant differences. However this does not necessarily imply that the BMP would not have been effective at higher influent concentrations.

2.1 Total Supended Solids

Figure 2. Box Plots of Influent/Effluent TSS Concentrations

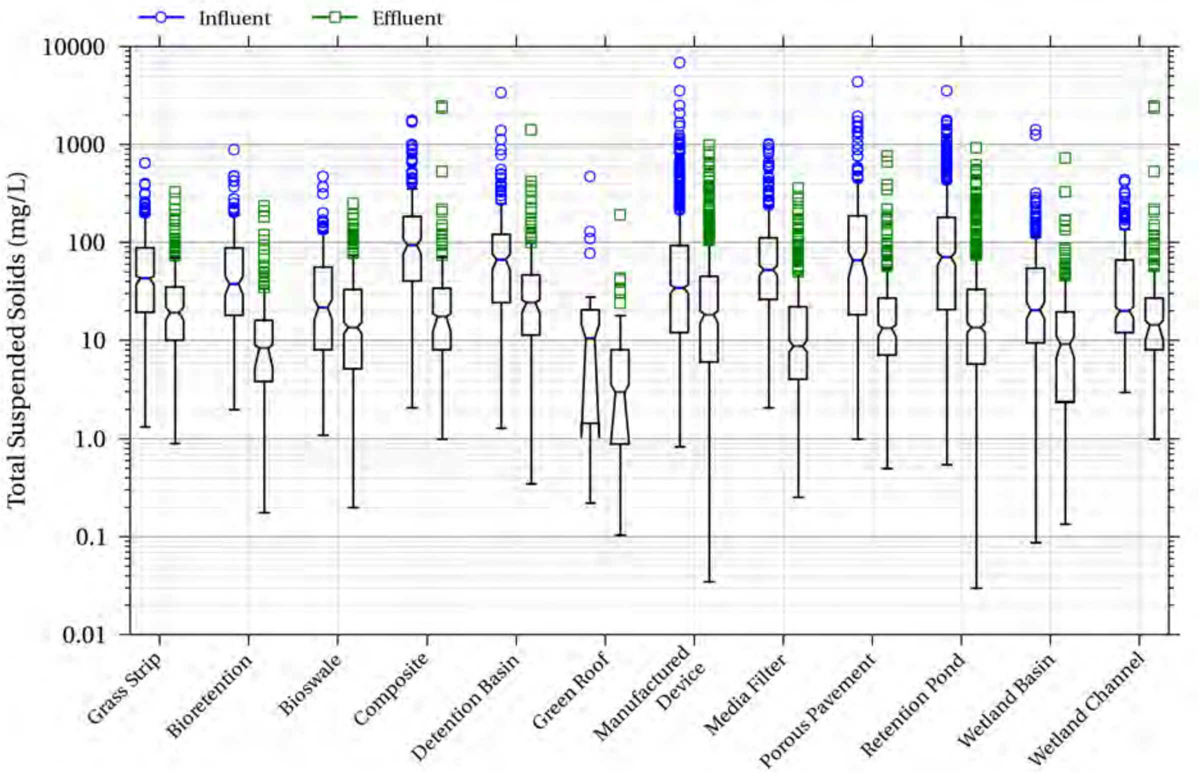

Table 2. Influent/Effluent Summary Statistics for TSS (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	19, 350	20, 286	19.3	10.0	43.1 (36.0, 45.0)	**19.1 (16.0, 21.5)****	88.0	35.0
Bioretention	14, 202	14, 193	18.0	3.8	37.5 (29.2, 45.0)	**8.3 (5.0, 9.0)****	87.8	16.0
Bioswale	21, 338	23, 354	8.00	5.12	21.7 (16.2, 26.0)	**13.6 (11.8, 15.3)****	56.0	33.0
Composite	10, 201	10, 163	40.3	8.0	94.0 (76.2, 107)	**17.4 (12.4, 18.8)****	184.0	34.0
Detention Basin	20, 278	21, 299	24.2	11.3	66.8 (52.3, 76.1)	**24.2 (19.0, 26.0)****	121.0	46.5
Green Roof	2, 20	4, 51	1.44	0.89	10.5 (1.13, 14.5)	2.9 (1.0, 3.5)	20.5	8.0
Manufactured Device	55, 923	63, 904	12.0	6.0	34.5 (30.0, 36.8)	**18.4 (15.0, 19.9)****	93.0	45.0
Media Filter	28, 442	29, 409	26.2	4.0	52.7 (45.9, 58.2)	**8.7 (7.4, 10.0)****	112.0	22.0
Porous Pavement	14, 246	23, 406	18.3	7.08	65.3 (45.0, 80.3)	**13.2 (11.0, 14.4)****	186.7	27.0
Retention Pond	47, 725	48, 723	20.7	5.72	70.7 (59.0, 79.0)	**13.5 (12.0, 15.0)****	180.0	33.0
Wetland Basin	15, 301	17, 305	9.4	2.36	20.4 (16.6, 24.4)	**9.06 (7.0, 10.9)****	54.4	19.5
Wetland Channel	8, 189	8, 154	12.0	8.0	20.0 (17.0, 22.0)	**14.3 (10.0, 16.0)****	66.0	27.0

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 2 shows statistically significant decreases for this BMP category.

2.2 Bacteria

2.2.1 Enterococcus

Figure 3. Box Plots of Influent/Effluent Enterococcus Concentrations

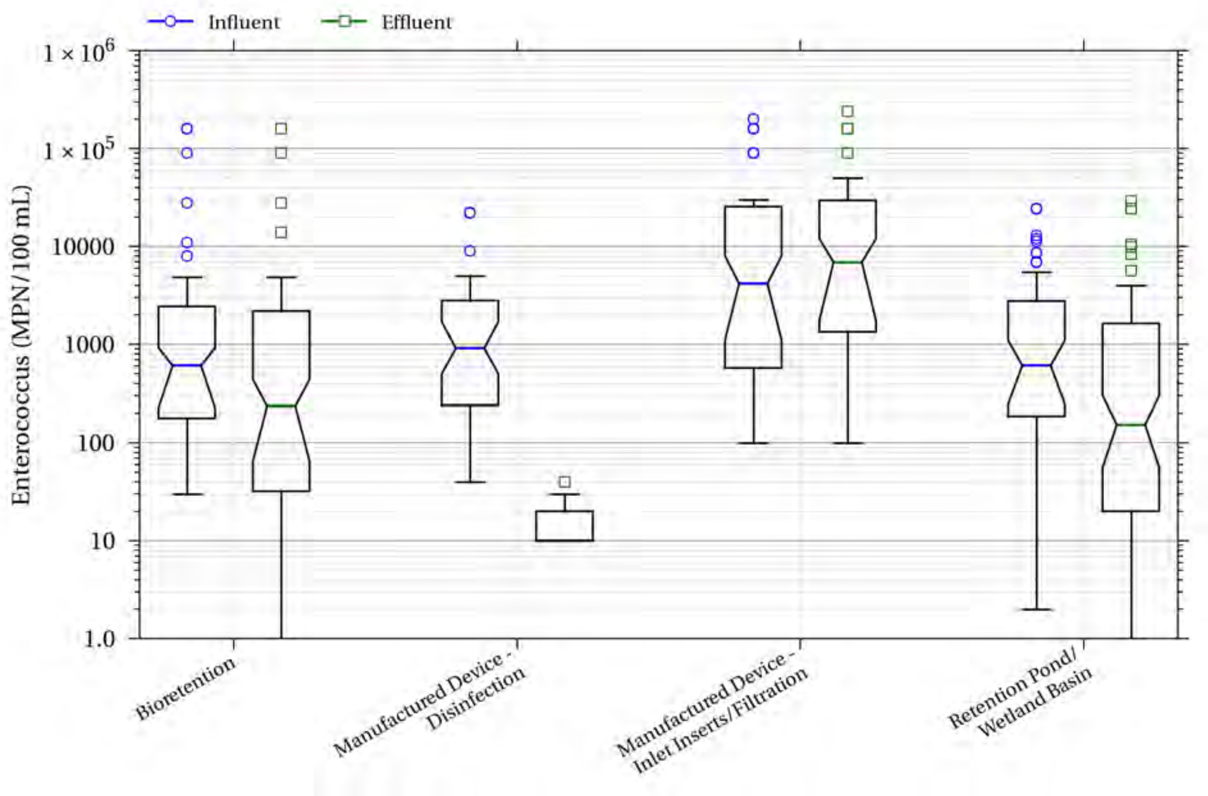

Table 3. Influent/Effluent Summary Statistics for Enterococcus (#/100 mL)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	NA	NA	NA	NA	NA	NA	NA	NA
Bioretention	3, 48	3, 49	178	32	605 (225, 922)	234 (58, 437)**	2440	2190
Bioswale	NA	NA	NA	NA	NA	NA	NA	NA
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	NA	NA	NA	NA	NA	NA	NA	NA
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-D	1, 33	1, 32	240	10	911 (500, 1700)	**10 (10, 10)****	1700	10
Manufactured Device-F	5, 48	5, 46	573	1340	4130 (1000, 8000)	6890 (1750, 12000)	25500	29500
Manufactured Device-P	NA	NA	NA	NA	NA	NA	NA	NA
Media Filter	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond or Wetland Basin	5, 78	5, 78	186	20	615 (248, 1110)	153 (56, 300)**	2770	1630
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 2 shows statistically significant decreases for this BMP category.

2.2.2 Escherichia coli

Figure 4. Box Plots of Influent/Effluent *E. coli* Concentrations

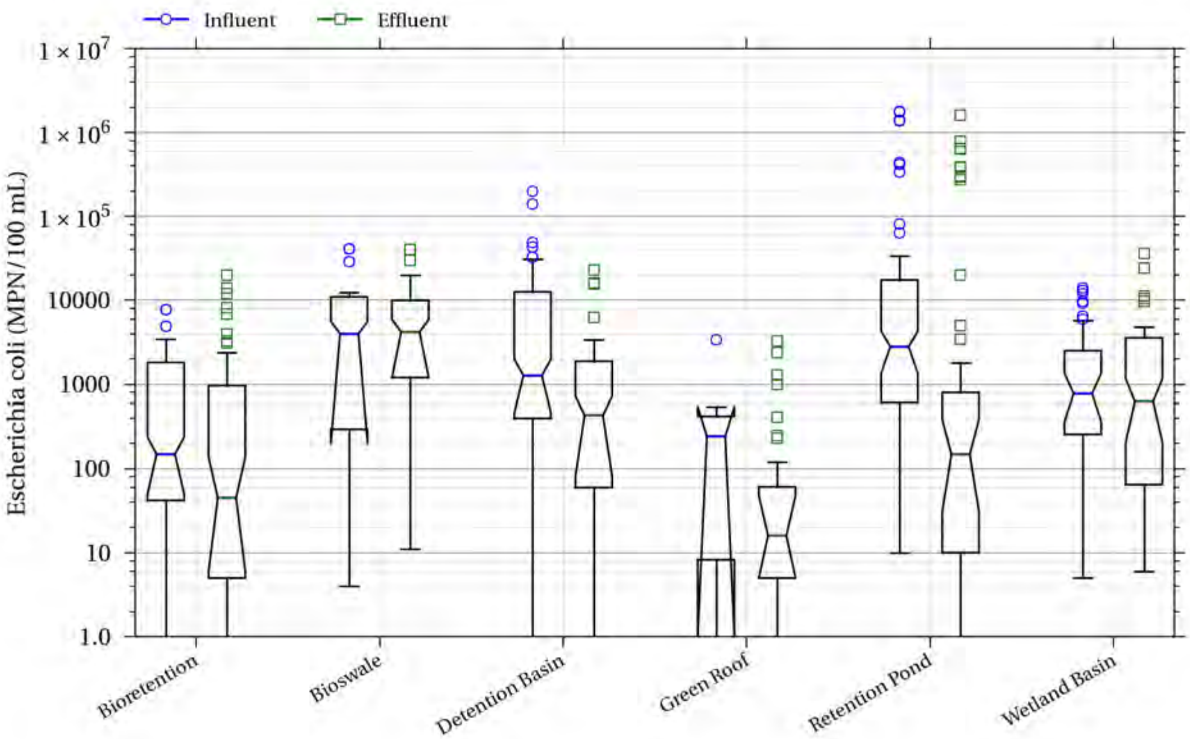

Table 4. Influent/Effluent Summary Statistics for *E. coli* (#/100 mL)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	NA	NA	NA	NA	NA	NA	NA	NA
Bioretention	3, 54	3, 54	42	5	150 (50, 210)	44 (6, 137)	1820	965
Bioswale	5, 39	5, 39	295	1200	3990 (200, 5600)	4190 (1200, 5900)	11000	10000
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	3, 32	3, 32	398	60	1300 (460, 1990)	429 (82, 720)**	12600	1880
Green Roof	1, 6	3, 39	8	5	232 (1, 550)	16 (5, 48)	5.0	61
Manufactured Device-D	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-F	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-P	NA	NA	NA	NA	NA	NA	NA	NA
Media Filter	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	4, 68	4, 69	607	10	2800 (1350, 4300)	**150 (31, 387)****	17500	800
Wetland Basin	3, 42	3, 42	257	65	785 (363, 1350)	632 (199, 1160)	2510	3580

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 2 shows statistically significant decreases for this BMP category.

2.2.3 Fecal Coliform

Figure 5. Box Plots of Influent/Effluent Fecal Coliform Concentrations

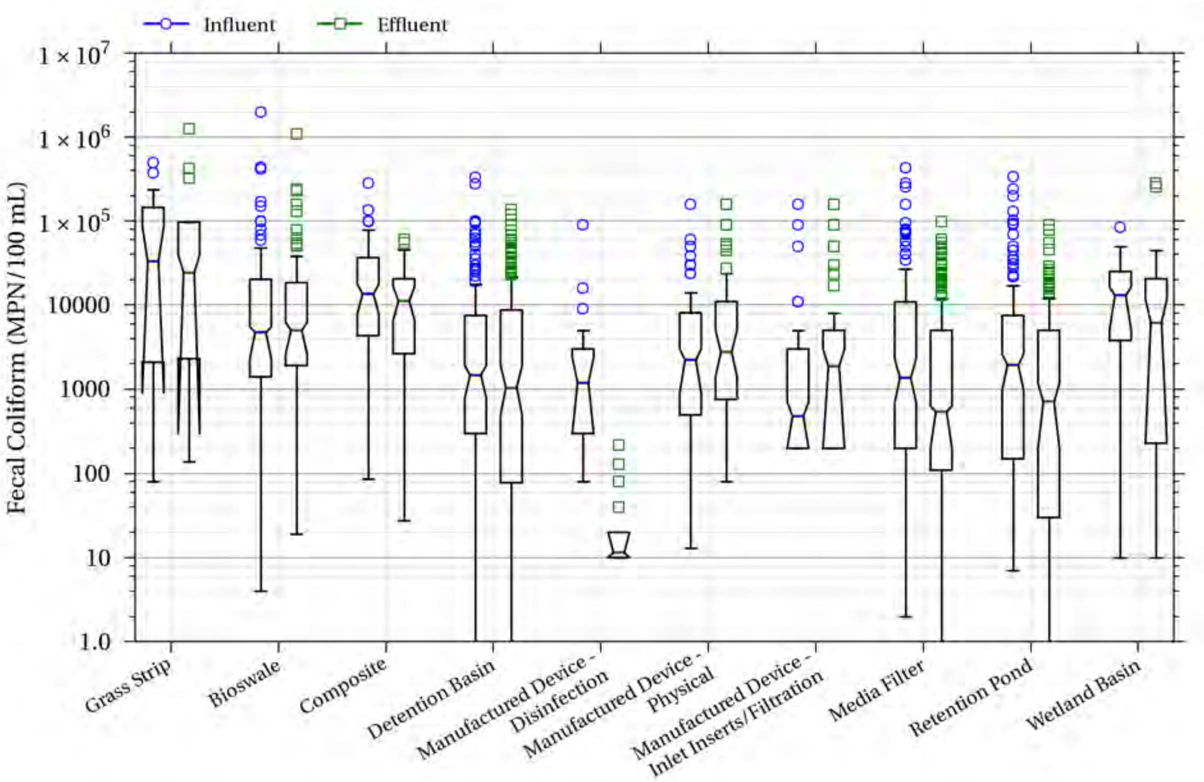

Table 5. Influent/Effluent Summary Statistics for Fecal Coliform (#/100 mL)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	2, 14	2, 13	2090	2300	32000 (1450, 91700)	23200 (300,39600)	145000	97200
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	10, 79	10, 79	1400	1900	4720 (2120, 5500)	5000 (2600, 6200)	20300	18500
Composite	4, 56	5, 49	4320	2640	13500 (7740, 18300)	11200 (6590, 16000)	36700	20600
Detention Basin	13, 139	14, 170	300	78	1480 (789, 1900)	1030 (500, 1900)	7520	8720
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device-D	1, 33	1, 32	300	10	1190 (300, 3000)	12 (10, 20)	3000	20
Manufactured Device-F	5, 45	5, 48	200	200	478 (200, 1300)	1890 (200, 3000)	3000	5000
Manufactured Device-P	5, 59	5, 59	500	752	2210 (900, 3000)	2750 (1400, 5000)	8080	11000
Media Filter	19, 191	20, 185	200	110	1350 (725, 2300)	**542 (200, 625)****	10900	5000
Retention Pond	11, 102	12, 129	150	30	1920 (970, 2650)	**707 (200, 1160)****	7520	5000
Wetland Basin	5, 37	5, 29	3780	230	13000 (5080, 21000)	6140 (230, 11800)	25100	20600

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 2 shows statistically significant decreases for this BMP category.

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2.3 Metals

2.3.1 Arsenic

Figure 6. Box Plots of Influent/Effluent Dissolved Arsenic Concentrations

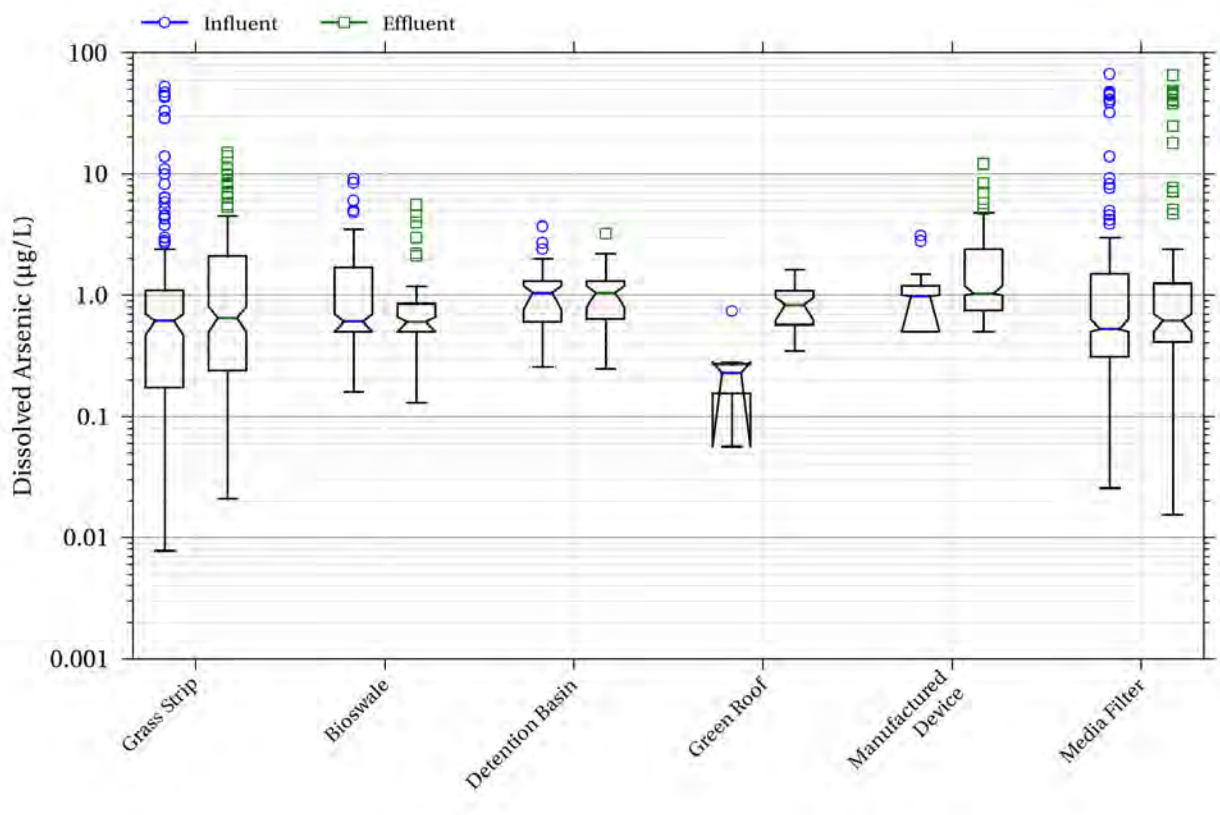

Table 6. Influent/Effluent Summary Statistics for Dissolved Arsenic (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 152	0.17	0.24	0.61 (0.46, 0.70)	0.64 (0.50, 0.80)	1.10	2.10
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	8, 45	8, 37	0.50	0.50	0.60 (0.50, 0.70)	0.60 (0.50, 0.66)	1.70	0.85
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	5, 44	5, 42	0.60	0.63	1.04 (0.77, 1.20)	1.04 (0.80, 1.20)	1.30	1.30
Green Roof	1, 6	3, 29	0.16	0.57	0.23 (0.06, 0.28)	0.84 (0.62, 0.95)	0.27	1.09
Manufactured Device	2, 28	8, 55	0.50	0.75	0.98 (0.50, 1.00)	1.02 (1.00, 1.20)	1.2	2.40
Media Filter	12, 123	12, 119	0.31	0.41	0.53 (0.50, 0.63)	0.62 (0.50, 0.70)	1.50	1.25
Porous Pavement	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

Figure 7. Box Plots of Influent/Effluent Total Arsenic Concentrations

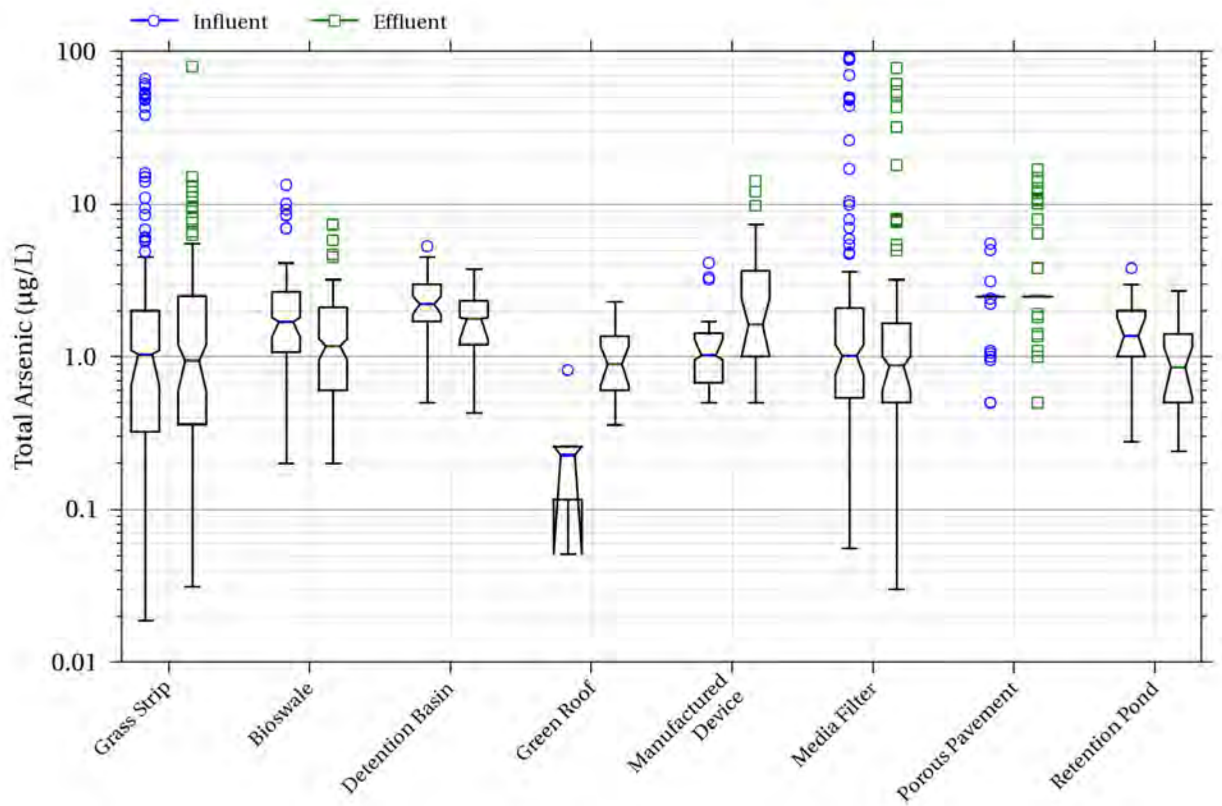

Table 7. Influent/Effluent Summary Statistics for Total Arsenic (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 153	0.32	0.36	1.04 (0.65, 1.10)	0.94 (0.55, 1.20)	2	2.50
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	8, 44	8, 37	1.07	0.60	1.68 (1.30, 1.81)	**1.17 (0.95, 1.30)****	2.65	2.10
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	6, 62	6, 56	1.70	1.20	2.21 (1.89, 2.50)	**1.78 (1.29, 1.80)****	2.98	2.32
Green Roof	1, 6	3, 29	0.12	0.60	0.22 (0.05, 0.26)	0.89 (0.65, 1.17)	0.26	1.36
Manufactured Device	2, 28	8, 55	0.68	1.00	1.02 (0.95, 1.30)	1.63 (1.00, 2.40)	1.0	3.65
Media Filter	12, 123	12, 119	0.54	0.50	1.01 (0.75, 1.20)	0.87 (0.61, 1.00)	2.07	1.65
Porous Pavement****	3, 111	3, 105	2.50	2.50	2.50 (2.50, 2.50)	2.50 (2.50, 2.50)	2.50	2.50
Retention Pond	3, 25	3, 24	1.00	0.50	1.36 (1.00, 1.80)	**0.85 (0.54, 1.15)****	2	1.41
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.

****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

2.3.2 Cadmium

Figure 8. Box Plots of Influent/Effluent Dissolved Cadmium Concentrations

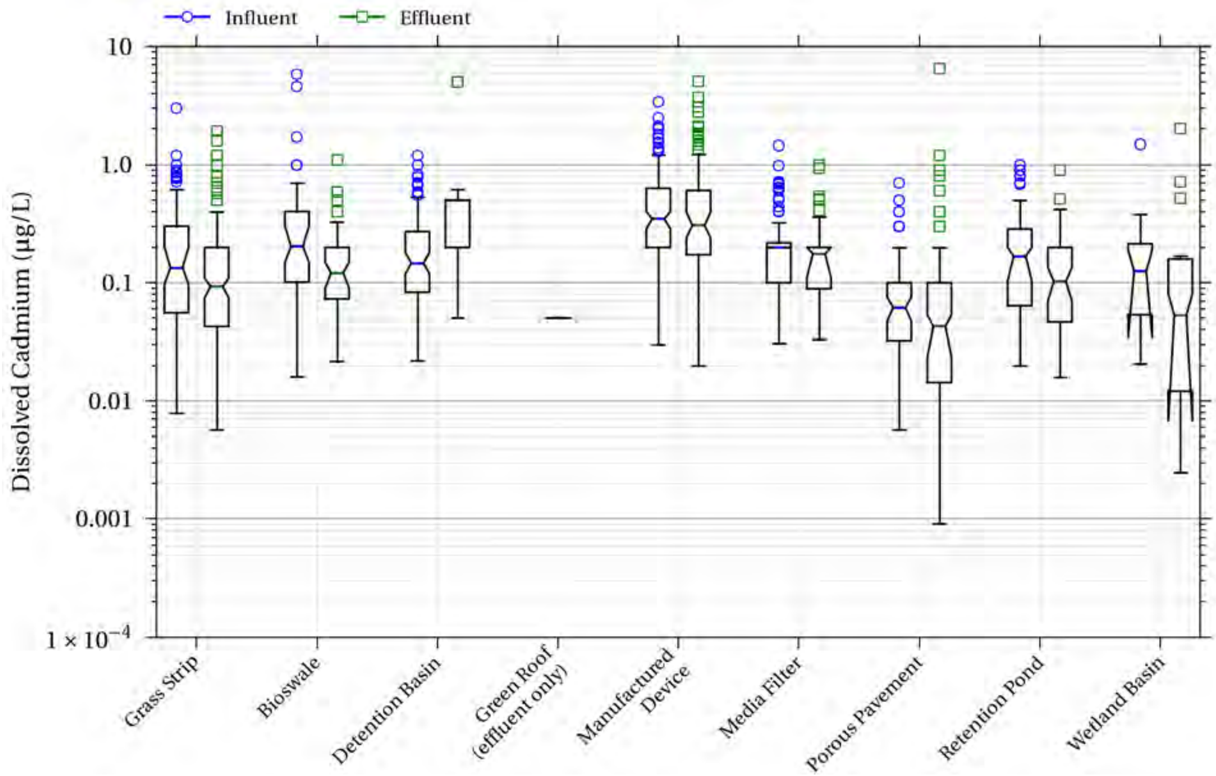

Table 8. Influent/Effluent Summary Statistics for Dissolved Cadmium (ug/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 219	12, 152	0.06	0.04	0.13 (0.10, 0.20)	0.09 (0.07, 0.11)	0.30	0.20
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	12, 83	12, 75	0.10	0.07	0.21 (0.15, 0.30)	**0.12 (0.09, 0.15)****	0.40	0.20
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	9, 141	9, 147	0.08	0.20	0.15 (0.12, 0.18)	***0.50 (0.50, 0.50)******	0.27	0.50
Green Roof****	NA	2, 12	NA	0.05	NA	0.05 (0.05, 0.05)	NA	0.05
Manufactured Device	13, 149	19, 174	0.20	0.17	0.35 (0.29, 0.40)	0.30 (0.24, 0.39)	0.63	0.60
Media Filter	13, 136	13, 131	0.10	0.09	0.20 (0.20, 0.20)	0.18 (0.11, 0.20)	0.22	0.20
Porous Pavement****	3, 113	3, 105	0.03	0.01	0.06 (0.05, 0.07)	**0.04 (0.02, 0.05)****	0.10	0.10
Retention Pond	4, 63	4, 78	0.06	0.05	0.17 (0.10, 0.20)	0.10 (0.07, 0.13)	0.28	0.20
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 3 shows statistically significant *increases* for this BMP category.
****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

RB-AR33125

Figure 9. Box Plots of Influent/Effluent Total Cadmium Concentrations

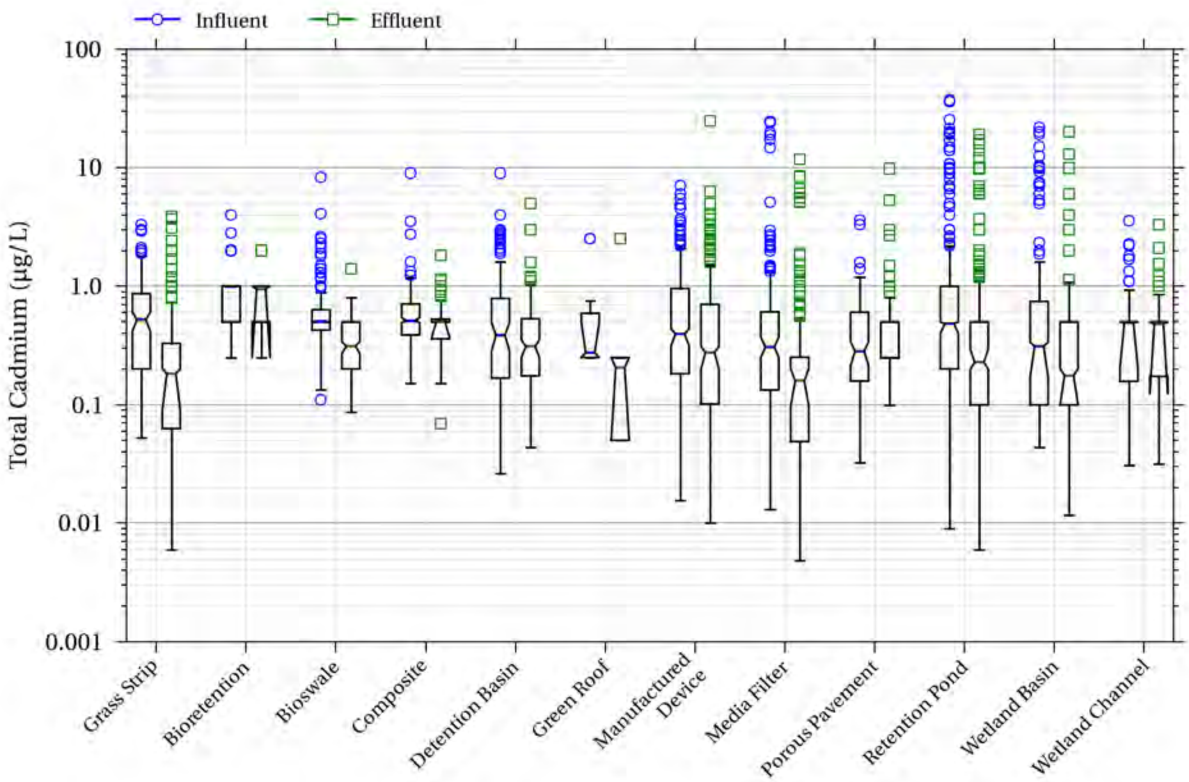

Table 9. Influent/Effluent Summary Statistics for Total Cadmium (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 153	0.20	0.06	0.52 (0.42, 0.60)	**0.18 (0.09, 0.20)****	0.86	0.33
Bioretention****	3, 40	3, 37	0.50	0.50	0.99 (1.00, 1.00)	**0.94 (0.25, 1.00)****	1.00	1.00
Bioswale	14, 136	14, 123	0.43	0.20	0.50 (0.50, 0.50)	**0.31 (0.27, 0.34)****	0.63	0.50
Composite	5, 83	6, 80	0.39	0.36	0.51 (0.50, 0.54)	**0.50 (0.43, 0.50)****	0.71	0.52
Detention Basin	12, 162	13, 178	0.17	0.17	0.39 (0.28, 0.49)	0.31 (0.25, 0.35)	0.79	0.53
Green Roof****	1, 14	3, 28	0.25	0.05	0.27 (0.25, 0.50)	0.21 (0.05, 0.25)	0.59	0.25
Manufactured Device	18, 234	25, 260	0.18	0.10	0.40 (0.32, 0.44)	**0.28 (0.20, 0.31)****	0.95	0.70
Media Filter	21, 268	21, 250	0.13	0.05	0.31 (0.20, 0.31)	**0.16 (0.10, 0.20)****	0.60	0.25
Porous Pavement****	3, 113	4, 111	0.16	0.25	0.28 (0.21, 0.35)	0.25 (0.25, 0.25)	0.60	0.50
Retention Pond	25, 374	25, 384	0.20	0.10	0.49 (0.40, 0.50)	**0.23 (0.20, 0.29)****	1.00	0.50
Wetland Basin	5, 100	5, 117	0.10	0.10	0.31 (0.19, 0.34)	**0.18 (0.10, 0.20)****	0.74	0.50
Wetland Channel	3, 69	3, 54	0.16	0.17	0.50 (0.23, 0.50)	0.49 (0.19, 0.50)	0.50	0.50

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.

***Hypothesis testing in Attachment 1 shows statistically significant *increases* for this BMP category.

****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

2.3.3 Chromium

Figure 10. Box Plots of Influent/Effluent Dissolved Chromium Concentrations

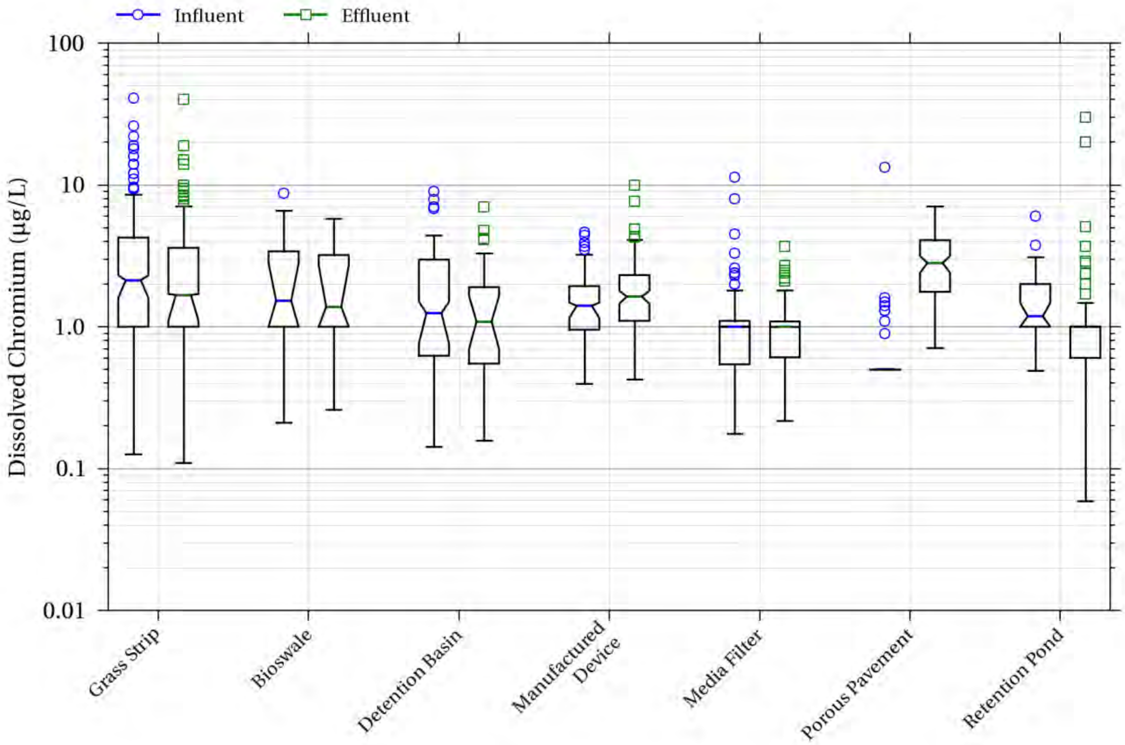

Table 10. Influent/Effluent Summary Statistics for Dissolved Chromium (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 152	1.00	1.00	2.13 (1.60, 2.30)	1.68 (1.20, 1.70)	4.25	3.60
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	6, 37	6, 29	1.00	1.00	1.53 (1.00, 2.80)	1.38 (1.00, 2.70)	3.40	3.20
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	4, 42	4, 36	0.62	0.55	1.25 (0.76, 1.50)	1.08 (0.70, 1.65)	2.97	1.90
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	10, 117	16, 144	0.95	1.10	1.40 (1.13, 1.48)	1.63 (1.46, 1.80)	1.93	2.31
Media Filter	13, 133	13, 128	0.54	0.61	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.10	1.10
Porous Pavement****	3, 113	3, 106	0.50	1.76	0.50 (0.50, 0.50)	***2.82 (2.40, 3.10)****	0.50	4.07
Retention Pond	4, 67	4, 81	1.00	0.60	1.18 (1.00, 1.47)	**1.00 (1.00, 1.00)***	2.00	1.00
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 3 shows statistically significant *increases* for this BMP category.
****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

Figure 11. Box Plots of Influent/Effluent Total Chromium Concentrations

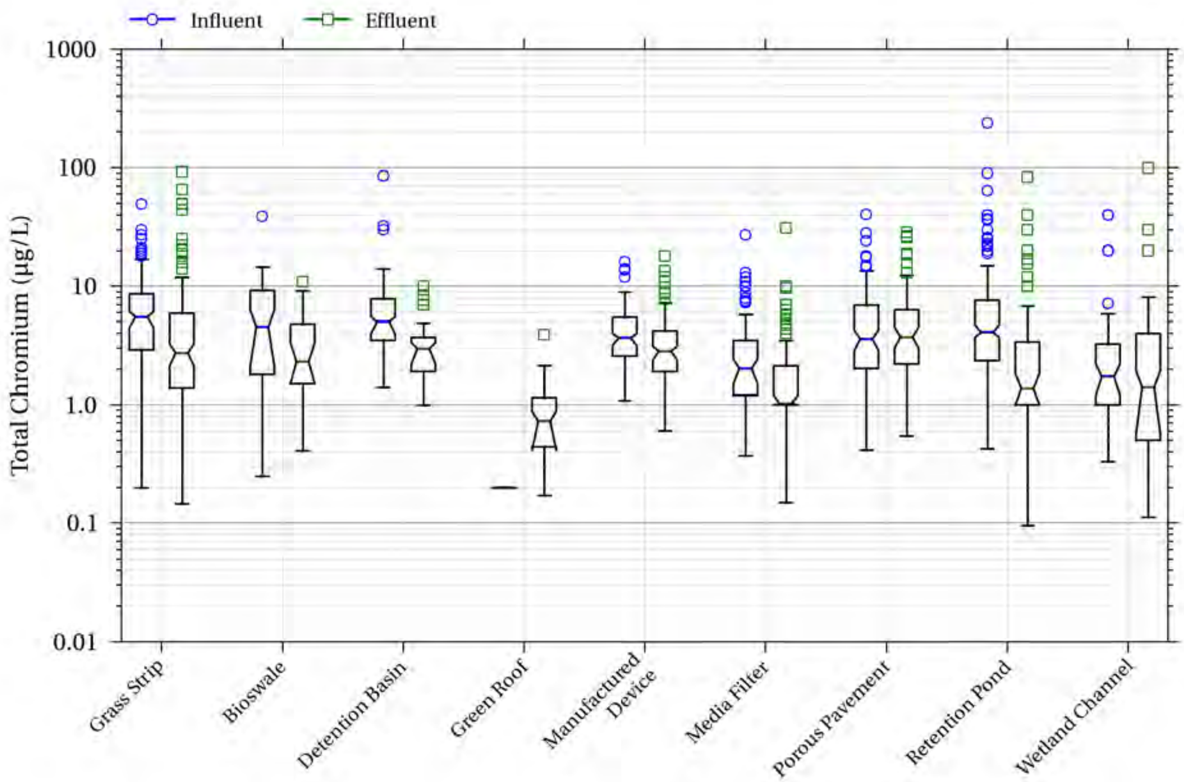

Table 11. Influent/Effluent Summary Statistics for Total Chromium (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	13, 223	13, 156	2.90	1.37	5.49 (4.50, 6.10)	**2.73 (2.10, 3.25)****	8.60	5.90
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	6, 37	6, 29	1.80	1.50	4.53 (2.10, 6.30)	2.32 (1.50, 3.30)	9.20	4.80
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	6, 60	5, 46	3.50	1.90	5.02 (3.97, 5.50)	**2.97 (2.20, 3.35)****	7.80	3.70
Green Roof****	1, 6	3, 23	0.20	0.44	0.20 (0.20, 0.20)	0.73 (0.41, 0.88)	0.20	1.15
Manufactured Device	11, 120	17, 145	2.57	1.90	3.66 (3.17, 4.00)	**2.82 (2.40, 3.11)****	5.45	4.20
Media Filter	13, 134	13, 128	1.20	1.00	2.02 (1.50, 2.43)	**1.02 (1.00, 1.20)****	3.49	2.12
Porous Pavement****	3, 113	3, 105	2.02	2.20	3.60 (2.81, 4.24)	3.73 (2.99, 4.42)	6.90	6.30
Retention Pond	12, 153	12, 162	2.35	1.00	4.09 (3.70, 4.72)	**1.36 (1.00, 1.84)****	7.60	3.39
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	3, 70	3, 55	1.00	0.50	1.72 (1.20, 2.19)	1.41 (0.57, 1.92)	3.25	4.00

**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 1 shows statistically significant *increases* for this BMP category.
****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

2.3.4 Copper

Figure 12. Box Plots of Influent/Effluent Dissolved Copper Concentrations

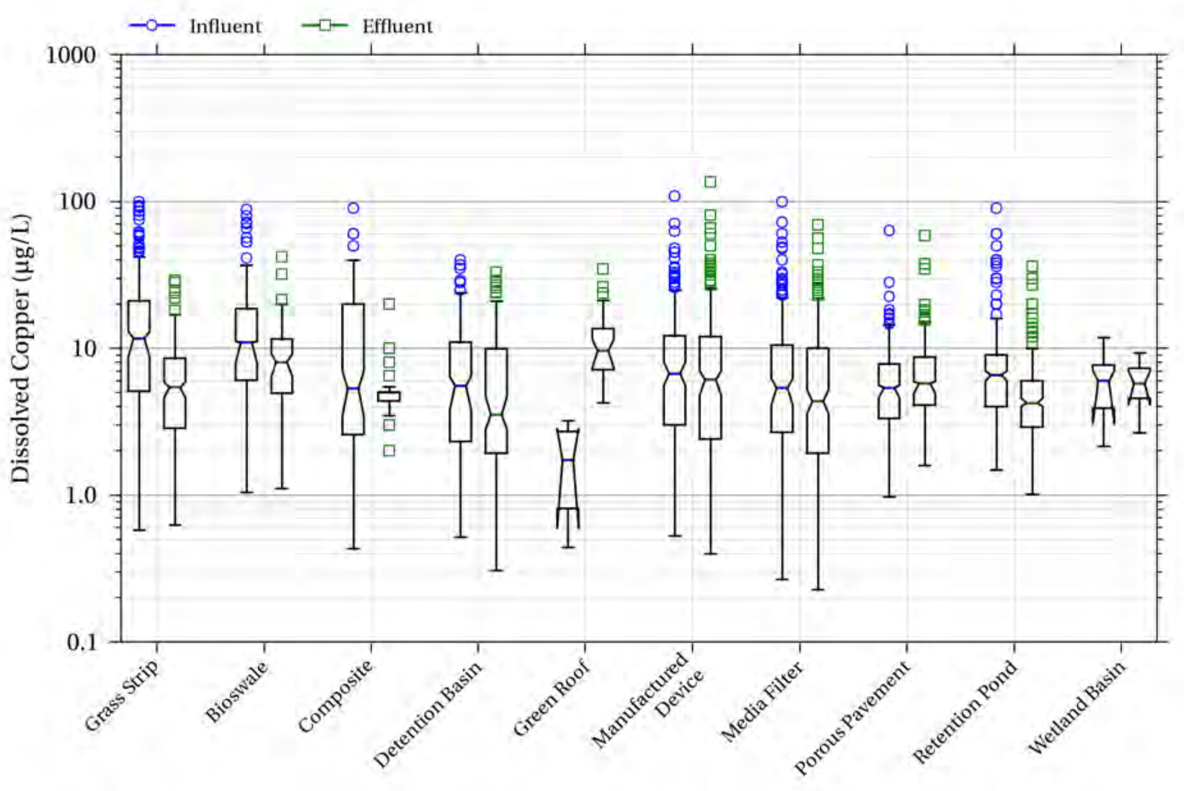

Table 12. Influent/Effluent Summary Statistics for Dissolved Copper (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 233	12, 163	5.10	2.85	11.66 (8.60, 13.00)	**5.40 (4.50, 5.90)****	21.00	8.55
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	13, 109	13, 92	6.05	4.94	11.01 (7.39, 11.10)	8.02 (6.30, 9.24)	18.60	11.55
Composite	3, 59	3, 52	2.58	4.38	5.32 (3.44, 7.00)	5.00 (5.00, 5.00)	20.00	5.00
Detention Basin	9, 170	9, 170	2.32	1.93	5.56 (3.80, 6.30)	3.52 (2.80, 4.72)	11.00	9.92
Green Roof	1, 6	3, 39	0.81	7.14	1.72 (0.44, 2.83)	9.55 (7.34, 11.50)	2.71	13.60
Manufactured Device	17, 219	23, 307	3.00	2.41	6.70 (5.60, 8.00)	6.08 (4.82, 7)	12.15	12.00
Media Filter	13, 191	13, 186	2.68	1.92	5.37 (4.30, 6.50)	4.35 (3.58, 5.10)	10.50	10.00
Porous Pavement	6, 138	7, 190	3.32	4.10	5.37 (4.60, 5.60)	5.75 (4.90, 5.91)	7.80	8.70
Retention Pond	10, 202	10, 213	4.00	2.90	6.57 (5.96, 7.00)	**4.24 (4.00, 4.57)****	9.00	6.00
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.

RB-AR33129

Figure 13. Box Plots of Influent/Effluent Total Copper Concentrations

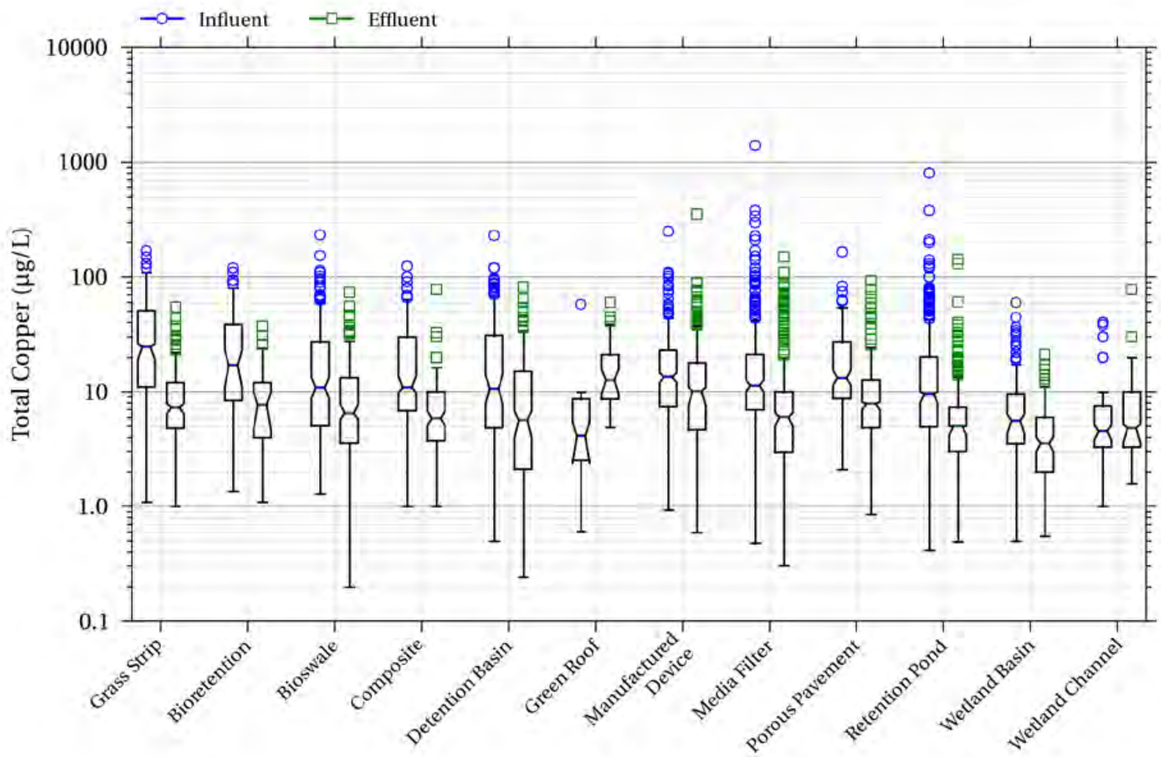

Table 13. Influent/Effluent Summary Statistics for Total Copper (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	13, 237	13, 167	11.00	4.80	24.52 (19, 26)	**7.30 (6.40, 7.90)****	51.00	12.00
Bioretention	4, 63	4, 56	8.35	3.98	17.00 (11.00, 23.00)	**7.67 (4.60, 9.85)****	38.50	12.00
Bioswale	16, 258	18, 300	5.02	3.57	10.86 (8.70, 13.20)	**6.54 (5.70, 7.70)****	27.00	13.20
Composite	6, 123	7, 109	6.84	3.74	10.93 (9.71, 13.63)	**5.88 (5.05, 6.79)****	30.00	10.00
Detention Basin	12, 193	13, 203	4.83	2.11	10.62 (7.78, 14.00)	**5.67 (4.00, 6.80)****	31.00	15.00
Green Roof	2, 20	4, 55	2.52	8.61	4.12 (2.38, 5.40)	12.60 (9.58, 15.60)	8.63	21.00
Manufactured Device	26, 349	33, 434	7.40	4.65	13.42 (11.90, 14.70)	**10.16 (7.94, 11.0)****	23.00	17.85
Media Filter	25, 408	25, 377	6.96	2.95	11.28 (10.00, 12.68)	**6.01 (5.10, 6.60)****	21.10	10.00
Porous Pavement	11, 190	12, 236	8.70	4.84	13.07 (11.45, 15.30)	**7.83 (6.80, 8.10)****	27.00	12.62
Retention Pond	33, 525	33, 517	4.93	3.00	9.57 (8.00, 10.00)	**4.99 (4.06, 5.00)****	20.10	7.32
Wetland Basin	6, 149	6, 148	3.53	2.00	5.61 (4.36, 6.34)	**3.57 (3.00, 4.00)****	9.57	6.00
Wetland Channel	3, 95	3, 77	3.30	3.30	4.52 (3.80, 5.10)	4.81 (3.61, 5.20)	7.50	10.00

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.

2.3.5 Iron

Figure 14. Box Plots of Influent/Effluent Dissolved Iron Concentrations

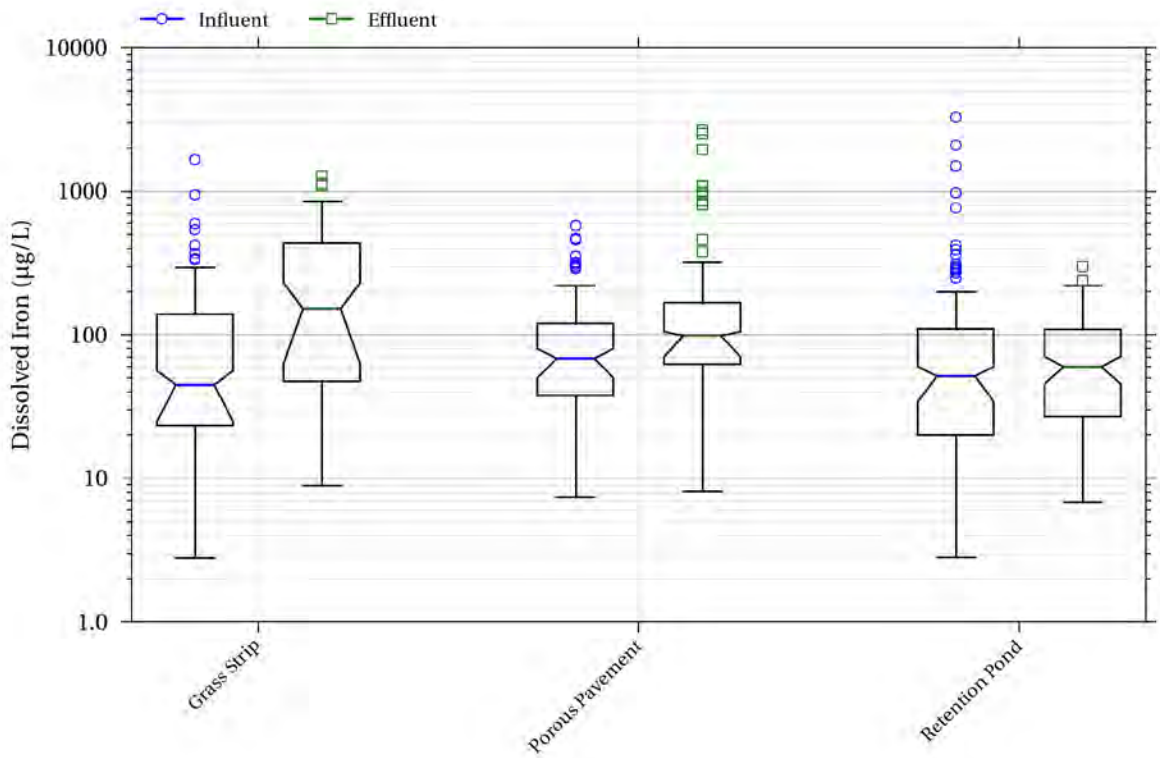

Table 14. Influent/Effluent Summary Statistics for Dissolved Iron (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	5, 67	4, 52	23.2	47.3	44.9 (25.0, 56.0)	***151.9 (63.0, 226.5)****	139.0	435.0
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	NA	NA	NA	NA	NA	NA	NA	NA
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	NA	NA	NA	NA	NA	NA	NA	NA
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	NA	NA	NA	NA	NA	NA	NA	NA
Media Filter	NA	NA	NA	NA	NA	NA	NA	NA
Porous Pavement	3, 113	3, 106	37.9	62.5	68.4 (49.4, 80.0)	98.63(70.0, 105.0)	120.0	167.5
Retention Pond	5, 118	5, 129	20.0	27.0	51.5 (35.0, 60.0)	59.72 (45.4, 70.8)	110.0	109.0
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

***Hypothesis testing in Attachment 3 shows statistically significant *increases* for this BMP category.

Figure 15. Box Plots of Influent/Effluent Total Iron Concentrations

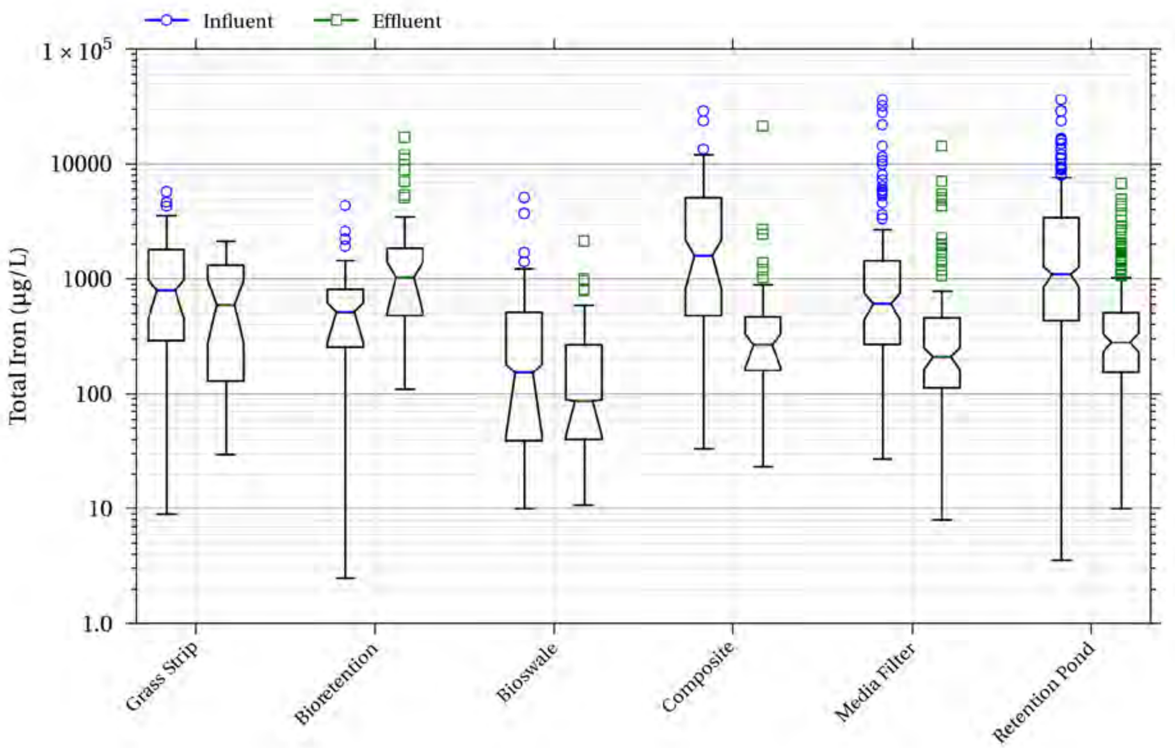

Table 15. Influent/Effluent Summary Statistics for Total Iron (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	5, 67	4, 52	291	129	792 (490, 1000)	590 (287, 939)	1800	1307
Bioretention	3, 44	3, 42	253	478	515 (280, 619)	1032 (510, 1380)	805	1845
Bioswale	3, 55	4, 75	39	40	151 (45, 180)	86 (43, 88)	514	265
Composite	3, 67	3, 54	477	160	1603 (820, 2170)	**264 (165, 330)****	5095	464
Detention Basin	NA	NA	NA	NA	NA	NA	NA	NA
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	NA	NA	NA	NA	NA	NA	NA	NA
Media Filter	7, 141	7, 123	267	113	606 (437, 754)	**210 (163, 250)****	1430	455
Porous Pavement	NA	NA	NA	NA	NA	NA	NA	NA
Retention Pond	15, 299	16, 305	430	153	1094 (858, 1265)	**280 (230, 335)****	3404	510
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.

2.3.6 Lead

Figure 16. Box Plots of Influent/Effluent Dissolved Lead Concentrations

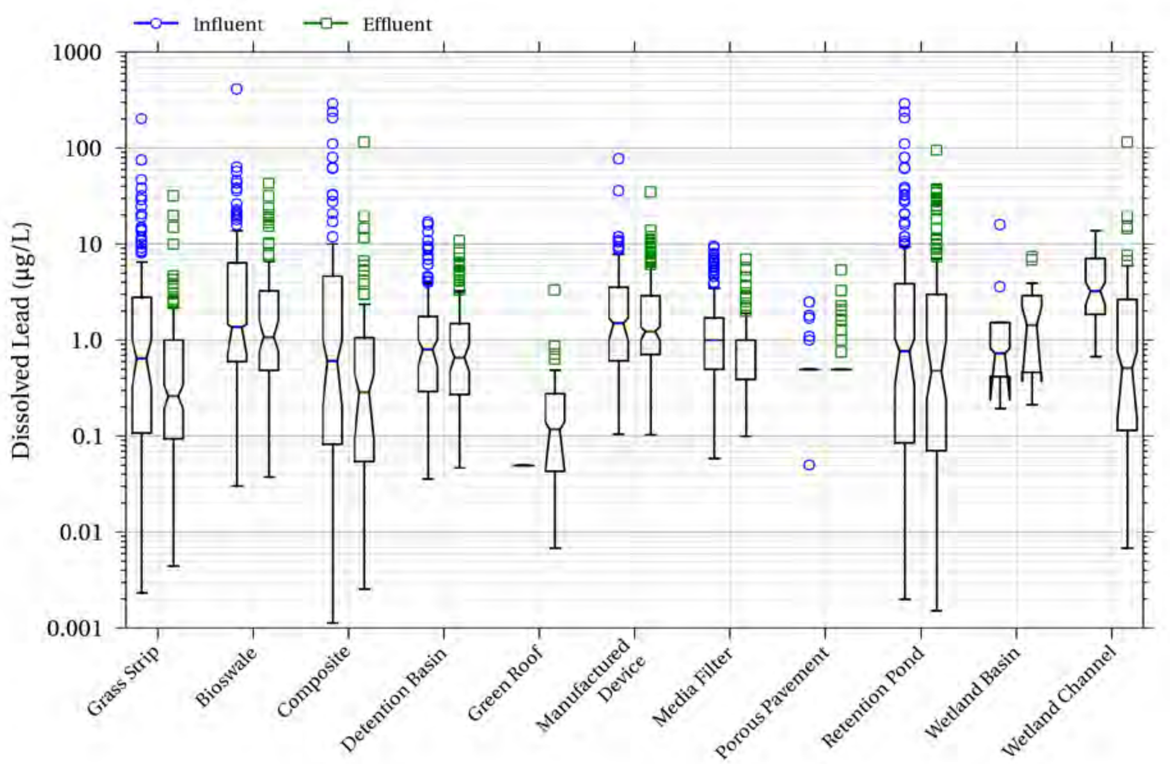

Table 16. Influent/Effluent Summary Statistics for Dissolved Lead (μg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 232	12, 164	0.11	0.09	0.64 (0.32, 1.00)	0.26 (0.19, 0.35)	2.80	1.00
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	13, 109	13, 92	0.60	0.49	1.36 (0.70, 1.46)	1.08 (0.76, 1.60)	6.40	3.26
Composite	5, 64	5, 56	0.08	0.05	0.61 (0.21, 0.99)	0.29 (0.09, 0.44)	4.63	1.07
Detention Basin	9, 170	9, 171	0.29	0.27	0.79 (0.54, 1.00)	0.66 (0.48, 0.90)	1.76	1.49
Green Roof****	1, 6	3, 39	0.05	0.04	0.05 (0.05, 0.05)	0.12 (0.05, 0.14)	0.05	0.28
Manufactured Device	14, 159	20, 245	0.61	0.71	1.49 (1.00, 1.70)	1.24 (1.00, 1.38)	3.55	2.90
Media Filter	13, 191	13, 186	0.50	0.39	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.70	1.00
Porous Pavement****	3, 113	3, 106	0.50	0.50	0.50 (0.50, 0.50)	0.50 (0.50, 0.50)	0.50	0.50
Retention Pond	14, 202	14, 214	0.08	0.07	0.76 (0.34, 1.03)	0.48 (0.23, 0.96)	3.85	3.00
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	3, 53	3, 47	1.85	0.12	3.26 (2.35, 3.98)	**0.52 (0.12, 0.75)****	7.09	2.66

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.

****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

RB-AR33133

Figure 17. Box Plots of Influent/Effluent Total Lead Concentrations

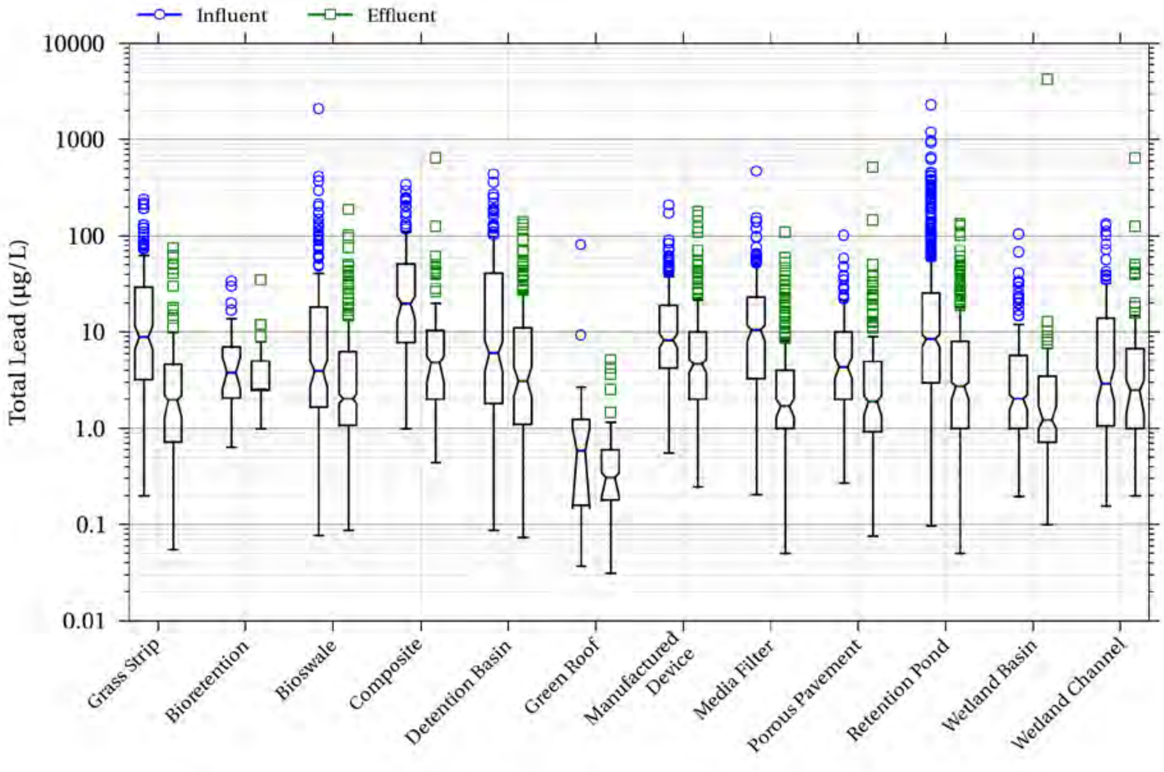

Table 17. Influent/Effluent Summary Statistics for Total Lead (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	13, 237	13, 167	3.20	0.72	8.83 (6.60, 11.50)	**1.96 (1.30, 2.20)****	29.00	4.60
Bioretention	3, 47	3, 43	2.06	2.50	3.76 (2.49, 5.50)	2.53 (2.50, 2.50)	7.00	5.00
Bioswale	17, 277	19, 318	1.65	1.08	3.93 (2.80, 5.00)	**2.02 (1.80, 2.29)****	18.20	6.27
Composite	9, 158	10, 149	7.78	2.00	19.7 (13.27, 23.45)	**4.78 (3.00, 5.61)****	51.00	10.30
Detention Basin	12, 193	13, 204	1.80	1.10	6.08 (3.86, 8.00)	3.10 (2.15, 4.30)	41.00	11.00
Green Roof	2, 20	4, 55	0.16	0.18	0.58 (0.15, 1.00)	0.30 (0.19, 0.35)	1.20	0.59
Manufactured Device	20, 247	27, 334	4.20	2.00	8.24 (6.77, 9.56)	**4.63 (3.80, 5.16)****	18.95	10.00
Media Filter	25, 394	25, 362	3.28	1.00	10.5 (8.02, 11.79)	**1.69 (1.30, 2.00)****	23.00	3.99
Porous Pavement	8, 162	13, 174	1.99	0.93	4.30 (3.28, 5.47)	**1.86 (1.38, 2.21)****	9.98	4.93
Retention Pond	40, 631	40, 627	2.97	1.00	8.48 (6.80, 9.41)	**2.76 (2.00, 3.00)****	25.30	8.00
Wetland Basin	6, 121	6, 121	1.00	0.71	2.03 (1.57, 2.24)	**1.21 (1.00, 1.55)****	5.73	3.47
Wetland Channel	6, 117	6, 102	1.06	1.00	2.94 (1.90, 4.20)	2.49 (1.40, 3.11)	14.00	6.73

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.
****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

2.3.7 Nickel

Figure 18. Box Plots of Influent/Effluent Dissolved Nickel Concentrations

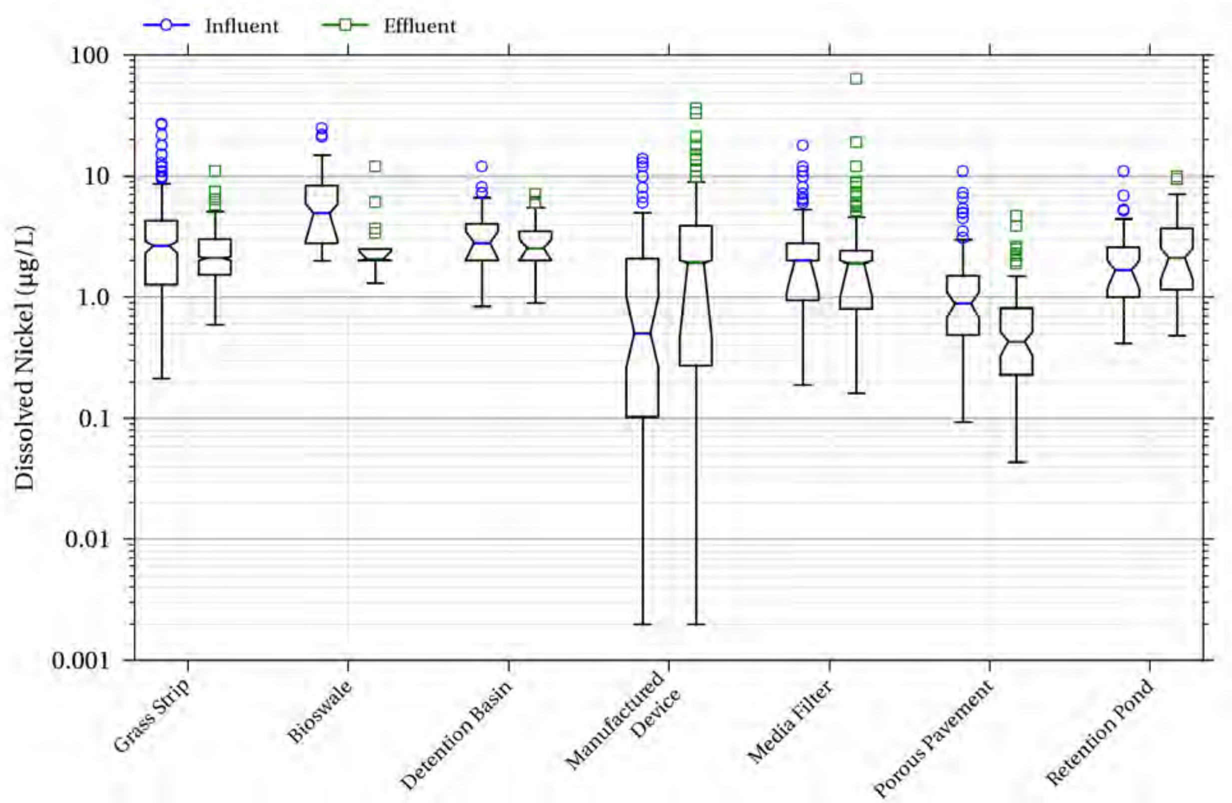

Table 18. Influent/Effluent Summary Statistics for Dissolved Nickel (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 152	1.27	1.53	2.68 (2.30, 2.90)	**2.09 (2.00, 2.15)****	4.30	3.00
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	5, 31	5, 23	2.80	2.00	4.93 (2.90, 5.90)	**2.04 (2, 2.40)****	8.35	2.50
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	5, 52	5, 46	2.00	2.00	2.82 (2.05, 3.47)	2.55 (2.00, 3.00)	4.05	3.50
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	9, 102	15, 129	0.10	0.27	0.50 (0.26, 1.03)	1.92 (0.44, 2.00)	2.07	3.90
Media Filter	13, 133	13, 128	0.94	0.80	1.99 (1.02, 2.00)	1.90 (0.99, 2.00)	2.80	2.43
Porous Pavement****	3, 113	3, 106	0.49	0.23	0.88 (0.68, 1.10)	**0.43 (0.33, 0.52)****	1.50	0.81
Retention Pond	4, 45	4, 45	1.00	1.16	1.68 (1.17, 2.00)	2.11 (1.40, 2.53)	2.59	3.70
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	NA	NA	NA	NA	NA	NA	NA	NA

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 3 shows statistically significant decreases for this BMP category.
****Conclusions are limited for this BMP category due to a large percentage of non-detects in the influent.

Figure 19. Box Plots of Influent/Effluent Total Nickel Concentrations

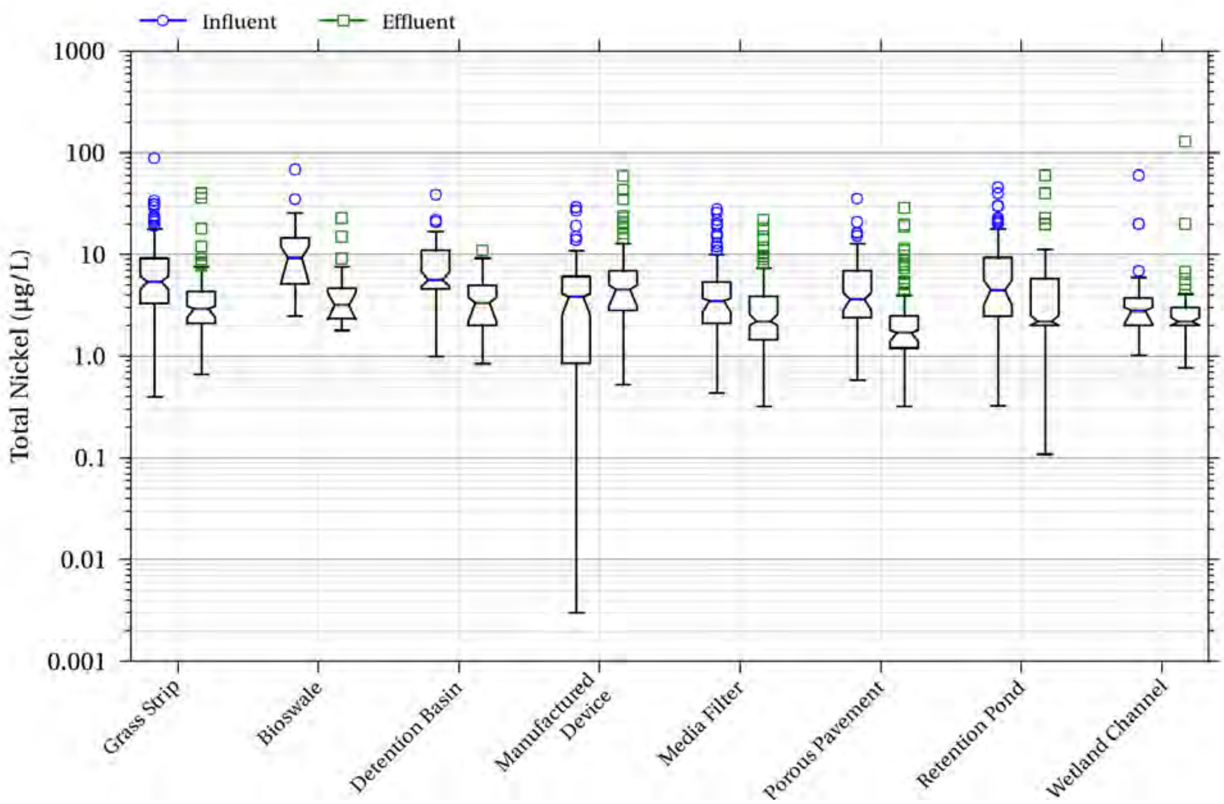

Table 19. Influent/Effluent Summary Statistics for Total Nickel (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 220	12, 153	3.30	2.10	5.41 (4.50, 6.10)	**2.92 (2.40, 3.10)****	9.20	4.30
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	5, 31	5, 23	5.15	2.35	9.26 (5.20, 12.00)	**3.16 (2.30, 4.20)****	14.50	4.65
Composite	NA	NA	NA	NA	NA	NA	NA	NA
Detention Basin	6, 60	6, 54	4.57	2.00	5.64 (4.85, 6.60)	**3.35 (2.20, 3.75)****	11.00	4.98
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	9, 102	15, 129	0.85	2.80	3.84 (2.50, 4.10)	4.51 (3.11, 5.00)	6.07	6.90
Media Filter	13, 134	13, 128	2.10	1.45	3.51 (2.70, 3.70)	**2.20 (2.00, 2.60)****	5.38	3.90
Porous Pavement	3, 113	3, 106	2.40	1.20	3.64 (2.80, 4.20)	**1.71 (1.40, 1.80)****	6.90	2.50
Retention Pond	10, 115	10, 112	2.48	2.00	4.46 (3.19, 5.59)	**2.19 (2.00, 2.60)****	9.34	5.82
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	3, 68	3, 53	2.00	2.00	2.80 (2.09, 3.00)	2.18 (2.00, 2.40)	3.75	3.00

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 1 shows statistically significant decreases for this BMP category.

RB-AR33136

Figure 20. Box Plots of Influent/Effluent Dissolved Zinc Concentrations

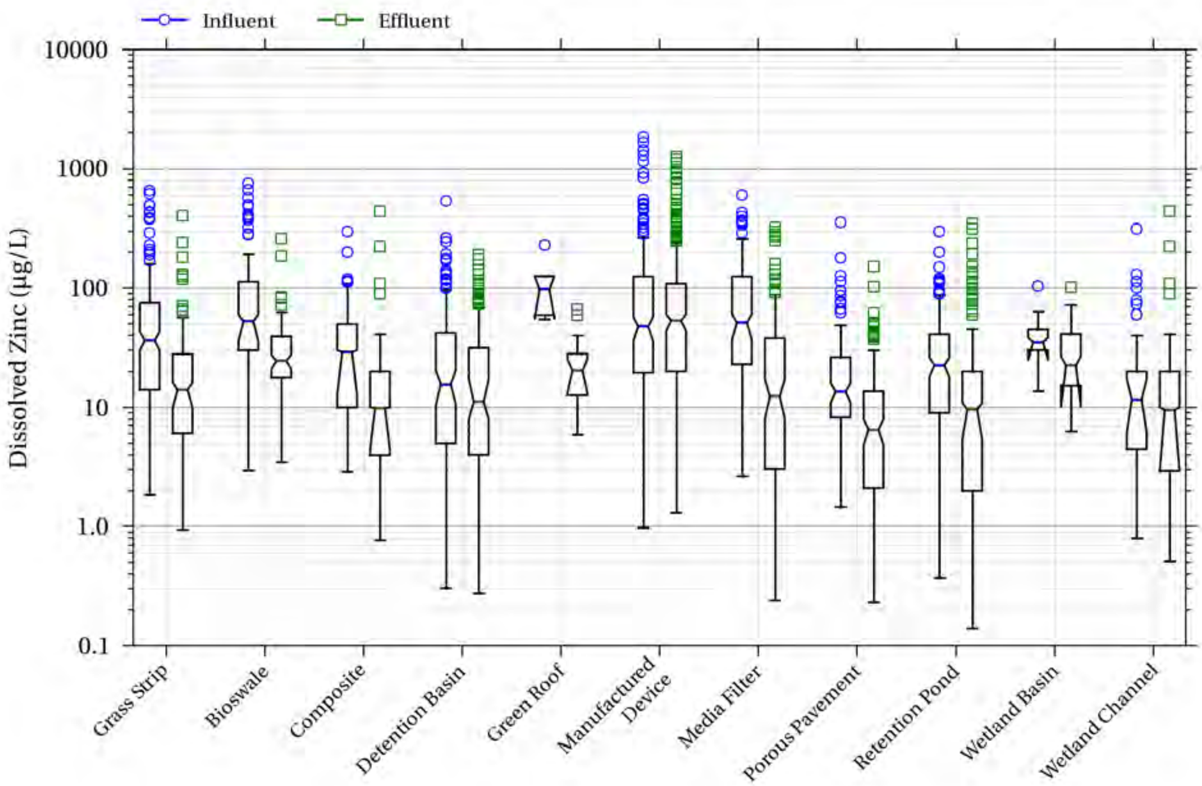

Table 20. Influent/Effluent Summary Statistics for Dissolved Zinc (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	12, 233	12, 163	14.0	6.0	36.1 (30.0, 43.1)	**14.0 (10.0, 16.0)****	75.0	28.0
Bioretention	NA	NA	NA	NA	NA	NA	NA	NA
Bioswale	13, 109	13, 92	30.0	17.7	52.7 (35.8, 59.9)	**24.5 (21.3, 27.5)****	113.0	39.2
Composite	4, 72	4, 61	10.0	4.0	29.0 (10.2, 30.0)	**9.9 (4.4, 10.0)****	50.0	20.0
Detention Basin	9, 169	9, 171	5.0	4.0	15.6 (10.8, 21.0)	11.08 (8, 17)	42.0	31.5
Green Roof	1, 6	3, 39	59.4	12.6	97.3 (55.2, 126.0)	20.3 (13.3, 25.2)	126.0	28.1
Manufactured Device	18, 219	24, 307	19.5	20.0	47.8 (36.0, 55.0)	53.3 (44.0, 64.0)	125.0	109.0
Media Filter	13, 191	13, 185	23.0	3.0	51.3 (37.1, 60.0)	**12.2 (8.3, 17.0)****	125.0	38.0
Porous Pavement	6, 138	7, 189	8.3	2.1	13.5 (10.9, 15.9)	**6.5 (4.9, 7.9)****	26.3	13.6
Retention Pond	11, 201	11, 212	9.0	2.0	22.5 (18.0, 26.0)	**9.6 (5.3, 10.9)****	41.0	20.0
Wetland Basin	NA	NA	NA	NA	NA	NA	NA	NA
Wetland Channel	3, 64	3, 56	4.5	2.9	11.6 (6.2, 17.0)	9.5 (2.9, 10.0)	20.0	20.0

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 1 shows statistically significant decreases for analyzed BMPs for total zinc

RB-AR33137

2.3.8 Zinc

Figure 21. Box Plots of Influent/Effluent Total Zinc Concentrations

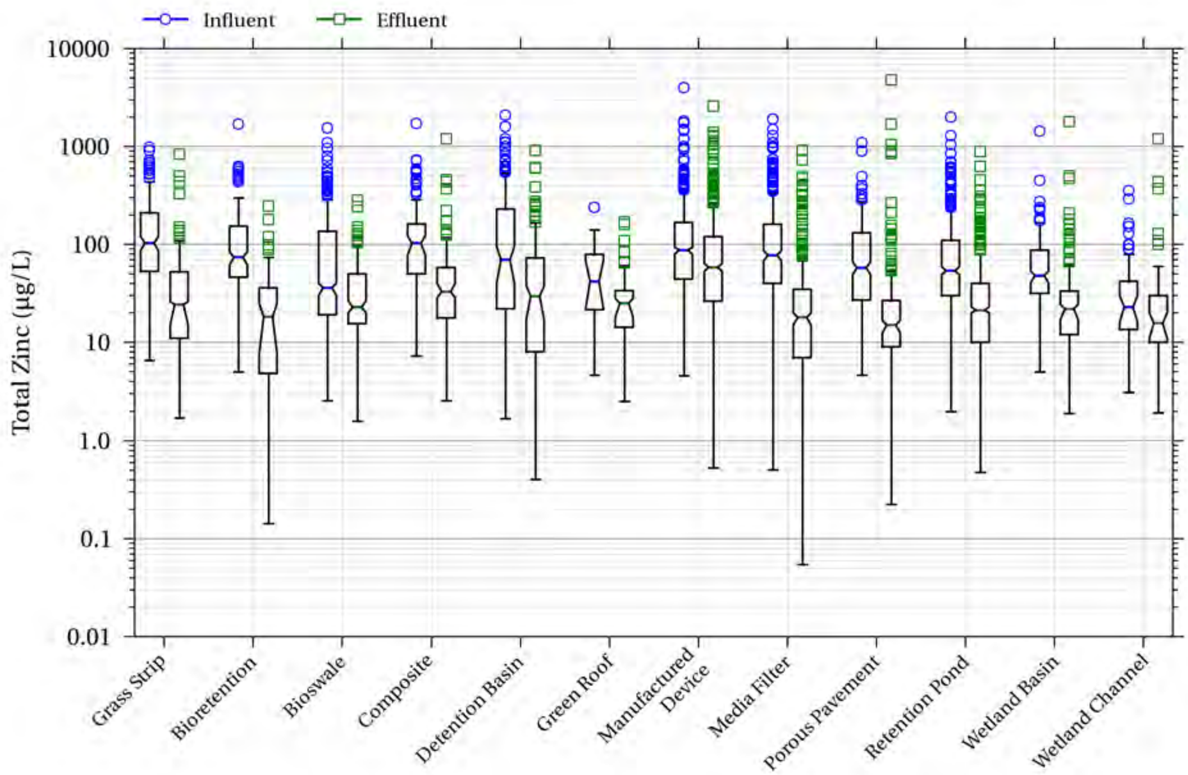

Table 21. Influent/Effluent Summary Statistics for Total Zinc (µg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	13, 237	13, 167	53.0	11.0	103.3 (86.0, 120.0)	**24.3 (16.0, 26.0)****	210.0	52.5
Bioretention	6, 106	6, 99	46.3	4.8	73.8 (62.0, 83.5)	**18.3 (7.7, 25.0)****	153.8	36.0
Bioswale	18, 292	20, 327	19.1	15.5	36.2 (30.0, 40.0)	**22.9 (20.0, 26.6)****	136.0	50.0
Composite	7, 137	8, 118	50.0	17.7	102.9 (77.4, 122.2)	**33.0 (28.5, 39.5)****	161.5	57.9
Detention Basin	12, 193	14, 212	22.0	8.0	70.0 (40.0, 95.0)	**29.7 (17.1, 38.2)****	230.0	72.8
Green Roof	2, 20	5, 60	21.5	14.3	41.8 (22.0, 68.1)	25.0 (18.0, 28.2)	79.1	33.7
Manufactured Device	39, 507	46, 593	44.3	26.3	87.7 (79.0, 95.0)	**58.5 (52.8, 63.5)****	167.5	120.0
Media Filter	28, 450	28, 406	40.0	7.0	77.3 (68.2, 86.0)	**17.9 (15.0, 20.0)****	160.8	34.8
Porous Pavement	12, 201	17, 261	27.0	9.0	57.6 (49.6, 66.0)	**15.0 (12.5, 16.8)****	131.4	26.7
Retention Pond	39, 574	40, 579	30.0	10.0	53.6 (49.0, 59.0)	**21.2 (20.0, 23.0)****	110.0	40.0
Wetland Basin	9, 177	9, 176	31.6	12.0	48.0 (40.6, 53.2)	**22.0 (16.7, 24.3)****	87.3	33.3
Wetland Channel	4, 107	4, 86	13.5	10.0	23.0 (16.0, 30.0)	15.6 (11.0, 20.0)	42.0	30.0

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 3 shows statistically significant decreases for analyzed BMPs for total zinc.

2.4 Nutrients

2.4.1 Phosphorus

Figure 22. Box Plots of Influent/Effluent Total Phosphorus Concentrations

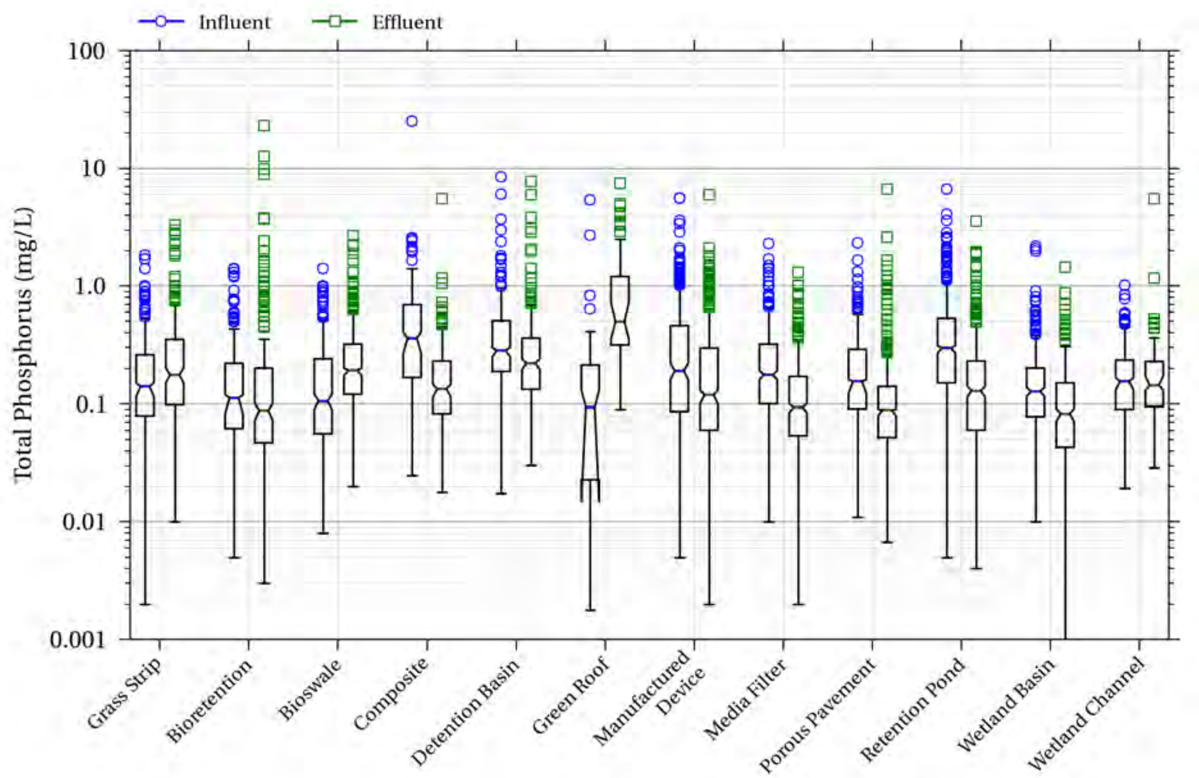

Table 22. Influent/Effluent Summary Statistics for Total Phosphorus (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval*)		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	20, 358	20, 280	0.08	0.10	0.14 (0.11, 0.15)	***0.18 (0.15, 0.20)****	0.26	0.35
Bioretention	18, 271	18, 249	0.06	0.05	0.11 (0.08, 0.12)	0.09 (0.07, 0.10)	0.22	0.20
Bioswale	20, 331	22, 364	0.06	0.12	0.11 (0.09, 0.12)	***0.19 (0.17, 0.20)****	0.24	0.32
Composite	9, 176	10, 153	0.17	0.08	0.36 (0.27, 0.40)	**0.13 (0.11, 0.15)**	0.69	0.23
Detention Basin	18, 250	19, 275	0.19	0.13	0.28 (0.25, 0.30)	**0.22 (0.19, 0.24)**	0.51	0.36
Green Roof	2, 22	5, 60	0.02	0.31	0.09 (0.02, 0.13)	0.50 (0.36, 0.72)***	0.21	1.20
Manufactured Device	45, 602	52, 641	0.09	0.06	0.19 (0.16, 0.22)	**0.12 (0.10, 0.13)**	0.46	0.30
Media Filter	28, 433	28, 403	0.10	0.05	0.18 (0.16, 0.19)	**0.09 (0.08, 0.10)**	0.32	0.17
Porous Pavement	13, 231	22, 389	0.09	0.05	0.15 (0.12, 0.16)	**0.09 (0.08, 0.09)**	0.29	0.14
Retention Pond	46, 657	48, 654	0.15	0.06	0.30 (0.27, 0.31)	**0.13 (0.12, 0.14)**	0.53	0.23
Wetland Basin	13, 282	13, 278	0.08	0.04	0.13 (0.11, 0.14)	**0.08 (0.07, 0.09)**	0.20	0.15
Wetland Channel	8, 167	8, 147	0.09	0.10	0.15 (0.13, 0.17)	0.14 (0.13, 0.17)	0.23	0.23

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

Figure 23. Box Plots of Influent/Effluent Orthophosphate Concentrations

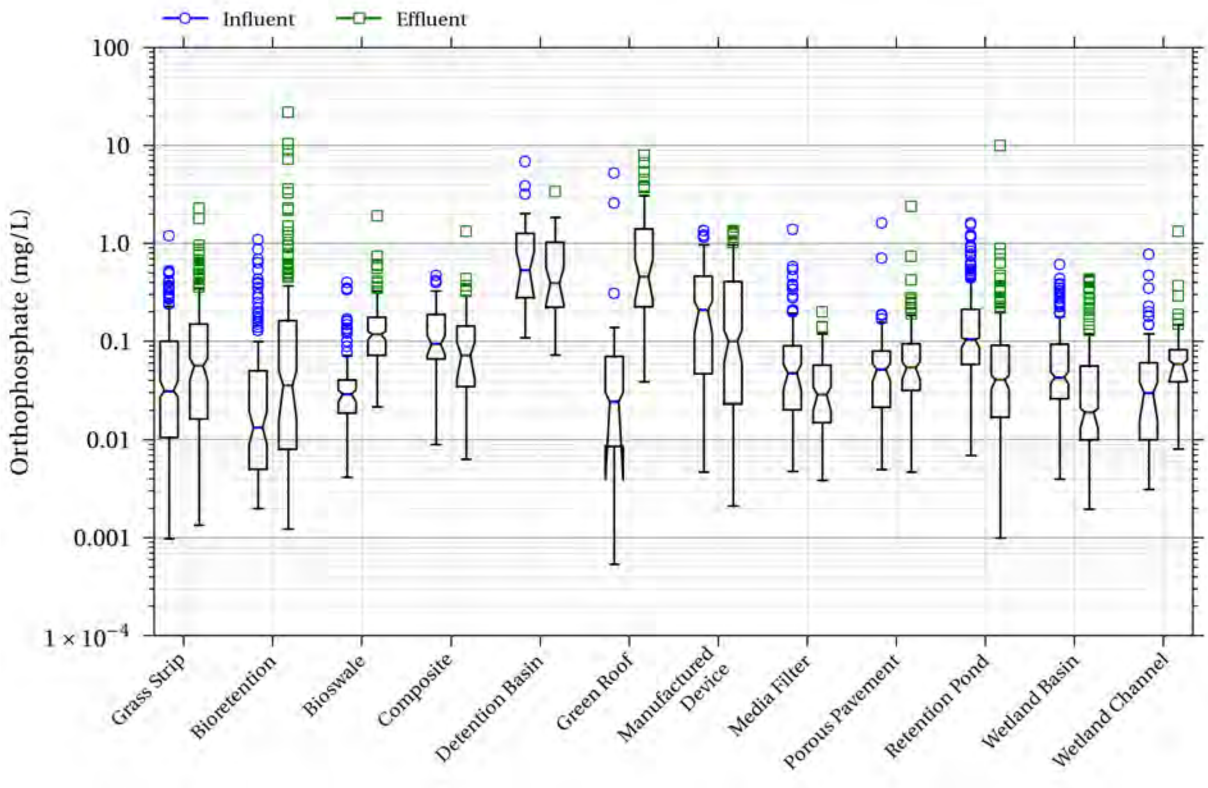

Table 23. Influent/Effluent Summary Statistics for Orthophosphate (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	14, 274	14, 223	0.01	0.02	0.03 (0.03, 0.04)	***0.06 (0.04, 0.07)****	0.10	0.15
Bioretention	13, 164	13, 164	0	0.01	0.01 (0.01, 0.02)	***0.04 (0.02, 0.05)****	0.05	0.16
Bioswale	5, 140	7, 197	0.02	0.07	0.03 (0.02, 0.03)	***0.12 (0.10, 0.13)****	0.04	0.18
Composite	4, 56	4, 47	0.07	0.03	0.09 (0.07, 0.12)	0.07 (0.04, 0.10)	0.19	0.14
Detention Basin	2, 31	2, 31	0.28	0.22	0.53 (0.28, 0.82)	0.39 (0.24, 0.56)	1.26	1.03
Green Roof	2, 21	4, 55	0.01	0.23	0.02 (0.003, 0.03)	0.46 (0.26, 0.68)***	0.23	1.41
Manufactured Device	14, 201	14, 185	0.05	0.02	0.21 (0.12, 0.25)	**0.10 (0.06, 0.13)****	0.46	0.41
Media Filter	9, 170	9, 157	0.02	0.01	0.05 (0.03, 0.06)	**0.03 (0.02, 0.03)****	0.09	0.06
Porous Pavement	7, 87	9, 112	0.02	0.03	0.05 (0.04, 0.06)	0.05 (0.04, 0.06)	0.08	0.09
Retention Pond	27, 361	28, 357	0.06	0.02	0.10 (0.09, 0.11)	**0.04 (0.03, 0.05)****	0.21	0.09
Wetland Basin	5, 166	5, 161	0.03	0.01	0.04 (0.04, 0.05)	**0.02 (0.01, 0.02)****	0.09	0.06
Wetland Channel	3, 84	3, 63	0.01	0.04	0.03 (0.02, 0.04)	***0.06 (0.04, 0.06)****	0.06	0.08

NA – not available or less than 3 studies for BMP/constituent.
*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

Figure 24. Box Plots of Influent/Effluent Dissolved Phosphorus Concentrations

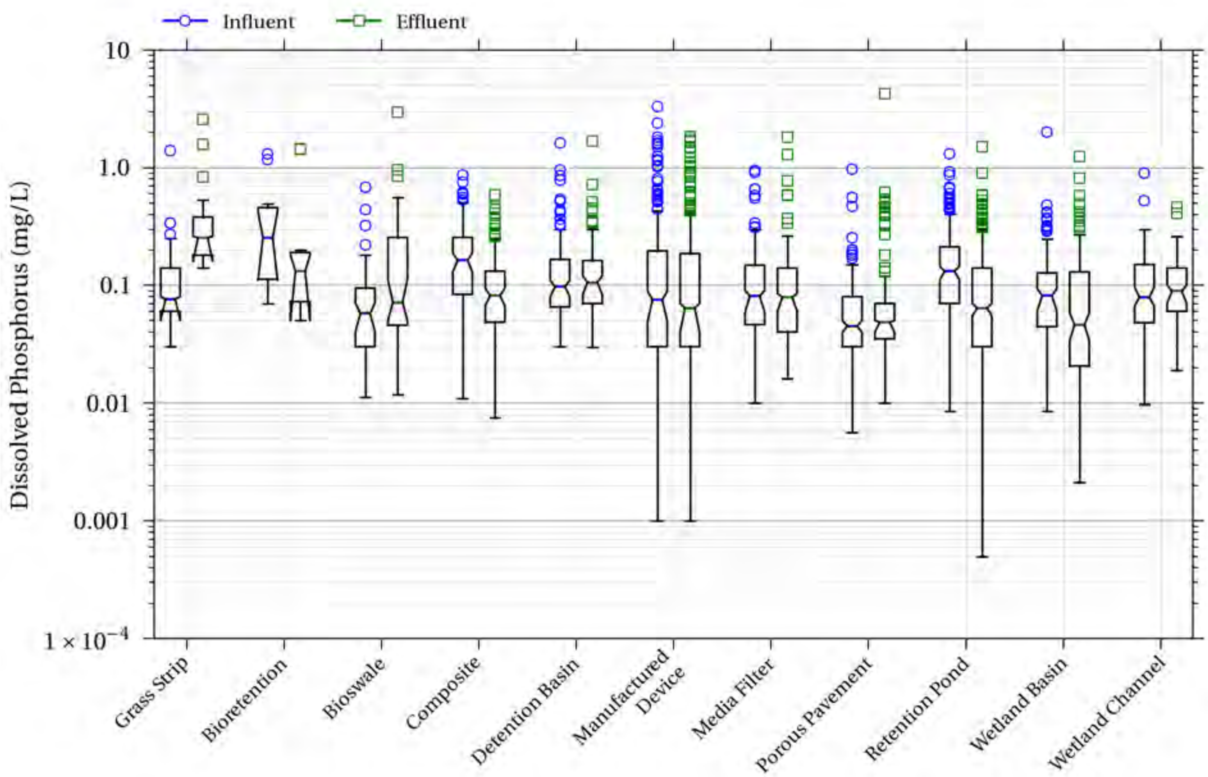

Table 24. Influent/Effluent Summary Statistics for Dissolved Phosphorus (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	3, 21	3, 17	0.06	0.18	0.08 (0.05, 0.08)	***0.25 (0.16, 0.26)***	0.14	0.38
Bioretention	1, 10	1, 10	0.11	0.07	0.25 (0.11, 0.43)	0.13 (0.05, 0.18)	0.46	0.19
Bioswale	6, 66	6, 52	0.03	0.05	0.06 (0.04, 0.07)	0.07 (0.05, 0.11)***	0.09	0.26
Composite	7, 143	8, 142	0.08	0.05	0.16 (0.13, 0.19)	**0.08 (0.06, 0.09)****	0.26	0.13
Detention Basin	8, 91	9, 94	0.07	0.07	0.10 (0.08, 0.11)	0.11 (0.08, 0.12)	0.17	0.16
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	16, 239	23, 265	0.03	0.03	0.08 (0.05, 0.09)	0.06 (0.04, 0.07)	0.20	0.19
Media Filter	13, 103	13, 96	0.05	0.04	0.08 (0.05, 0.09)	0.08 (0.06, 0.09)	0.15	0.14
Porous Pavement	4, 114	5, 125	0.03	0.03	0.04 (0.04, 0.05)	0.05 (0.04, 0.05)	0.08	0.07
Retention Pond	19, 379	20, 371	0.07	0.03	0.13 (0.11, 0.14)	**0.06 (0.06, 0.07)****	0.21	0.14
Wetland Basin	5, 114	5, 113	0.04	0.02	0.08 (0.06, 0.09)	**0.05 (0.03, 0.06)****	0.13	0.13
Wetland Channel	5, 92	5, 89	0.05	0.06	0.08 (0.07, 0.10)	0.09 (0.07, 0.10)	0.15	0.14

NA – not available or less than 3 studies for BMP/constituent.

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.

***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

2.4.2 Nitrogen

Figure 25. Box Plots of Influent/Effluent Total Nitrogen Concentrations

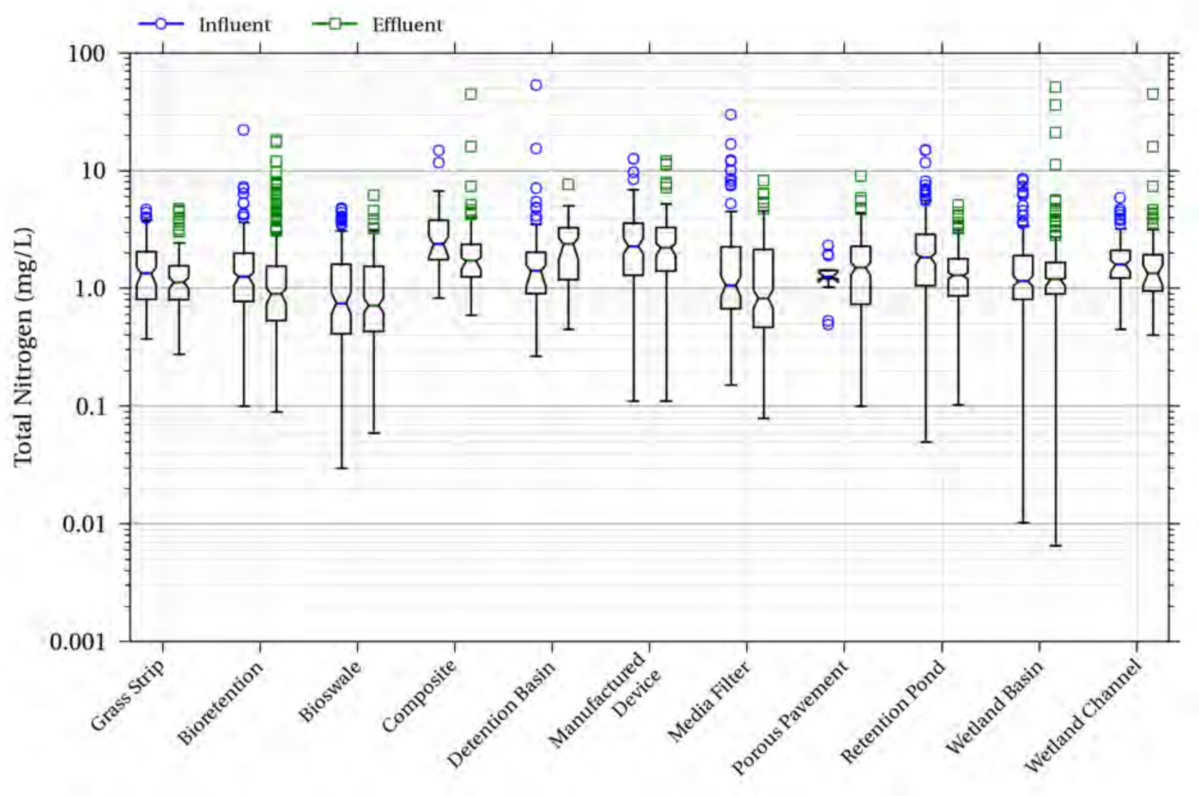

Table 25. Influent/Effluent Summary Statistics for Total Nitrogen (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	8, 138	8, 122	0.80	0.80	1.34 (1.06, 1.50)	1.13 (1.00, 1.23)	2.04	1.55
Bioretention	12, 218	12, 200	0.77	0.53	1.25 (1.06, 1.35)	**0.90 (0.74, 0.99)****	1.99	1.54
Bioswale	6, 181	8, 238	0.41	0.43	0.75 (0.60, 0.92)	0.71 (0.63, 0.82)	1.60	1.54
Composite	3, 53	4, 64	1.75	1.25	2.37 (1.85, 2.75)	**1.71 (1.45, 1.81)****	3.79	2.36
Detention Basin	3, 52	3, 64	0.90	1.18	1.40 (1.03, 1.57)	***2.37 (1.75, 2.69)**** *	2.02	3.27
Green Roof	NA	NA	NA	NA	NA	NA	NA	NA
Manufactured Device	8, 133	8, 117	1.29	1.40	2.27 (1.98, 2.65)	2.22 (1.90, 2.41)	3.58	3.29
Media Filter	5, 100	5, 87	0.67	0.46	1.06 (0.85, 1.25)	0.82 (0.68, 0.99)**	2.25	2.13
Porous Pavement	1, 14	9, 136	1.20	0.73	1.26 (1.13, 1.38)	1.49 (1.28, 1.65)	1.42	2.28
Retention Pond	19, 259	19, 272	1.05	0.86	1.83 (1.60, 1.98)	**1.28 (1.19, 1.36)****	2.87	1.78
Wetland Basin	6, 222	6, 223	0.80	0.89	1.14 (1.04, 1.28)	1.19 (1.04, 1.21)	1.90	1.66
Wetland Channel	5, 83	6, 88	1.22	0.95	1.59 (1.38, 1.78)	1.33 (1.05, 1.56)	2.10	1.92

NA – not available or less than 3 studies for BMP/constituent.
*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

Figure 26. Box Plots of Influent/Effluent Total Kjeldahl Nitrogen Concentrations

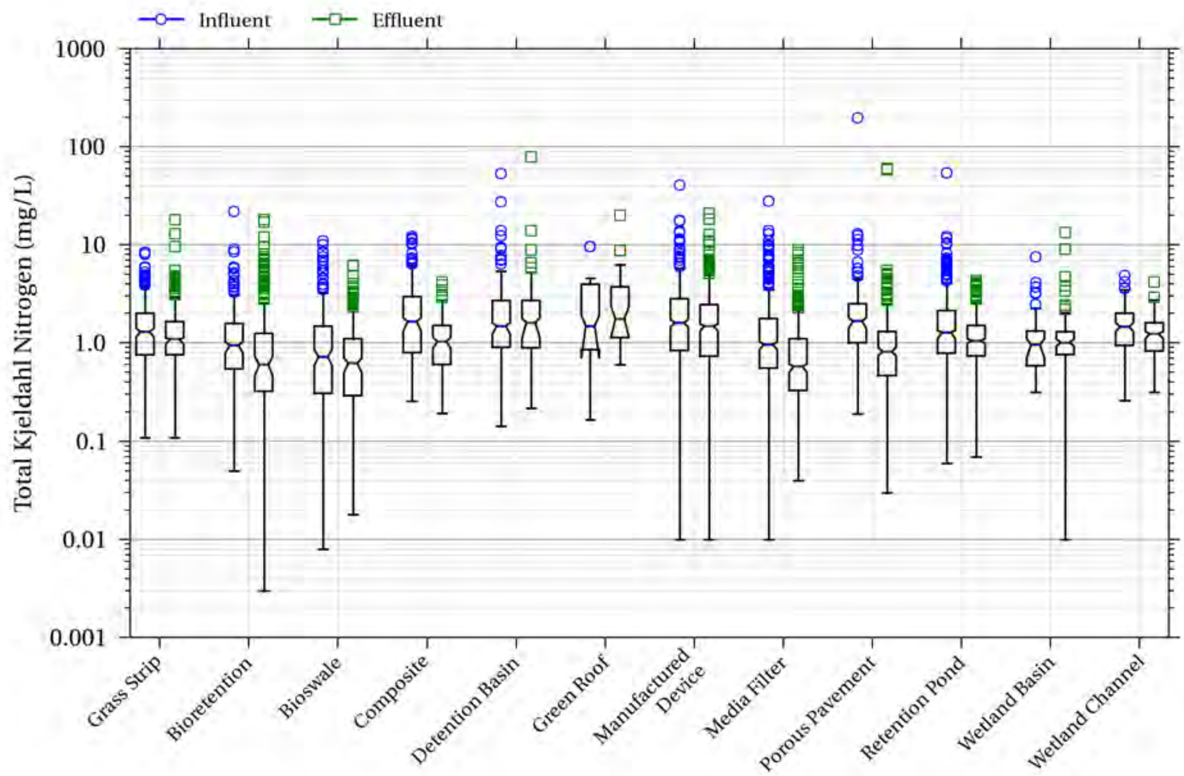

Table 26. Influent/Effluent Summary Statistics for Total Kjeldahl Nitrogen (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	19, 350	19, 272	0.75	0.75	1.29 (1.15, 1.41)	**1.09 (0.97, 1.12)**	2.00	1.64
Bioretention	14, 214	14, 201	0.54	0.32	0.94 (0.77, 1.04)	**0.60 (0.46, 0.72)****	1.58	1.25
Bioswale	17, 288	19, 324	0.31	0.29	0.72 (0.59, 0.85)	0.62 (0.50, 0.70)	1.48	1.10
Composite	7, 130	9, 145	0.79	0.60	1.64 (1.33, 1.80)	**1.02 (0.88, 1.14)****	2.96	1.50
Detention Basin	11, 175	12, 185	0.90	0.89	1.49 (1.22, 1.59)	1.61 (1.16, 1.78)	2.70	2.71
Green Roof	1, 15	3, 32	0.85	1.13	1.51 (0.70, 1.90)	1.75 (1.14, 2.35)	3.95	3.72
Manufactured Device	24, 390	31, 433	0.83	0.73	1.59 (1.44, 1.73)	1.48 (1.32, 1.55)	2.82	2.45
Media Filter	26, 411	25, 374	0.55	0.33	0.96 (0.85, 1.02)	**0.57 (0.50, 0.61)****	1.77	1.10
Porous Pavement	12, 224	23, 396	1.00	0.46	1.66 (1.40, 1.80)	**0.80 (0.74, 0.90)****	2.50	1.30
Retention Pond	36, 482	39, 496	0.78	0.73	1.28 (1.10, 1.33)	**1.05 (0.98, 1.10)****	2.13	1.50
Wetland Basin	6, 72	8, 184	0.58	0.76	0.95 (0.69, 1.10)	1.01 (0.92, 1.09)	1.32	1.29
Wetland Channel	6, 122	7, 139	0.94	0.83	1.45 (1.30, 1.60)	**1.23 (1.10, 1.30)****	2.00	1.60

NA – not available or less than 3 studies for BMP/constituent.
*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)
**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.
***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

Figure 27. Box Plots of Influent/Effluent NO_x as Nitrogen Concentrations

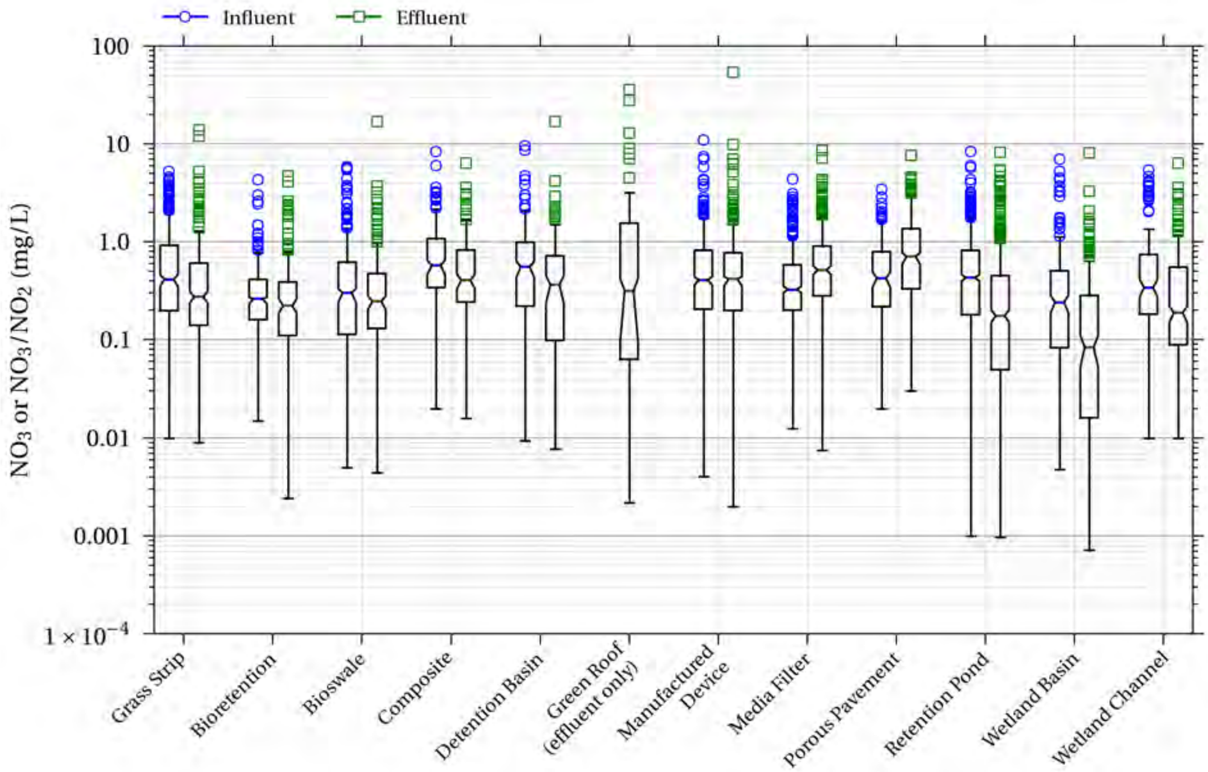

Table 27. Influent/Effluent Summary Statistics for NO_x as Nitrogen (mg/L)

BMP Type	Count of Studies and EMCs		25th Percentile		Median (95% Conf. Interval)*		75th Percentile	
	In	Out	In	Out	In	Out	In	Out
Grass Strip	20, 360	20, 287	0.20	0.14	0.41 (0.35, 0.46)	**0.27 (0.24, 0.31)****	0.92	0.61
Bioretention	17, 278	17, 259	0.16	0.11	0.26 (0.23, 0.27)	0.22 (0.19, 0.25)**	0.41	0.39
Bioswale	20, 335	22, 372	0.11	0.13	0.30 (0.24, 0.33)	0.25 (0.20, 0.28)	0.62	0.47
Composite	9, 157	10, 142	0.34	0.24	0.57 (0.45, 0.65)	**0.40 (0.33, 0.46)****	1.08	0.82
Detention Basin	13, 201	14, 213	0.22	0.10	0.55 (0.43, 0.63)	**0.36 (0.24, 0.45)****	0.99	0.72
Green Roof	2, 21	4, 55	0.07	0.06	0.39 (0.06, 0.68)	0.31 (0.10, 0.42)	0.89	1.55
Manufactured Device	33, 504	40, 546	0.20	0.20	0.41 (0.36, 0.44)	0.41 (0.35, 0.44)	0.82	0.77
Media Filter	27, 434	26, 391	0.20	0.28	0.33 (0.30, 0.35)	***0.51 (0.46, 0.57)******	0.58	0.90
Porous Pavement	13, 229	23, 401	0.22	0.33	0.42 (0.34, 0.49)	***0.71 (0.59, 0.77)******	0.79	1.36
Retention Pond	43, 639	43, 626	0.18	0.05	0.43 (0.40, 0.46)	**0.18 (0.15, 0.20)****	0.82	0.45
Wetland Basin	11, 245	11, 246	0.08	0.02	0.24 (0.19, 0.28)	**0.08 (0.05, 0.11)****	0.50	0.28
Wetland Channel	8, 149	8, 132	0.18	0.09	0.34 (0.27, 0.40)	**0.19 (0.15, 0.22)****	0.74	0.55

NA – not available or less than 3 studies for BMP/constituent.

*Computed using the BCa bootstrap method described by Efron and Tibishirani (1993)

**Hypothesis testing in Attachment 4 shows statistically significant decreases for this BMP category.

***Hypothesis testing in Attachment 4 shows statistically significant *increases* for this BMP category.

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4 ATTACHMENTS

Attachment 1. TSS Statistical Summary Report
Attachment 2. Bacteria Statistical Summary Report
Attachment 3. Metals Statistical Summary Report
Attachment 4. Nutrients Statistical Summary Report

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International Stormwater Best Management Practices (BMP) Database

BMP Performance Data Summary Table

Prepared by

Wright Water Engineers, Inc.
Geosyntec Consultants, Inc.

Under Support From
Water Environment Research Foundation
Federal Highway Administration
Environment and Water Resources Institute of the
American Society of Civil Engineers

November 2011

Disclaimer

The BMP Database ("Database") was developed as an account of work sponsored by the Water Environment Research Foundation (WERF), the American Society of Civil Engineers (ASCE)/Environmental and Water Resources Institute (EWRI), the American Public Works Association (APWA), the Federal Highway Administration (FHWA), and U.S. Environmental Protection Agency (USEPA) (collectively, the "Sponsors"). The Database is intended to provide a consistent and scientifically defensible set of data on Best Management Practice ("BMP") designs and related performance. Although the individuals who completed the work on behalf of the Sponsors ("Project Team") made an extensive effort to assess the quality of the data entered for consistency and accuracy, the Database information and/or any analysis results are provided on an "AS-IS" basis and use of the Database, the data information, or any apparatus, method, or process disclosed in the Database is at the user's sole risk. The Sponsors and the Project Team disclaim all warranties and/or conditions of any kind, express or implied, including, but not limited to any warranties or conditions of title, non-infringement of a third party's intellectual property, merchantability, satisfactory quality, or fitness for a particular purpose. The Project Team does not warrant that the functions contained in the Database will meet the user's requirements or that the operation of the Database will be uninterrupted or error free, or that any defects in the Database will be corrected.

UNDER NO CIRCUMSTANCES, INCLUDING CLAIMS OF NEGLIGENCE, SHALL THE SPONSORS OR THE PROJECT TEAM MEMBERS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, OR CONSEQUENTIAL DAMAGES INCLUDING LOST REVENUE, PROFIT OR DATA, WHETHER IN AN ACTION IN CONTRACT OR TORT ARISING OUT OF OR RELATING TO THE USE OF OR INABILITY TO USE THE DATABASE, EVEN IF THE SPONSORS OR THE PROJECT TEAM HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

The Project Team's tasks have not included, and will not include in the future, recommendations of one BMP type over another. However, the Project Team's tasks have included reporting on the performance characteristics of BMPs based upon the entered data and information in the Database, including peer reviewed performance assessment techniques. Use of this information by the public or private sector is beyond the Project Team's influence or control. The intended purpose of the Database is to provide a data exchange tool that permits characterization of BMPs solely upon their measured performance using consistent protocols for measurements and reporting information.

The Project Team does not endorse any BMP over another and any assessments of performance by others should not be interpreted or reported as the recommendations of the Project Team or the Sponsors.

International Stormwater BMP Database Performance Data Summary Table

In 2010, the Water Environment Research Foundation (WERF), Federal Highway Administration (FHWA), and the American Society of Civil Engineers' Environmental and Water Resources Institute (EWRI) co-sponsored a comprehensive stormwater best management practice (BMP) performance analysis technical paper series relying on data contained in the International Stormwater BMP Database (BMP Database).[1] The BMP Database is a publically-available research database that contains results of stormwater BMP studies independently conducted and provided by researchers throughout the U.S. and several other countries. The BMP Database contains performance data for over 450 BMP studies, including over 265,000 water quality records, along with precipitation and flow data. The database is currently limited to post-construction, permanent stormwater BMPs in urban areas. The project is a long-term, multi-faceted effort that includes guidance on BMP monitoring, standardized database reporting information, and recommended performance analysis protocols.

During 2010-2011, a WERF Research Digest and performance analysis technical paper series were completed, providing information on BMP performance for these stormwater parameter categories:

- Nutrients
- Solids
- Metals
- Fecal indicator bacteria
- Runoff volume

This short paper provides a tabular summary of data used in these technical summaries. The WERF Research Digest (available through www.werf.org) or the underlying individual technical summaries should be obtained (www.bmpdatabase.org) for more detailed information.

For each pollutant category analyzed in the technical paper series, a variety of statistics have been completed. For a quick reference, Table 1 provides the median influent and effluent concentrations and associated 95% confidence limits for the median values. Important considerations for use of this table include:

[1] The BMP Database is a long-term project that began in 1994 through the vision of members active in the Urban Water Resources Research Council of ASCE and the leadership of EPA. Funded for many years by EPA, the project is now supported by a coalition of partners including WERF, FHWA, EWRI and the American Public Works Association (APWA).

- The median concentrations in this table are based on a “storm-weighted” approach. There are several viable approaches to evaluating data in the BMP Database, with the two approaches used in previous BMP Database summaries being the “BMP-weighted” and “storm-weighted” approaches. The BMP-weighted approach represents the influent and effluent for each BMP with one value representing the central tendency for each BMP, whereas the storm-weighted approach combines all of the storm events for the BMPs in each category and analyzes the overall storm-based data sets. (Each storm is weighted equally in the storm event based approach.) The storm-weighted approach has been selected for this summary because it provides a much larger number of values for statistical analysis, while retaining the overall variability of storm event concentrations. Some modifications to this approach were used for fecal indicator bacteria, as described in the fecal indicator bacteria technical paper.

- For simplicity, this table does not show number of samples or the number of BMP studies associated with each BMP-constituent concentration; however, this information is provided in the individual technical papers. Some BMP types such as wetland basins and channels, porous pavement and bioretention have much more limited data sets for a number of parameters. Assumptions related to data screening (i.e., excluded studies) are also provided in the individual pollutant summaries.

- Information regarding statistically significant differences between influent and effluent values is provided in the individual technical papers. Comparison of the confidence limits for the medians can provide an approximate measure of significance of differences between the values. Specifically, if the 95% confidence intervals for the inflow and outflow medians do not overlap, the medians are, roughly, significantly different at about a 95% confidence level. More robust hypothesis testing has also been provided in attachments to the solids, nutrients and metals summaries. Specifically, the Mann-Whitney test for independent data sets (unpaired samples) and the Wilcoxon signed rank test (using log-transformed data) for paired inflow-outflow data have been provided.

- Manufactured devices included in the BMP Database incorporate a broad range of unit treatment processes that may result in widely varying performance for individual devices within this broad category. For example, some manufactured devices rely on hydrodynamic gravitational separation only, some provide filtration, others provide peak attenuation, and some provide a treatment train of multiple unit processes. The “manufactured device” category summarized in Table 1 provides only a gross characterization of the range of performance provided by this broad category. More refined analysis based on finer segmentation by unit treatment processes is necessary to draw conclusions for a particular type of device. As a result, the primary use of the data summaries at the broad category level is only for general information related to ranges of effluent concentrations potentially achievable with this general category of BMPs. For example, none of the manufactured devices analyzed for fecal indicator bacteria would be capable of achieving an instream primary contact recreation standard; whereas, some types of manufactured devices can reduce total suspended solids concentrations below 30 mg/L. The on-line BMP Database search tool (www.bmpdatabase.org) could then be

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used as a follow-up to refine such broad, general observations and further evaluate how individual manufactured devices performed.

- Rounding in this table may differ slightly from the underlying data summaries.
- Some analyses (e.g., dissolved metals) are affected by large numbers of non-detects, which may not be fully apparent in this condensed summary table, although some flagging has been provided, as described in the table footnotes. Methods used to address non-detects (censored data) are described in each technical memorandum.
- The BMP Database data set is continually growing; therefore, the statistics reported in this table will change as the data set grows. The analysis data set for Table 1 is based on the August 2010 version of the BMP Database for all parameters except metals, which is based on the December 2010 version of the BMP Database.
- A table key defining acronyms and describing how to interpret the reported data is provided following the two-page table.

Users of this storwater quality table should be aware that pollutant load reductions can be achieved by reducing pollutant concentrations, surface runoff volumes, and/or a combination of both. Using bioretention as an example, the existing BMP Database dataset does not show a statistically significant reduction in nitrate concentrations; however, nitrate loads are expected to be reduced at bioretention sites that effectively reduce volumes discharged to surface waters.

Table 1. Summary of Inflow and Outflow Data by BMP Category (Median Values with 95% Confidence Limits for the Median Values)

		BR	BS	DB	BI	MD	MF	PP	RP	WB	WC
TSS (mg/L)	In	50 (39-68)	21 (15-26)	64 (47-76)	51 (45-59)	41 (36-46)	42 (36-48)	22 (16-28)	60 (49-70)	20 (16-26)	31 (22-42)
	Ef	10 (6-13)	10 (7-11)	24 (19-27)	18 (14-20)	23 (19-25)	8 (6-8)	14 (10-17)	12 (10-12)	8 (6-9)	14 (8-16)
TDS (mg/L)	In	NA	77 (66-79)	100 (83-129)	46 (34-52)	126 (96-165)	38 (27-40)	NA	104 (79-124)	NA	NA
	Ef	NA	70 (56-79)	110 (79-121)	90 (76-98)	87 (72-122)	54 (46-58)	NA	167 (130-181)	NA	NA
Tur-bidity (NTU)	In	NA	NA	39 (27-50)	NA	6 (5-7)	25 (14-27)	NA	17 (10-20)	NA	NA
	Ef	NA	NA	19 (15-26)	NA	4 (4-5)	5 (4-6)	NA	1 (1-1)	NA	NA
Phos-phorus (Total) (mg/L)	In	0.14 (0.12-0.15)	0.26 (0.21-0.26)	0.16 (0.14-0.19)	0.12 (0.09-0.16)	0.22 (0.16-0.22)	0.19 (0.16-0.20)	0.12 (0.09-0.13)	0.27 (0.23-0.29)	0.12 (0.10-0.12)	0.18 (0.15-0.22)
	Ef	0.13 (0.10-0.16)	0.21 (0.18-0.23)	0.21 (0.16-0.23)	0.20 (0.17-0.20)	0.14 (0.11-0.14)	0.10 (0.08-0.11)	0.10 (0.07-0.11)	0.11 (0.08-0.11)	0.08 (0.06-0.08)	0.14 (0.11-0.15)
Ortho-P (mg/L)	In	0.04 (0.01-0.04)	NA	0.04 (0.03-0.04)	0.03 (0.03-0.03)	0.21 (0.13-0.25)	0.04 (0.03-0.05)	NA	0.11 (0.09-0.13)	0.05 (0.04-0.06)	0.05 (0.02-0.05)
	Ef	0.16 (0.07-0.45)	NA	0.08 (0.05-0.10)	0.12 (0.11-0.13)	0.12 (0.07-0.13)	0.02 (0.02-0.03)	NA	0.04 (0.04-0.05)	0.02 (0.02-0.03)	0.06 (0.03-0.07)
Phos-phorus (D) (mg/L)	In	NA	0.09 (0.07-0.10)	0.08 (0.06-0.08)	0.09 (0.06-0.11)	0.08 (0.05-0.11)	0.10 (0.07-0.11)	NA	0.11 (0.08-0.11)	0.08 (0.05-0.09)	0.08 (0.07-0.10)
	Ef	NA	0.09 (0.06-0.11)	0.23 (0.16-0.26)	0.30 (0.21-0.35)	0.07 (0.05-0.08)	0.09 (0.08-0.11)	NA	0.06 (0.04-0.06)	0.04 (0.03-0.04)	0.09 (0.07-0.10)
Nitrogen (Total) (mg/L)	In	1.38 (1.25-1.59)	1.40 (1.13-1.62)	NA	0.59 (0.50-0.63)	2.25 (1.98-2.65)	1.02 (0.85-1.39)	NA	1.75 (1.50-1.90)	1.14 (1.05-1.28)	1.62 (1.38-1.89)
	Ef	1.09 (0.98-1.24)	2.45 (1.77-2.75)	NA	0.62 (0.54-0.66)	2.21 (1.85-2.34)	0.77 (0.67-0.91)	NA	1.27 (1.16-1.35)	1.21 (1.06-1.21)	1.78 (1.40-2.00)
TKN (mg/L)	In	1.10 (0.92-1.20)	1.40 (1.11-1.42)	1.50 (1.40-1.60)	0.70 (0.46-0.86)	1.60 (1.43-1.75)	1.20 (0.92-1.25)	1.50 (1.10-2.20)	1.30 (1.15-1.36)	0.99 (0.62-1.05)	1.60 (1.20-1.70)
	Ef	1.01 (0.84-1.30)	1.60 (1.20-1.80)	1.30 (1.10-1.40)	0.50 (0.43-0.62)	1.51 (1.40-1.60)	0.71 (0.61-0.80)	1.15 (0.91-1.35)	1.10 (1.00-1.15)	1.06 (0.95-1.13)	1.20 (0.90-1.30)
Nitrate (NO_x) (mg/L)	In	0.30 (0.26-0.35)	0.50 (0.36-0.53)	0.63 (0.48-0.68)	0.30 (0.25-0.35)	0.38 (0.33-0.40)	0.34 (0.29-0.38)	0.66 (0.49-0.77)	0.40 (0.32-0.42)	0.21 (0.15-0.23)	0.55 (0.39-1.15)
	Ef	0.23 (0.17-0.27)	0.38 (0.22-0.47)	0.42 (0.33-0.51)	0.28 (0.23-0.30)	0.43 (0.38-0.45)	0.53 (0.45-0.63)	1.00 (0.83-1.23)	0.15 (0.11-0.16)	0.08 (0.05-0.10)	0.62 (0.33-0.96)
TOC (mg/L)	In	NA	13 (11-17)	9 (8-10)	13 (11-20)	27 (23-28)	12 (8-14)	NA	14 (13-15)	NA	NA
	Ef	NA	13 (11-16)	13 (11-13)	13 (11-14)	23 (19-26)	11 (8-12)	NA	11 (10-11)	NA	NA
Fecal Coliform (#/100 mL)	In	NA	NA	749 (303-7563)	2628 (1116-18620)	993 (499-2187)	605 (179-1112)	NA	1971 (521-2673)	NA	NA
	Ef	NA	NA	813 (196-3647)	4724 (2852-18572)	2462 (1438-3431)	216 (101-464)	NA	133 (35-411)	NA	NA

Metals (µg/L)		BR	BS	DB	BI	MD	MF	PP	RP	WB	WC
As D	In	NA	0.5* (0.5-0.6)	1.1 (0.8-1.2)	0.6* (0.5-0.7)	NA	0.5 (0.5-0.6)	NA	NA	NA	NA
	Ef	NA	0.6* (0.5-0.7)	1.1 (0.8-1.2)	0.8* (0.5-1.0)	1.0 (1.0-1.2)	0.6 (0.5-0.6)	NA	NA	NA	NA
As T	In	NA	1.7 (1.2-1.9)	2.5 (1.9-2.6)	0.9 (0.6-1.0)	1.3 (1.0-1.6)	1.0 (0.8-1.2)	DL	1.3 (1.0-1.8)	NA	NA
	Ef	NA	1.2 (1.0-1.3)	1.8 (1.2-1.8)	1.0 (0.5-1.0)	1.9 (1.3-2.4)	0.9 (0.7-1.0)	DL	1.0 (0.5-1.0)	NA	NA
Cd D	In	NA	0.2 (0.2-0.3)	0.5* (0.5-0.5)	0.2 (0.2-0.2)	1.0* (1.0-1.0)	0.2 (0.2-0.2)	0.1* (0.1-0.1)	0.3* (0.3-0.3)	0.4* (0.1-0.5)	NA
	Ef	NA	0.2 (0.1-0.2)	0.5* (0.5-0.5)	0.2 (0.1-0.2)	1.0* (0.5-1.0)	0.2 (0.1-0.2)	0.1* (0.1-0.1)	0.1* (0.1-0.1)	0.5* (0.1-0.5)	NA
Cd T	In	NA	0.5 (0.4-0.5)	0.5* (0.5-0.5)	0.5 (0.4-0.6)	1.0* (1.0-1.0)	0.4 (0.3-0.4)	DL	0.6 (0.5-0.8)	0.3 (0.2-0.3)	2.4* (0.5-2.5)
	Ef	NA	0.3 (0.3-0.3)	0.5* (0.5-0.5)	0.2 (0.2-0.2)	1.0* (0.6-1.0)	0.2 (0.1-0.2)	DL	0.4 (0.3-0.5)	0.5 (0.1-0.5)	0.5* (0.5-0.5)
Cr D	In	NA	1.3 (1.0-1.4)	2.6 (1.4-3.1)	1.9 (1.4-2.1)	2.5 (2.5-2.5)	1.0 (1.0-1.0)	DL	2.0 (1.0-2.0)	NA	NA
	Ef	NA	1.2 (1.0-2.7)	1.9 (1.2-2.0)	1.6 (1.2-1.7)	2.5 (2.5-2.5)	1.0 (1.0-1.0)	DL	1.0 (1.0-1.0)	NA	NA
Cr T	In	NA	2.9 (1.8-5.8)	6.7 (4.9-7.5)	4.9 (3.8-5.6)	3.6 (2.5-4.0)	2.3 (1.6-2.5)	DL	5.0 (4.0-5.0)	NA	4.5 (2.7-5.0)
	Ef	NA	2.2 (1.5-3.3)	3.2 (2.2-3.5)	2.7 (2.3-3.3)	2.6 (2.5-3.5)	1.0 (1.0-1.0)	DL	2.0 (1.0-2.0)	NA	4.0 (1.0-4.0)
Cu D	In	NA	8.9 (7.9-11.0)	5.3 (3.7-6.9)	11.1 (8.7-13.0)	7.0 (6.0-8.0)	5.4 (4.5-6.5)	5.5 (3.8-5.6)	7.5 (7.0-8.2)	5.9 (4.8-8.0)	NA
	Ef	NA	7.9 (6.7-9.2)	4.8 (3.0-5.3)	5.3 (4.6-5.9)	6.0 (5.0-7.0)	4.2 (3.6-5.3)	6.0 (5.6-7.0)	5.0 (4.0-5.0)	5.0 (5.0-5.5)	NA
Cu T	In	18 (12-23)	12 (10-15)	10 (6-10)	24 (20-27)	14 (12-15)	15 (13-15)	13 (11-19)	10 (10-10)	6 (5-7)	10 (6-10)
	Ef	9 (6-11)	8 (7-9)	7 (5-9)	7 (6-8)	11 (9-12)	7 (5-8)	10 (9-11)	6 (5-6)	4 (3-4)	8 (5-10)
Pb D	In	NA	1.2 (1.0-1.4)	1.9* (1.0-2.5)	1.0 (1.0-1.0)	5.0* (3.4-5.0)	1.0 (1.0-1.0)	DL	1.8* (1.5-2.7)	1.0 (0.5-1.0)	9.0 (0.5-12)
	Ef	NA	1.1 (1.0-2.1)	2.0* (1.0-2.5)	0.5 (0.5-0.5)	2.6* (1.5-3.4)	1.0 (1.0-1.0)	DL	1.5* (1.0-1.5)	1.0 (1.0-2.0)	6.4 (0.5-25)
Pb T	In	NA	4.3 (3.4-6.4)	10.0 (5.0-10.0)	8.6 (6.3-11.0)	7.9 (5.9-12.0)	10.0 (6.9-10.0)	5.9 (5.0-7.6)	10.0 (8.0-10.0)	2.0 (1.6-2.3)	10.0 (10.0-10.0)
	Ef	NA	2.0 (2.0-2.0)	5.0 (2.5-7.9)	2.0 (1.3-2.2)	5.0 (5.0-5.0)	1.5 (1.1-1.5)	2.5 (2.5-2.5)	3.0 (2.0-3.0)	1.0 (1.0-1.0)	6.4 (3.6-10.0)
Ni D	In	NA	4.3 (2.0-4.5)	2.6 (2.0-3.7)	2.7 (2.1-2.9)	2.0* (1.0-2.0)	2.0 (2.0-2.0)	1.0* (1.0-1.0)	10.0* (1.6-10.0)	NA	NA
	Ef	NA	2.0 (2.0-2.0)	2.6 (2.0-3.2)	2.1 (2.0-2.2)	2.4* (2.0-2.8)	2.0 (2.0-2.0)	0.5* (0.5-0.5)	10.0* (2.3-10.0)	NA	NA
Ni T	In	NA	6.9 (4.8-9.6)	6.5 (5.0-10.0)	4.9 (4.3-5.3)	5.0 (3.0-5.5)	3.6 (3.2-4.2)	2.8 (2.5-3.3)	6.0 (4.0-7.7)	NA	4.5 (3.0-10.0)
	Ef	NA	3.0 (2.4-4.3)	3.7 (2.4-4.5)	2.9 (2.4-3.2)	5.0 (4.0-5.0)	2.3 (2.0-2.8)	1.8 (1.6-2.1)	2. 8 (2.1-5.0)	NA	3.0 (2.0-3.0)
Zn D	In	NA	45 (35-56)	15 (9-17)	39 (33-47)	47 (37-58)	52 (37-60)	12 (9-13)	23 (20-28)	45 (35-66)	10* (10-10)
	Ef	NA	25 (22-29)	13 (8-17)	14 (11-18)	54 (45-64)	12 (9-17)	7 (6-9)	10 (10-10)	19 (10-23)	10* (10-10)
Zn T	In	74 (66-94)	40 (30-40)	66 (40-107)	99 (80-110)	90 (79-97)	90 (80-101)	62 (49-81)	53 (49-60)	52 (45-60)	30 (20-30)
	Ef	20 (10-26)	30 (30-30)	24 (15-35)	24 (17-27)	60 (53-65)	15 (15-20)	18 (15-20)	20 (17-20)	20 (16-24)	15 (11-20)

Table Notes

Explanation of Data Provided:

Table Entry			Explanation
Zn T	In	74	Median influent total zinc value
		(66-94)	95% confidence interval for median influent zinc value
	Ef	20	Median effluent total zinc value
		(10-26)	95% confidence interval for median effluent zinc value

* = Greater than 50% non-detects in the influent
NA = Not available for analysis
DL = Data set has greater than 80% non-detects; summary statistics have been excluded from this table

BMP Type:
BR = Bioretention (with underdrains)
BS = Biofilter - grass swale
DB = Detention basin (dry, grass-lined)
BI = Biofilter - grass strip
MD = Manufactured device (all categories)
MF = Media filter (all categories)
PP = Permeable pavement (all categories)
RP = Retention pond (wet pond)
WB = Wetland basin
WC = Wetland channel

Sample Type:
In = influent
Ef = effluent

Units:
mg/L = milligrams per liter
μg/L = micrograms per liter (for metals)
NTU = nephelometric turbidity units (for turbidity)
#/100 mL = colonies per 100 milliliters (for bacteria)

Parameter-related Acronyms:
TSS = Total suspended solids
TDS = Total dissolved solids
Ortho-P = Phosphorus, Orthophosphate as Phosphorus
TKN = Total Kjeldahl nitrogen
TOC = Total organic carbon
As = Arsenic
Cd = Cadmium
Cr = Chromium
Cu = Copper
Pb = Lead
Ni = Nickel
Zn = Zinc

Sample Fraction:

D = Dissolved
T = Total

International Stormwater BMP Database 2010 Bacteria Data Set
Prepared by Wright Water Engineers and Geosyntec Consultants, July 19, 2010.

Spreadsheets Included in this Workbook
All Data: Contains a basic statistical summary of event-based bacteria data reported in the BMP Database for inflows and outflows to BMPs. Summary in "horizontal format" with all inflow storm events on one row per BMP study and all outflow events on one row per BMP study. This format is not conducive to additional statistical analysis; it is provided as a simple summary.

E. coli: Contains analysis data set for E. coli, screened based on minimum sample size. Database-style "vertical" format conducive to import into statistical programs.

Fecal Coliform: Contains analysis data set for E. coli, screened based on minimum sample size. Database-style "vertical" format conducive to import into statistical programs.

Enterococcus: Contains analysis data set for E. coli, screened based on minimum sample size. Database-style "vertical" format conducive to import into statistical programs.

MD Unit Processes: Identifies the unit processes identified for manufactured devices in the data set.

Censored Data: Counts non-detects and values greater than the upper quantitation limit, for general information only.

Analysis Data Set
For a BMP study to be included, a minimum of 5 outflow events must have been sampled.
For BMP studies with 5 or more outflow events but fewer than 5 inflow events, the inflow data is excluded from analysis.
Total coliform and fecal strep data are not included in detailed statistical analysis.
Values reported at the upper or lower quantitation limits have been analyzed using the quantitation limit (simple substitution method).
For sampling events with multiple grab samples, the median has been calculated to represent the storm event.
A limitation of this data set is that many of the BMP studies are based on grab samples, as opposed to EMCs.
Hamilton Ecoroof green roof studies that are divided into separate studies for 2001 and 2002 in the master database but have been joined into one data set for purposed of this analysis.

BMP Category Level Analysis
Composite BMP types are not included. (Only one of these has 5 or more samples.)
Only Fecal Coliform had adequate numbers of studies to conduct comparisons among BMP categories.
BMP category comparisons include only these BMP categories: DB (11), GS (9), MD (9), MF (14), RP (6). Be aware that unit treatment processes in the manufactured device category may vary substantially within this category.

Values Used for Threshold Comparisons

	EPA Primary Contact Std
Enterococcus	33/100 mL freshwater and 35/100 mL marine
Escherichia coli	126/100 mL
Fecal Coliform	200/100 mL (old EPA-recommended indicator)

INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR VENTURA COUNTY

Richard R. Horner†

ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in Ventura County, California will be reissued in 2007. The draft permit includes provisions for requiring the use of low impact development practices (LID) for certain kinds of development and redevelopment projects. Using six representative development project case studies, the author investigated the practicability and relative benefits of the permit's LID requirements. The results showed that (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; (2) Effective Impervious Area (EIA) can practicably be capped at three percent, a standard more protective than that proposed in the draft permit; and (3) in five out of six case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

† Richard R. Horner, Ph.D., Research Associate Professor, University of Washington Departments of Civil and Environmental Engineering and Landscape Architecture; Adjunct Associate Professor, University of Washington Center for Urban Horticulture

INTRODUCTION

The Assessment in Relation to Municipal Permit Conditions

This purpose of this study is to investigate the relative water quality and water reuse benefits of three levels of storm water treatment best management practices (BMPs): (1) basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), (2) commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and (3) low-impact development (LID) practices. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development covered by the Ventura County Municipal Separate Storm Sewer System Permit.

Low-impact development methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, and treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. For the study's purposes, verification of the practicability and utility of LID practices was based on a modified version of the Planning and Land Development Program (Part 4, section E) in the Draft Ventura County Municipal Separate Storm Sewer System Permit ("Draft Permit"). The Draft Permit requires that Effective Impervious Area (EIA) of certain types of new development and redevelopment projects be limited to five percent of total development project area. EIA is defined as hardened surface hydrologically connected via sheet flow or a discrete hardened conveyance to a drainage system or receiving water body. (Draft Permit p. 50) The study modified this requirement to three percent, as a way to test both the feasibility of meeting the higher, five percent standard in the draft permit and because as the lower, three percent EIA is essential to protect the Ventura County aquatic environment (see Attachment A).

The Draft Permit further requires minimizing the overall percentage of impervious surfaces in new development and redevelopment projects to support storm water infiltration. The Draft Permit also directs an integrated approach to minimizing and mitigating storm water pollution, using a suite of strategies including source control, LID, and treatment control BMPs. (Draft Permit p. 50) It is noted in this section of the document that impervious surfaces can be rendered "ineffective" if runoff is dispersed through properly designed vegetated swales. In testing the practicability of the draft permit's requirements and a three percent EIA standard, this study broadened this approach to encompass not only vegetated swales (channels for conveyance at some depth and velocity) but also vegetated filter strips (surfaces for conveyance in thin sheet flow) and bioretention areas (shallow basins with a range of vegetation types in which runoff infiltrates through soil either to groundwater or a subdrain for eventual surface discharge). The Draft Permit's stipulation of "properly designed" facilities was interpreted to entail, among other requirements, either determination that existing site soils can support runoff reduction through infiltration or that soils will be amended using accepted LID techniques to attain this objective. Finally, the study further broadened implementation options to include water harvesting (collection and storage for use in, for example, irrigation or gray water systems), roof downspout infiltration trenches, and porous pavements.

The Draft permit was interpreted to require management of EIA, other impervious area (what might be termed Not-Connected Impervious Area, NCIA), and pervious areas as follows:

- Runoff from EIA is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge.

- NCIA must be drained onto a properly designed vegetated surface or its runoff managed by one of the other options discussed in the preceding paragraph. To the extent NCIA runoff is not eliminated prior to discharge from the site in one of these ways, it is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge.

- Runoff from pervious areas is subject to treatment control and the Draft Permit's Hydromodification Mitigation Control requirements before discharge. This provision applies to pervious areas that both do and do not receive drainage from NCIA.

Where treatment control BMPs are required to manage runoff from the site, the Draft Permit's Volumetric or Hydrodynamic (Flow Based) Treatment Control design bases were assumed to apply. The former basis applies to storage-type BMPs, like ponds, and requires capturing and treating either the runoff volume from the 85th percentile 24-hour rainfall event for the location, the volume of annual runoff to achieve 80 percent or more volume treatment, or the volume of runoff produced from a 0.75 inch storm event. The calculations in this analysis used the 0.75-inch quantity. The Hydrodynamic basis applies to flow-through BMPs, like swales, and requires treating the runoff flow rate produced from a rain event equal to at least 0.2 inches per hour intensity (or one of two other approximately equivalent options).

Scope of the Assessment

With respect to each of the six development case studies, three assessments were undertaken: a baseline scenario incorporating no storm water management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID storm water management strategies.

To establish a baseline for each case study, annual storm water runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no storm water management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies.

The first group of calculations estimated the extent to which basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site.

The second group of calculations estimated the extent to which commonly used soil-based BMPs and LID site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates. When evaluating LID strategies, it was presumed that EIA would be limited to three percent and runoff from EIA, NCIA, and pervious areas would be managed as indicated above. The assessment of basins, biofiltration, and low-impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that could work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedances of California Toxics Rule (CTR) acute saltwater criteria for copper and zinc.

The results of this analysis show that:

- Developments implementing no post-construction BMPs result in storm water runoff volume and pollutant loading that are substantially increased, and recharge rates that are substantially decreased, compared to pre-development conditions.

- Developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but storm water runoff volume and recharge rates are similar to developments with no BMPs.

- Developments implementing traditional basins and biofilters, and even more so low-impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

- Typical development categories, ranging from single family residential to large commercial, can feasibly implement low-impact post-construction BMPs designed in compliance with the draft permit's requirements, as modified to include a lower, three percent EIA requirement.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, draws conclusions, and makes recommendations relative to the feasibility of utilizing low-impact development practices in Ventura County developments.

CASE STUDIES

Six case studies were selected to represent a range of urban development types considered to be representative of coastal Southern California, including Ventura County. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR) and a sizeable commercial retail installation (COMM).[1]

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average.[2] The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide.

Exclusive of the COMM case, the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees). For the COMM scenario, the hypothetical total impervious cover was enlarged by 10 percent to represent the landscaping, on the belief that a typical retail commercial establishment would typically be mostly impervious.

Table 1 (page 5) summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

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[1] Building permit records from the City of San Marcos in San Diego County provided data on total site areas for the first four case studies, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies using assumptions described herein. Larger developments were not represented in the sampling of building permits from the San Marcos database. To take larger development projects into account in the subsequent analysis, the two larger scale case studies were hypothesized. The Lg-SFR scenario scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The hypothetical COMM scenario consisted of a building with a 2-acre footprint and 500 parking spaces. As with the smaller-scale cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, as described herein.

[2] J. Gibbons, *Parking Lots*, NONPOINT EDUCATION FOR MUNICIPAL OFFICERS, Technical Paper No. 5 (1999) (http://nemo.uconn.edu/tools/publications/tech_papers/tech_paper_5.pdf).

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
No. buildings	11	23	1	1	1000	1
Total area (ft^2)	476,982	132,227	33,669	92,612	5,749,000	226,529
Roof area (ft^2)	184,338	34,949	3,220	7,500	1,519,522	87,120
No. parking spaces	438	-	33	37	-	500
Parking area (ft^2)	77,088	-	5808	6512	-	88,000
Access road area (ft^2)	22,212	-	6097	6456	-	23,732
Walkway area (ft^2)	33,960	10,656	1362	2078	463,289	7,084
Driveway area (ft^2)	-	13,800	-	-	600,000	-
Landscape area (ft^2)	159,384	72,822	17,182	70,066	3,166,190	20,594

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

METHODS OF ANALYSIS

Annual Storm Water Runoff Volumes

Annual surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study site. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used:

$$C = (0.009)\, I + 0.05$$

where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. A 0.75-inch rainfall event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff.

To select CN for the pre-development case, an analysis performed in the area of the Cedar Fire in San Diego County was used in which CN was determined before and after the 2003 fire.[3] In the San Diego analysis, CN = 83 was estimated for the pre-existing land cover, which was generally chaparral, a vegetative cover also typical of Ventura County. As indicated below, soils are also similar in Ventura and San Diego Counties, making the parameter selection reasonable for use in both locations. For post-development landscaping, CN = 86 was selected based on tabulated data in NRCS (1986) and professional judgment.

Pre- and post-development runoff quantities were computed with these CN values and the 0.75-inch rainfall, and then divided by the rainfall to obtain runoff coefficients. The results were 0.07

[3] American Forests, *San Diego Urban Ecosystem Analysis After the Cedar Fire* (Feb. 3, 2006) (http://www.ufei.org/files/pubs/SanDiegoUrbanEcosystemAnalysis-PostCedarFire.pdf).

and 0.12, respectively. Finally, total annual runoff volumes were estimated based on an average annual precipitation in the City of Ventura of 14.71 inches.[4]

Storm Water Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 0.75-inch precipitation event was used as a basis for volumes. Storm water pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low-impact development practices of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment B (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in Ventura County developments under the permit now in force? This permit is open-ended and provides regulated entities with a large number of choices and few fixed requirements. These options presumably include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study, although it is not clear that these BMPs, in actuality, have been implemented consistently within Ventura County to date.

The principal basis for the analysis of BMP performance was the California Department of Transportation's (CalTrans, 2004) BMP Retrofit Pilot Program, performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips lost 40, 50 and 30 percent, respectively, of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The CalTrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations, and equations were developed for the functional

[4] Ventura County Watershed Protection District (http://www.vcwatershed.org/fws/specialmedia.htm). The City of Ventura is considered to be representative of most of the developed and developing areas in Ventura County. However, there is some variation around the county, with the maximum precipitation registered at Ojai (annual average 21.32 inches). Ojai is about 15 miles inland and lies at elevation 745 ft at the foot of the Topatopa Mountains, the orographic effect of which influences its meteorology. Ojai's higher rainfall was taken into account in the calculations, and the report notes the few instances where it affected the conclusions.

relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the CalTrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly-lengthy ponding, while not allowing percolating water to reach ground-water before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by CalTrans after the pilot study. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff. This was accomplished by determining the infiltration capability of the pervious areas in their original condition for each development case study, and further assessing the pervious areas' infiltration capabilities if soils were modified according to low impact development practices.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve each 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. The most prominent soils in Ventura County, at least relatively near the coast, are loams, sandy loams, loamy sands, and silty clay loams, thus making the conclusions of the San Fernando Valley study applicable for these purposes.[5] This information was used to estimate how much of each case study site's annual runoff would be infiltratable, and if the pervious portion would provide sufficient area for infiltration. For instance, if sufficient area were available, the infiltration configuration would not have to be in basin form but could be shallower and larger in surface area. This study's analyses assumed the use of bioretention areas rather than traditional infiltration basins.

Volume and Pollutant Source Reduction Strategies

As mentioned above, the essence of low-impact development is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If a site's existing infiltration and treatment capabilities are inadequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then LID-based source reduction strategies can be implemented, infiltration and treatment capabilities can be upgraded, or both.

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[5] Cabrillo Port Liquefied Natural Gas Deepwater Port Draft EIS/EIR (Oct. 2004) (http://www.cabrilloport.ene.com/files/eiseir/4.05%20%20-Agriculture%20and%20Soils.pdf).

Source reduction can be accomplished through various LID techniques. Soil can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition. Soil amendment, as this practice is known, is a standard LID technique.

Upgraded soils are used in bioretention cells that hold runoff and effect its transfer to the subsurface zone. This standard LID tool can be used where sufficient space is available. This study analyzed whether the six development case study sites would have sufficient space to effectively reduce runoff using bioretention cells, assuming the soils and vegetation could be amended and enhanced where necessary.

Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. For such approaches to be most effective, the soils must be capable of infiltrating the runoff passing through, and may require renovation.

Source reduction can be enhanced by the LID practice of water harvesting, in which water from impervious surfaces is captured and stored for reuse in irrigation or gray water systems. For example, runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings.[6] Many successful systems of this type are in operation, such as the Natural Resources Defense Council offices (Santa Monica, CA), the King County Administration Building (Seattle, WA), and two buildings on the Portland State University campus (Portland, OR). This investigation examined how water harvesting could contribute to storm water management for case study sites where infiltration capacity, available space, or both appeared to be limited.

RESULTS OF THE ANALYSIS

1. "Base Case" Analysis: Development without Storm Water Controls

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 (page 9) presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no storm water controls on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would lose less than half of the site's pre-development recharge.

[6] New Buildings Institute, Inc., *Advanced Buildings* (2005) (http://www.poweryourdesign.com/LEEDGuide.pdf).

Table 2. Pre- and Post-Development without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	13.4	3.72	0.95	2.60	162	6.37
Pre-development runoff[c]	0.94	0.26	0.07	0.18	11	0.45
Pre-development recharge[d]	12.5	3.46	0.88	2.42	150	5.92
Post-development impervious runoff[c]	8.48	1.59	0.44	0.60	69	5.50
Post-development pervious runoff[c]	0.54	0.25	0.06	0.24	11	0.07
Post-development total runoff[c]	9.02	1.83	0.50	0.84	80	5.57
Post-development recharge[d]	4.39	1.88	0.45	1.76	82	0.80
Post-development recharge loss (% of pre-development recharge)	8.08 (65%)	1.57 (46%)	0.43 (49%)	0.66 (27%)	68 (45%)	5.12 (86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings.

Table 3. Pollutant Concentrations and Loadings for Case Study Land Use and Cover Types

Land Use	Concentrations				Loadings			
	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
Residential roof	25	0.013	0.159	0.11	79	0.041	0.503	0.348
Commercial roof	18	0.014	0.281	0.14	57	0.044	0.889	0.443
Access road/driveway	120	0.022	0.118	0.66	380	0.070	0.373	2.088
Parking	75	0.036	0.097	0.14	237	0.114	0.307	0.443
Walkway	25	0.013	0.059	0.11	79	0.041	0.187	0.348
Landscaping	213	0.013	0.059	2.04	85	0.005	0.024	0.815

The CTR acute criteria for copper and zinc are 0.0048 mg/L and 0.090 mg/L, respectively. Table 3 shows that all developed land uses are expected to discharge copper above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from some land covers would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 shows the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.090 mg/L acute zinc criterion, and the retail commercial development does so by a wide margin. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.175
Lbs. TSS/year	1321	345	125	242	15016	853
Lbs. TCu/year	0.46	0.074	0.032	0.045	3.21	0.37
Lbs. TZn/year	3.09	0.607	0.174	0.301	26.4	2.64
Lbs. TP/year	6.58	2.39	0.72	1.78	104	3.36

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial

2. *"Conventional BMP" Analysis: Effect of Basic Treatment BMPs*

Effect of Basic Treatment BMPs on Post-Development Runoff Volumes

The current permit allows regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. The range includes drain inlet inserts, CDS units, and other manufactured BMPs, detention vaults, and sand filters, all of which isolate runoff from the soil; as well as basins and biofiltration BMPs built in soil and generally having vegetation. Treatment BMPs that do not permit any runoff contact with soils discharge as much storm water runoff as equivalent sites with no BMPs, and hence yield zero savings in recharge. As mentioned above, the CalTrans (2004) study found that BMPs with a natural surface can reduce runoff by substantial margins (30-50 percent for extended-detention basins and biofiltration).

With such a wide range of BMPs in use, runoff reduction ranging from 0 to 50 percent, and a lack of clearly ascertainable requirements, it is not possible to make a single estimate of how much recharge savings are afforded by maximal implementation of the current permit. We made the following assumptions regarding implementation of BMPs. Assuming natural-surface BMPs perform at the average of the three types tested by CalTrans (2004), i.e., 40 percent runoff reduction, the estimate can be bounded as shown in Table 5 (page 11). The table demonstrates that allowing free choice of BMPs without regard to their ability to direct water into the ground forfeits substantial groundwater recharge benefits when hardened-surface BMPs are selected. Use of soil-based conventional BMPs could cut recharge losses from half or e more of the full potential to about one-quarter to one-third or less, except with the highly impervious commercial development. This analysis shows the wisdom of draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way. But as subsequent analyses showed, soil amendment can gain considerably greater benefits.

Table 5. Pre- and Post-Development with Conventional BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater

Annual Volume (acre-ft)	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Precipitation[b]	13.4	3.72	0.95	2.60	162	6.37
Pre-development runoff[c]	0.94	0.26	0.07	0.18	11	0.45
Pre-development recharge	12.5	3.46	0.88	2.42	150	5.92
Post-development impervious runoff[c, d]	5.09-8.48	0.95-1.59	0.26-0.44	0.36-0.60	41-69	3.30-5.50
Post-development pervious runoff[c, d]	0.32-0.54	0.15-0.25	0.04-0.06	0.14-0.24	6.6-11	0.04-0.07
Post-development total runoff[c, d]	5.41-9.02	1.10-1.83	0.30-0.50	0.50-0.84	48-80	3.34-5.57
Post-development recharge[d, e]	4.39-7.99	1.88-2.62	0.45-0.65	1.76-2.10	82-114	0.80-3.03
Post-development recharge loss (% of pre-development recharge) [d, e]	4.51-8.08 (36-65%)	0.84-1.57 (24-46%)	0.23-0.43 (26-49%)	0.32-0.66 (13-27%)	36-68 (24-45%)	2.89-5.12 (49-86%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial. Ranges represent 40 percent runoff volume reduction, with full site coverage by BMPs having a natural surface, to no reduction, with BMPs isolating runoff from soil.
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Ranging from the quantity with hardened bed BMPs to the quantity with soil-based BMPs
[e] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Effect of Basic Treatment BMPs on Pollutant Discharges

Table 6 (page 12) presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The manufactured CDS BMPs in this table, which do not expose runoff to soil or vegetation, are not expected to drop any of the concentrations sufficiently to meet the acute zinc criterion at the discharge point. The loading reduction results show the CDS units always performing below 50 percent reduction for all pollutants analyzed, and most often in the vicinity of 20 percent, with zero copper reduction.

When treated with swales or filter strips, effluents from each development case study site are expected to fall below the CTR acute zinc criterion. All but the large commercial site would meet the criterion with EDB treatment. These natural-surface BMPs, if fully implemented and well maintained, are predicted to prevent the majority of the pollutant masses generated on most of the development sites from reaching a receiving water. Only total phosphorus reduction falls below 50 percent for two case studies. Otherwise, mass loading reductions range from about 60 to above 80 percent for the EDB, swale, and filter strip. This data indicates that draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way, pays water quality as well as hydrologic dividends.

Table 6. Pollutant Concentration and Loading Reduction Estimates with Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.131
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.098
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.068
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.048
Loading Reductions:						
CDS TSS loading reduction	15.7%	19.9%	22.0%	24.0%	19.9%	16.9%
CDS TCu loading reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn loading reduction	22.7%	22.4%	22.9%	23.1%	22.4%	25.1%
CDS TP loading reduction	30.6%	41.5%	40.7%	45.9%	41.5%	20.3%
EDB TSS loading reduction	68.1%	73.7%	79.0%	81.1%	73.7%	71.7%
EDB TCu loading reduction	61.9%	55.7%	66.2%	63.0%	55.7%	66.8%
EDB TZn loading reduction	59.7%	59.6%	60.4%	61.9%	59.6%	66.6%
EDB TP loading reduction	61.9%	69.7%	69.1%	72.9%	69.7%	54.5%
Swale TSS loading reduction	68.8%	71.1%	73.1%	73.9%	71.1%	69.4%
Swale TCu loading reduction	72.5%	68.5%	78.2%	73.3%	68.5%	75.8%
Swale TZn loading reduction	78.4%	78.1%	84.3%	78.8%	78.1%	80.7%
Swale TP loading reduction	66.3%	70.7%	67.2%	76.2%	70.7%	55.0%
Filter strip TSS loading reduction	69.9%	75.4%	80.6%	82.6%	75.4%	72.3%
Filter strip TCu loading reduction	74.4%	69.1%	78.2%	75.4%	69.1%	78.7%
Filter strip TZn loading reduction	78.3%	77.9%	78.4%	78.7%	77.9%	80.9%
Filter strip TP loading reduction	48.4%	53.1%	63.7%	59.8%	53.1%	34.6%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; CDS— continuous deflective separation unit; EDB—extended-detention basin

3. *LID Analysis: Development According to Modified Draft Permit Provisions*

(a) Hydrologic Analysis

The LID analysis was first performed according to the Draft Permit provisions under the Planning and Land Development Program (Part 4, section E). In this analysis, however, EIA was limited to three instead of five percent, under the reasoning presented in Attachment A. All runoff from NCIA was assumed to drain to vegetated surfaces, as provided in the Draft Permit.

One goal of this exercise was to identify methods that reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate substantial proportions of the developed site runoff, advancing the hydromodification mitigation objective of the Draft Permit. When runoff is dispersed into the soil instead of being rapidly collected and conveyed away, it recharges groundwater, supplementing a resource that maintains dry season stream flow and wetlands. An increased water balance can be tapped by humans for potable, irrigation, and process water supply. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

Accordingly, the analysis considered the practicability of more than one scenario by which the draft permit's terms could be met, as modified to reflect three percent EIA. In one option, all roof runoff is harvested and stored for some beneficial use. A second option disperses runoff into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like the large commercial and office buildings, while distribution in the soil would fit best with residences and relatively small commercial developments. The analysis was repeated with the assumptions of harvesting OFF and COMM roof runoff for some beneficial use and dispersing roof runoff from the remaining four cases in roof downspout infiltration systems.

Expected Infiltration Capacities of the Case Study Sites

The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate. This assessment tested the feasibility of draining all but three percent of impervious area to pervious land on the sites. Based on the findings of Chralowicz et al. (2001), it was assumed that an infiltration zone of 0.1-0.5 acres in area and 2-3 ft deep would serve a drainage catchment area in the size range 0-5 acres and infiltrate 0.9-1.9 acre-ft/year. The conclusions of Chralowicz et al. (2001) were extrapolated to conservatively assume that 0.5 acre would be required to serve each additional five acres of catchment, and would infiltrate an incremental 1.4 acre-ft/year (the midpoint of the 0.9-1.9 acre-ft/year range). According to these assumptions, the following schedule of estimates applies:

Pervious Area Available for Infiltration	Catchment Served acres	Infiltration Capacity
0.5 acres	0-5 acres	1.4 acre-ft/year
1.0 acres	5-10 acres	2.8 acre-ft/year
1.5 acres	10-15 acres	4.2 acre-ft/year
(Etc.)	...	...

As a formula, infiltration capacity ≈ 2.8 x available pervious area. To apply the formula conservatively, the available area was reduced to the next lower 0.5-acre increment before multiplying by 2.8.

As shown in Table 7, five of the six sites have adequate or greater capacity to infiltrate the full annual runoff volume from NCIA and pervious areas where EIA is limited to three percent of the total site area (four at the higher Ojai rainfall). Indeed, five of the six development types have sufficient pervious area to infiltrate *all* runoff, including runoff from EIA areas. With the most representative rainfall, only the large commercial development, with little available pervious area, falls short of the needed capacity to infiltrate all rainfall, but it still has the capacity to meet the terms of the draft permit, as modified for this analysis. These results are based on infiltrating in the native soils with no soil amendment. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration. Notably, the four case studies with far greater than necessary infiltration capacity would offer substantial flexibility in designing infiltration, allowing ponding at less than 2-3 ft depth.

Table 7. Infiltration and Runoff Volume With 3 Percent EIA and All NCIA Draining to Pervious Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
EIA runoff (acre-ft/year)	0.38	0.11	0.03	0.07	4.6	0.18
NCIA + pervious area runoff (acre-ft/year)	**8.63**	**1.73**	**0.47**	**0.76**	**75.0**	**5.39**
Total runoff (acre-ft/year)	9.01	1.84	0.50	0.83	79.6	5.57
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.47
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**1.4**
Infiltration capacity [c]	> 100%[d]	> 100%	> 100%	> 100%	> 100%	~26% [d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Compare runoff production from NCIA + pervious area (**row 3**) with estimated infiltration capacity (**row 6**)
[d] At Ojai rainfall levels, capacity would be ~78 percent at the MFR site and ~18 percent at the COMM site.

As Table 7 shows, five of the six case study sites have the capacity to infiltrate *all* runoff produced onsite by draining impervious surfaces to pervious areas. Even runoff from the area assumed to be EIA could be infiltrated in most cases based on the amount of pervious area available in typical development projects. By showing that it is possible under normal site conditions and using native soils to retain *all* runoff in typical developments, these results demonstrate that a three percent EIA requirement, which would not demand that all runoff be retained, is feasible and practicable.

Additional Source Reduction Capabilities of the Case Study Sites: Water Harvesting Example

Infiltration is one of a wide variety of LID-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other source LID measures can enhance a site's runoff retention capability. For example, soil amendment, which improves infiltration, is a standard LID technique. Water harvesting is another. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Table 8 shows the added implementation flexibility created by subtracting roof runoff by harvesting it or efficiently directing it into the soil through downspout dispersion systems, further demonstrating the feasibility of meeting the draft permit's proposed requirements, as modified to include a three percent EIA standard.

Table 8. Infiltration and Runoff Volume Reduction Analysis Including Roof Runoff Harvesting or Disposal in Infiltration Trenches (Assuming 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
EIA runoff (acre-ft/year)	0.38	0.11	0.03	0.07	4.6	0.18
Roof runoff (acre-ft/year)	4.92	0.93	0.09	0.20	41	2.33
Other NCIA + pervious area runoff (acre-ft/year)	**3.71**	**0.79**	**0.39**	**0.56**	**35**	**3.06**
Total runoff (acre-ft/year)	9.01	1.84	0.50	0.83	79.6	5.57
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.47
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**1.4**
Infiltration capacity [c]	> 100%	> 100%	> 100%	> 100%	> 100%	~45% [d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Comparison of runoff production from NCIA + pervious area **(row 3)** with estimated infiltration capacity **(row 6)**
[d] If the higher rainfall at Ojai is assumed, capacity would be ~32 percent of the amount needed for the COMM case.

Effect of Full LID Approach on Recharge

Table 9 (page 15) shows the recharge benefits of preventing roofs from generating runoff and infiltrating as much as possible of the runoff from the remainder of the case study sites. The data show that LID methods offer significant benefits relative to the baseline (no storm water controls) in all cases. These benefits are particularly impressive in developments with relatively high site imperviousness, such as in the MFR and COMM cases. In the latter case the full LID approach (excluding the common and effective practice of soil amendment) would cut loss of the potential water resource represented by recharge and harvesting from 86 to 37 percent.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use With a Full LID Approach Compared to Development With No BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Pre-development recharge[b] (acre-ft)	12.5	3.46	0.88	2.42	150	5.92
No BMPs:						
post-development recharge [b] (acre-ft)	4.39	1.88	0.45	1.76	82	0.80
post-development runoff (acre-ft)	8.08	1.57	0.43	0.66	68	5.12
post-development % recharge lost	65%	46%	49%	27%	45%	86%
Full LID approach:						
post-development runoff capture (acre-ft)[c]	12.5	3.46	0.88	2.42	150	3.73
post-development runoff (acre-ft)	0	0	0	0	0	2.19
post-development % recharge lost	0%	0%	0%	0%	0%	37%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial
[b] Quantity of water infiltrating the soil; the difference between precipitation and runoff
[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs. For the first five case studies, EIA was not distinguished from the remainder of the development, because these sites have the potential to capture all runoff.

(b) Water Quality Analysis

As outlined above, it was assumed that EIA discharges, as well as runoff from all pervious surfaces, are subject to treatment control. For purposes of the analysis, treatment control was assumed to be provided by conventional sand filtration. This choice is appropriate for study purposes for two reasons. First, sand filters can be installed below grade, and land above can be put to other uses. Under the Draft Permit's approach, pervious area should be reserved for receiving NCIA drainage, and using sand filters would not draw land away from that service or other site uses. A second reason for the choice is that sand filter performance data equivalent to the data used in analyzing other conventional BMPs are available from the CalTrans (2004) work. Sand filters may or may not expose water to soil, depending on whether or not they have a hard bed. This analysis assumed a hard bed, meaning that no infiltration would occur and thus there would be no additional recharge in sand filters. Performance would be even better than shown in the analytical results if sand filters were built in earth.

Pollutant Discharge Reduction Through LID Techniques

The preceding analyses demonstrated that each of the six case studies could feasibly comply with the draft permit's requirements, as modified to include a more protective three percent EIA standard. Moreover, for five of the six case studies, *all* storm water discharges could be eliminated at least under most meteorological conditions by dispersing runoff from impervious surfaces to pervious areas. Therefore, pollutant additions to receiving waters would also be eliminated. This demonstrates not only that a lower EIA (three percent) is a feasible and practicable approach to maintaining the natural hydrology of land being developed, as discussed above, but that a lower EIA is a feasible and practicable way to eliminate the discharge of pollutants that could cause or contribute to violations of water quality standards.

While the high proportion of impervious area present on the large commercial site relative to pervious area would not allow eliminating all discharge, harvesting roof water and draining NCIA to properly-prepared pervious area would substantially decrease the volume discharged. Deployment of treatment control BMPs (e.g. sand filter treatment) could cut contaminant discharges from pollutants in the remaining volume of runoff to low levels.

Table 10 presents the pollutant reductions from the untreated case achievable through the complete LID approach described above in comparison to conventional treatments (from Table 6). Assuming EIA still discharges through sand filters, pollutant loadings from the untreated condition are expected to decrease by more than 96 percent for all but the COMM case. In that challenging case loadings would still fall by at least 89 percent for TSS and the metals and by 83 percent for total phosphorus, assuming City of Ventura rainfall levels, and slightly less assuming the higher Ojai rainfall levels. Thus, the Draft Permit's basic premise of disconnecting most impervious area, supplemented by specially managing roof water, is shown by both water quality and hydrologic results to be feasible and to afford broad and significant environmental benefits.

Table 10. Pollutant Loading Reduction Estimates With a Full LID Approach Relative to Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	COMM[a]
Conventional TSS loading reduction[b]	15.7-69.9%	19.9-75.4%	22.0-80.6%	24.0-82.6%	19.9-75.4%	16.9-72.3%
Conventional TCu loading reduction[b]	0.0-74.4%	0.0-69.1%	0.0-78.2%	0.0-75.4%	0.0-69.1%	0.0-78.7%
Conventional TZn loading reduction[b]	22.7-78.4%	22.4-78.1%	22.9-84.3%	23.1-78.8%	22.4-78.1%	25.1-80.9%
Conventional TP loading reduction[b]	30.6-66.3%	41.5-70.7%	40.7-69.1%	45.9-76.2%	41.5-70.7%	20.3-55.0%
LID TSS loading reduction[c]	99.4%	99.3%	99.5%	99.4%	99.3%	89.0%[d]
LID TCu loading reduction[c]	98.1%	96.7%	98.0%	96.2%	96.7%	90.6%[d]
LID TZn loading reduction[c]	99.1%	98.8%	98.9%	98.3%	98.8%	94.8%[d]
LID TP loading reduction[c]	98.1%	98.6%	98.8%	98.7%	98.6%	83.1%[d]

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; COMM—retail commercial; CDS—continuous deflective separation unit; EDB—extended-detention basin; NCIA—not connected impervious area; EIA—effective (connected) impervious area
[b] Range from Table 6 represented by treatment by CDS unit, EDB, biofiltration swale, or biofiltration strip
[c] Based on directing roof runoff to downspout infiltration trenches (MFR, Sm-SFR, REST, and Lg-SFR) or harvesting it (OFF and COMM), draining other NCIA to pervious areas, and treating EIA with sand filters
[d] If the higher rainfall at Ojai is assumed, reduction estimates for TSS, TCu, TZn, and TP would be 84.0, 86.3, 92.5, and 75.5 percent, respectively.

SUMMARY AND CONCLUSIONS

This paper demonstrated that common Ventura County area residential and commercial development types subject to the Municipal NPDES Permit are likely, without storm water management, to reduce groundwater recharge from the predevelopment state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed CTR acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Conventional soil-based BMP solutions that promote and are component parts of low-impact development approaches, by contrast, regain about 30-50 percent of the recharge lost in development without storm water management, although commercially-manufactured filtration and hydrodynamic BMPs for storm water management give no benefits in this area. It is expected the soil-based BMPs generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that a three percent Effective Impervious Area standard can be met in typical developments, and that by draining all site runoff to pervious areas, runoff can be eliminated entirely in most development types. This result was reached assuming the use of native soils. Soil enhancement (typically, with compost) can further advance infiltration. Draining impervious surfaces onto the loam soils typical of Ventura County, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) should eliminate runoff from all but mostly impervious developments. Even in the development scenario involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from more than 85 to less than 40 percent, and pollutant mass loadings would fall by 83-95 percent from the untreated scenario when draining to pervious areas was supplemented with water harvesting. These results demonstrate the basic soundness of the Draft Permit's concept to limit directly connected impervious area and drain the remainder over pervious surfaces.

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ATTACHMENT A

JUSTIFICATION OF PROPOSED EFFECTIVE IMPERVIOUS AREA LIMITATION

Summary

The literature shows that adverse impacts to the physical habitat and biological integrity of receiving waters occur as a result of the conversion of natural areas to impervious cover. These effects are observed at the lowest levels of impervious cover in associated catchments (two to three percent) and are pronounced by the point that impervious cover reaches five percent. To protect biological productivity, physical habitat, and other beneficial uses, effective impervious area should be capped at no more than three percent.

I. Impacts to physical habitat of California receiving waters observed at three percent impervious cover

Stein *et al.*[7] note that while studies from parts of the country with climates more humid than California's indicate that physical degradation of stream channels can initially be detected when watershed impervious cover approaches 10%, biological effects, which may be more difficult to detect, may occur at lower levels (CWP 2003).[8] Recent studies from both northern and southern California indicate that intermittent and ephemeral streams in California are more susceptible to the effects of hydromodification than streams from other regions of the US, with stream degradation being recognized when the associated catchment's impervious cover is as little as 3-5% (Coleman *et al.* 2005).[9] Furthermore, supplemental landscape irrigation in semi-arid regions, like California, can substantially increase the frequency of erosive flows (AQUA TERRA Consultants 2004).[10]

Coleman, *et al.*[3] report that the ephemeral/intermittent streams in southern California (northwestern Los Angeles County through southern Ventura County to central Orange County) appear to be more sensitive to changes in percent impervious cover than streams in other areas. Stream channel response can be represented using an *enlargement curve*, which relates the percent of impervious cover to a change in cross-sectional area. The data for southern California streams forms a relationship very similar in shape to the enlargement curves developed for other North American streams. However, the curve for southern California streams is above the general curve for streams in other climates. This suggests that a specific enlargement ratio is produced at a lower value of impervious surface area in southern California than in other parts of North America. Specifically, the estimated threshold of response is approximately 2-3% impervious cover, as compared to 7-10% for other portions of the U.S. It is important to note that this conclusion applies specifically to streams with a catchment drainage area less than 5 square miles.

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[7] Stein, E.D., S. Zaleski, (2005) *Managing Runoff to Protect Natural Streams: The Latest Developments on Investigation and Management of Hydromodification in California*. (Proceedings of a Special Technical Workshop Co-sponsored by California Stormwater Quality Association (CASQA), Stormwater Monitoring Coalition (SMC), University of Southern California Sea Grant (USC Sea Grant), Technical Report #475).

[8] Center for Watershed Protection (CWP), (2003) *Impacts of Impervious Cover on Aquatic Systems*. Ellicott City, MD.

[9] Coleman, D., C. MacRae, and E.D. Stein, (2005) *Effect of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Streams*. Southern California Coastal Water Research Project Technical Report #450, Westminster, CA.

[10] AQUA TERRA Consultants, (2004) *Urbanization and Channel Stability Assessment in the Arroyo Simi Watershed of Ventura County CA*. FINAL REPORT. Prepared for Ventura County Watershed Protection Division, Ventura CA.

This study concludes that disconnecting impervious areas from the drainage network and adjacent impervious areas is a key approach to protecting channel stability. Utilizing this strategy can make it practical to keep the effective impervious cover (*i.e.* the amount hydrologically connected to the stream) equal to or less than the identified threshold of 2-3%.

II. Impacts to biological integrity of receiving waters observed with any conversion from natural to impervious surface

Two separate studies conducted by Horner *et al.*[11,12] in the Puget Sound region (Washington State), Montgomery County, Maryland, and Austin, Texas built a database totaling more than 650 reaches on low-order streams in watersheds ranging from no urbanization and relatively little human influence (the reference state, representing "best attainable" conditions) to highly urban (>60 percent total impervious area, "TIA"). Biological health was assessed according to the benthic index of biotic integrity (B-IBI) and, in Puget Sound, the ratio of young-of-the-year coho salmon (*Oncorhynchus kisutch*), a relatively stress-intolerant fish, to cutthroat trout (*Oncorhynchus clarki*), a more stress-tolerant species. The following discussion summarizes the results and conclusions of these two studies.

There is no single cause for the decline of water resource conditions in urbanizing watersheds. Instead, it is the cumulative effects of multiple stressors that are responsible for degraded aquatic habitat and water quality. Imperviousness, while not a perfect yardstick, appears to be a useful predictor of ecological condition. However, a range of stream conditions can be associated with any given level of imperviousness. In general, only streams that retain a significant proportion of their natural vegetative land-cover <u>and</u> have very low levels of watershed imperviousness appear to retain their natural ecological integrity. It is this change in watershed land-cover that is largely responsible for the shift in hydrologic regime from a sub-surface flow dominated system to one dominated by surface runoff.

While the decline in ecological integrity is relatively continuous and is consistent for all parameters, the impact on physical conditions appears to be more pronounced earlier in the urbanization process than chemical degradation. It is generally acknowledged, based on field research and hydrologic modeling, that it is the shift in hydrologic conditions that is the driving force behind physical changes in urban stream-wetland ecosystems.

Multiple scales of impact operate within urbanizing watersheds: landscape-level impacts, including the loss of natural forest cover and the increase in impervious surface area throughout the watershed; riparian corridor-specific impacts such as encroachment, fragmentation, and loss of native vegetation; and local impacts such as water diversions, exotic vegetation, stream channelization, streambank hardening, culvert installation, and pollution from the widespread use of pesticides and herbicides. All of these stressors contribute to the overall cumulative impact.

The researchers found that there is no clear threshold of urbanization below which there exists a "no-effect" condition. Instead, there appears to be a relatively continuous decline in almost all measures of water quality or ecological integrity. Losses of integrity occur from the lowest levels of TIA and are already pronounced by the point that TIA reaches 5 percent.

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[11] Horner, R. R., C. W. May, (2002) *The Limitations of Mitigation-Based Stormwater Management in the Pacific Northwest and the Potential of a Conservation Strategy based on Low-Impact Development Principles.* (Proceedings of the American Society of Engineers Stormwater Conference, Portland, OR).
[12] Horner, R.R., E. H. Livingston, C. W. May, J. Maxted, (2006) *BMPs, Impervious Cover, and Biological Integrity of Small Streams.* (Proceedings of the Eighth Biennial Stormwater Research and Watershed Management Conference, Tampa, FL).

Similarly, the Alliance for the Chesapeake Bay[13] reports that small-watershed studies by the Maryland Department of Natural Resources Biological Stream Survey have shown that some sensitive species are affected by even low amounts of impervious cover. In one study, no brook trout were observed in any stream whose watershed had more than 2 percent impervious cover, and brook trout were rare in any watershed with more than 0.5 percent impervious cover.

III. Ventura County's watersheds include biologically-significant water bodies

The literature discussed above is relevant to the watersheds of Ventura County, which contain rivers and streams that currently or historically support a variety of beneficial uses that may be impaired by water quality degradation and stream hydromodification as a result of storm water runoff from impervious land cover. Unlike some Southern California watersheds, Ventura County still has many natural stream systems with a high degree of natural functionality.

For instance, the Ventura River watershed in northwestern Ventura County "supports a large number of sensitive aquatic species,"[14] including steelhead trout, a federally-listed endangered species. Although "local populations of steelhead and rainbow trout have nearly been eliminated along the Ventura River" itself, the California Department of Fish and Game has "recognized the potential for the restoration of the estuary and enhancement of steelhead populations in the Ventura River."[15] Steelhead may also be present in tributaries such as San Antonio Creek.[16] Thriving rainbow trout populations exist in tributaries of the Ventura River including Matilija Creek and Coyote Creek.[17] The Ventura River either does or is projected to support the following beneficial uses: warm freshwater habitat; cold freshwater habitat; wildlife habitat; rare, threatened, or endangered species; migration of aquatic organisms; and spawning and reproduction.[18] Furthermore, the Ventura River Estuary also supports commercial fishing, shellfish harvesting, and wetland habitat.[19] The Ventura River receives municipal storm drain discharges from Ojai, San Buenaventura, and unincorporated areas of Ventura County.[20]

The Santa Clara River watershed in northern Ventura County "is the largest river system in southern California that remains in a relatively natural state."[21] Sespe Creek is one of the Santa Clara's largest tributaries, and "supports significant steelhead spawning and rearing habitat."[22] Other creeks in the Santa Clara River watershed that support steelhead are Piru Creek and Santa Paula Creek. Sespe Creek and the Santa Clara River also provide spawning habitat for the Pacific lamprey. Rainbow trout populations exist in tributaries of the Santa Clara River including Sespe Creek.[23] The creeks and the Santa Clara river do or are projected to support the following beneficial uses: warm freshwater habitat; cold freshwater habitat; wildlife habitat; preservation of biological habitats rare, threatened, or endangered species; migration of aquatic organisms; and spawning and reproduction.[24] Los Padres National Forest covers much of the Santa Clara River watershed, but increasing development in floodplain areas has been

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[13] Karl Blankenship, BAY JOURNAL,"It's a hard road ahead for meeting new sprawl goal: States will try to control growth of impervious" (July/August 2004), at http://www.bayjournal.com/article.cfm?article=66.
[14] Los Angeles Region Water Quality Control Plan (1994) p. 1-18 ("Basin Plan").
[15] Basin Plan, p. 1-16; Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[16] Ventura County Environmental & Energy Resources Division, "Steelhead Spawning in Ventura County," (2005), available at http://www.wasteless.org/Eye_articles/steehead2005.html.
[17] Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[18] Basin Plan, Table 2-1.
[19] Basin Plan, Table 2-4.
[20] Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
[21] Basin Plan, p. 1-16.
[22] Basin Plan, p. 1-16.
[23] Ventura County Environmental & Energy Resources Division, "Endangered Steelhead Trout in Ventura County: Past, Present, and Future," available at http://www.wasteless.org/Eye_articles/steelhead.htm.
[24] Basin Plan, Table 2-1.

identified as a threat to the river system's water quality.[25] Furthermore, the Santa Clara estuary supports the additional beneficial uses of shellfish harvesting and wetlands habitat.[26] The Santa Clara River receives municipal storm drain discharges from Fillmore, Oxnard, San Buenaventura, Santa Paula, and unincorporated areas of Ventura County.[27]

The Calleguas Creek watershed "empties into Mugu Lagoon, one of southern California's few remaining large wetlands."[28] It supports or is projected to support the following beneficial uses: estuarine habitat; marine habitat; wildlife habitat; preservation of biological habitats; rare, threatened, or endangered species; migration of aquatic organisms; spawning and reproduction; shellfish harvesting; and wetlands habitat.[29] Historically, Calleguas Creek drained largely agricultural areas. But this watershed has been under increasing pressure from sedimentation due to increased surface flow from municipal discharges and urban wastewaters, among other sources.[30] Increasing residential developments on steep slopes has been identified as a substantial contributing factor to the problem of accelerated erosion in the watershed (and sedimentation in the Lagoon). Calleguas Creek receives municipal storm drain discharges from Camarillo, Moorpark, Simi Valley, Thousand Oaks, and unincorporated areas of Ventura County.[31]

Ventura County's coastal streams also support a variety of beneficial uses:[32]

- Little Sycamore Canyon Creek in southern Ventura County (warm freshwater habitat; wildlife habitat; rare, threatened or endangered species; and spawning and reproduction);
- Lake Casitas tributaries (warm freshwater habitat; cold freshwater habitat; wildlife habitat; rare, threatened or endangered species; spawning and reproduction; and wetland habitat);
- Javon Canyon and Padre Juan Canyon (warm freshwater habitat; cold freshwater habitat; wildlife habitat; and spawning and reproduction); and
- Los Sauces Creek in northern Ventura County (warm freshwater habitat; cold freshwater habitat; wildlife habitat; migration of aquatic species; and spawning and reproduction).

IV. Conclusion

In order to protect the biological habitat, physical integrity, and other beneficial uses of the water bodies in Ventura County, effective impervious area should be capped at no more than three percent.

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25 Basin Plan, pp. 1-16, 1-18.
26 Basin Plan, Table 2-4.
27 Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
28 Basin Plan, p. 1-18.
29 Basin Plan, Table 2-1.
30 Basin Plan, pp. 1-16, 1-18.
31 Ventura County Watershed Protection District, *Report of Waste Discharge* (January 2005) at p. 3.
32 Basin Plan, Table 2-1.

ATTACHMENT B

POLLUTANT CONCENTRATIONS FOR URBAN SOURCE AREAS (HERRERA ENVIRONMENTAL CONSULTANTS, INC. UNDATED)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7
Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	

Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

RB-AR33177

INITIAL INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN FRANCISCO BAY AREA

Richard R. Horner[†]

ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in the San Francisco Bay Area, California will be reissued in 2007. The draft permit includes general provisions related to low impact development practices (LID) for certain kinds of development and redevelopment projects. Using six representative development project case studies, based on California building records, the author investigated the practicability and relative benefits of LID options for the majority of the region having soils potentially suitable for infiltration either in their natural state or after amendment using well recognized LID techniques. The results showed that (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; and (2) in each of the case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

[†] Richard R. Horner, Ph.D., Research Associate Professor, University of Washington Departments of Civil and Environmental Engineering and Landscape Architecture; Adjunct Associate Professor, University of Washington Center for Urban Horticulture

INTRODUCTION

The Assessment in Relation to Municipal Permit Conditions

This purpose of this study is to investigate the relative water quality and water reuse benefits of three levels of storm water treatment best management practices (BMPs): (1) basic "treat-and-release" BMPs (e.g., drain inlet filters, CDS units), (2) commonly used BMPs that expose runoff to soils and vegetation (extended-detention basins and biofiltration swales and filter strips), and (3) low impact development (LID) practices. The factors considered in the investigation are runoff volume, pollutant loading, and the availability of water for infiltration or other reuse. In order to assess the differential impact of storm water reduction approaches on these factors, this study examines six case studies typical of development covered by the proposed Municipal Regional Urban Runoff Phase I NPDES Stormwater Permit (MRP).

This report covers locations in the Bay Area most amenable to soil infiltration of stormwater runoff, those areas having soils in Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups A, B, or C as classified by the Natural Resources Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Depending on site-specific conditions, A and B soils would generally effectively infiltrate water without modification, whereas C soils could require organic amendments according to now standard LID methods. This report does not cover locations with group D soils, which are generally not amenable to infiltration, again depending on the specific conditions on-site. A subsequent report will examine options in these locations, which include other LID techniques (e.g., roof runoff harvesting for irrigation or gray water supply) and state-of-the-art conventional stormwater management practices. A minority but still substantial fraction of the Bay Area has group D soils (39.3, 68.0, 18.3, and 50.1 percent of the mapped areas of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively). Regarding any mapped soil type, it is important to keep in mind that soils vary considerably within small distances. Characteristics at specific locations can deviate greatly from those of the major mapped unit, making infiltration potential either more or less than may be expected from the mapping.

Low impact development methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating storm flows before they can enter surface receiving waters, and treating flow remaining on the surface through contact with vegetation and soil, or a combination of these strategies. Soil-based LID practices often use soil enhancements such as compost, and thus improve upon the performance of more traditional basins and biofilters. The study encompassed vegetated swales (channels for conveyance at some depth and velocity), vegetated filter strips (surfaces for conveyance in thin sheet flow), and bioretention areas (shallow basins with a range of vegetation types in which runoff infiltrates through soil either to groundwater or a subdrain for eventual surface discharge). Application of these practices in a low impact site design mode requires either determination that existing site soils can support runoff reduction through infiltration or that soils will be amended using accepted LID techniques to attain this objective. Finally, the study further broadened implementation options to include water harvesting (collection and storage for use in, for example, irrigation or gray water systems), roof downspout infiltration trenches, and porous pavements.

The investigation also considered whether typical development patterns and local conditions in the Bay Area would enable LID implementation as required by a new standard proposed for the 2007 Ventura County Municipal Storm Water Permit. This standard requires management of effective impervious area (EIA), limiting it to 5%, as well as other impervious area (what might be termed Not-Connected Impervious Area, NCIA), and pervious areas.

Where treatment control BMPs are required to manage runoff from a site, Volume or Flow Hydraulic Design Bases commonly used in California were assumed to apply. The former basis applies to storage-type BMPs, like ponds, and requires capturing and treating either the runoff volume from the 85th percentile, 24-hour rainfall event for the location or the volume of annual runoff to achieve 80 percent or more volume treatment. The calculations in this analysis used the 85th percentile 24-hour rainfall event basis. The Flow basis applies to flow-through BMPs, like swales, and requires treating the runoff flow rate produced from a rain event equal to at least 0.2 inches per hour intensity (or one of two other approximately equivalent options).

Scope of the Assessment

With respect to each of the six development case studies, three assessments were undertaken: a baseline scenario incorporating no stormwater management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID stormwater management strategies.

To establish a baseline for each case study, annual stormwater runoff volumes were estimated, as well as concentrations and mass loadings of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). These baseline estimates were based on the anticipated land use and cover with no stormwater management efforts.

Two sets of calculations were then conducted using the parameters defined for the six case studies. The first group of calculations estimated the extent to which basic BMPs reduce runoff volumes and pollutant concentrations and loadings, and what impact, if any, such BMPs have on recharge rates or water retention on-site.

The second group of calculations estimated the extent to which commonly used soil-based BMPs and LID site design strategies ameliorate runoff volumes and pollutant concentrations and loadings, and the effect such techniques have on recharge rates. When evaluating LID strategies in the context of the EIA concept employed in the draft Ventura County MS4 permit, it was presumed that EIA would be limited to three percent. It was also assumed that pervious surfaces on a site receiving runoff from other areas on the site would be sized and prepared to manage (through infiltration or storage) the volume directed there in addition to precipitation falling directly on those areas. The assessment of basins, biofiltration, and low impact design practices analyzed the expected infiltration capacity of the case study sites. It also considered related LID techniques and practices, such as source reduction strategies, that could work in concert with infiltration to serve the goals of: (1) preventing increase in annual runoff volume from the pre- to the post-developed state, (2) preventing increase in annual pollutant mass loadings between the two development states, and (3) avoiding exceedances of the Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan) criteria for copper and zinc.

The results of this analysis show that:

- A full-range of typical development categories common in the Bay Area, from single family residential to restaurants, housing developments, and commercial uses like office buildings, can feasibly implement standard LID techniques to achieve no stormwater discharge during rain events equal to, and in some cases greater than, design storm conditions. This conclusion is based on an analysis that used actual building records in California and annual rainfall records in two rainfall zones in the Bay Area to show that site conditions support this level of performance. In addition, site conditions typical at a wide range of development projects are more than sufficient to attain compliance with a three percent EIA limit, as is being contemplated in other MS4 re-issuance proceedings in California presently.

- Developments implementing no post-construction BMPs result in storm water runoff volume and pollutant loading that are substantially increased, and recharge rates that are substantially decreased, compared to pre-development conditions.

- Developments implementing basic post-construction treatment BMPs achieve reduced pollutant loading compared to developments with no BMPs, but stormwater runoff volume and recharge rates are similar to developments with no BMPs.

- Developments implementing traditional basins and biofilters, and even more so low impact post-construction BMPs, achieve significant reduction of pollutant loading and runoff volume as well as greatly enhanced recharge rates compared to both developments with no BMPs and developments with basic treatment BMPs.

This report covers the methods employed in the investigation, data sources, and references for both. It then presents the results, discusses their consequences, draws conclusions, and makes recommendations relative to the feasibility of utilizing low-impact development practices in Bay Area developments.

CASE STUDIES

Six case studies were selected to represent a range of urban development types considered to be representative of the Bay Area. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR), and a single home (SINGLE).[1]

Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. Code requirements vary by jurisdiction, with the tendency now to drop below the traditional 200 sq ft average. About 180 sq ft is common, but various standards for full- and compact-car spaces, and for the mix of the two, can raise or lower the average.[2] The 176 sq ft size is considered to be a reasonable value for conventional practice.

Roadways and walkways assume a wide variety of patterns. Exclusive of the two SFR cases, simple, square parking lots with roadways around the four sides and square buildings with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively.

Single-family residences were assumed each to have a driveway 20 ft wide and 30 ft long. It was further assumed that each would have a sidewalk along the front of the lot, which was calculated to be 5749 sq ft in area. Assuming a square lot, the front dimension would be 76 ft. A 40-ft walkway was included within the property. Sidewalks and walkways were taken to be 4 ft wide. For each case study the total area for all of these impervious features was subtracted from the total site area to estimate the pervious area, which was assumed to have conventional landscaping cover (grass, small herbaceous decorative plants, bushes, and a few trees).

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[1] Building permit records from the City of San Marcos in San Diego County provided data on total site areas for the first four case studies, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. While the building permit records made no reference to features such as roadways, walkways, and landscaping normally associated with development projects, these features were taken into account in the case studies using assumptions described herein. Larger developments and redevelopment were not represented in the sampling of building permits from the San Marcos database. To take these types of projects into account in the subsequent analysis, the Lg-SFR scenario scaled up all land use estimates from the Sm-SFR case in the ratio of 1000:23. The single home case (SINGLE) was derived from Bay Area records obtained at http://www.ppic.org/content/other/706EHEP_web_only_appendix.pdf, which showed 8000 ft^2 as a rough average for a single home lot in the region. As with the other cases, these hypothetical developments were assumed to have roadways, walkways, and landscaping, as described herein.

[2] J. Gibbons, *Parking Lots*, NONPOINT EDUCATION FOR MUNICIPAL OFFICERS, Technical Paper No. 5 (1999) (http://nemo.uconn.edu/tools/publications/tech_papers/tech_paper_5.pdf).

Table 1 summarizes the characteristics of the six case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Case Study Characteristics and Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
No. buildings	11	23	1	1	1000	1
Total area (ft^2)	476,982	132,227	33,669	92,612	5,749,000	8,000
Roof area (ft^2)	184,338	34,949	3,220	7,500	1,519,522	2114
No. parking spaces	438	-	33	37	-	-
Parking area (ft^2)	77,088	-	5808	6512	-	-
Access road area (ft^2)	22,212	-	6097	6456	-	-
Walkway area (ft^2)	33,960	10,656	1362	2078	463,289	518
Driveway area (ft^2)	-	13,800	-	-	600,000	835
Landscape area (ft^2)	159,384	72,822	17,182	70,066	3,166,190	4533

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

METHODS OF ANALYSIS

Annual Stormwater Runoff Volumes

Annual surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study site. Runoff volume was computed as the product of annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to rainfall received). For impervious areas the following equation was used:

$$C = (0.009)\,I + 0.05$$

where I is the impervious percentage. This equation was derived by Schueler (1987) from Nationwide Urban Runoff Program data (U.S. Environmental Protection Agency 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients was the Natural Resource Conservation Service's (NRCS) Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff as a function of precipitation and a variable representing land cover and soil, termed the curve number (CN). Larger events are forecast to produce a greater amount of runoff in relation to amount of rainfall because they more fully saturate the soil. Therefore, use of the model to estimate annual runoff requires selecting some event or group of events to represent the year. The 85th percentile, 24-hour rainfall event was used in the analysis here for the relative comparison between pre- and post-development and applied to deriving a runoff coefficient for annual estimates, recognizing that smaller storms would produce less and larger storms more runoff.

A memorandum titled Rainfall Data Analysis and Guidance for Sizing Treatment BMPs (http://www.cccleanwater.org/construction/Publications/CCCWPBasinSizingMemoFINAL_4-20-05.pdf) prepared for the Contra Costa Clean Water Program demonstrated a linear relationship between unit basin storage volume for 80 percent capture (which is related to the 85th percentile event) and mean annual precipitation. Rainfall for Bay Area 85th percentile, 24-hour events could thus be determined from locations where events have been established in direct proportion to mean annual rainfall.

In order to obtain appropriate regional estimates of annual precipitation, rainfall records were obtained from a number of sites in the four counties, plus the city of Vallejo, covered by the permit.[3] The mean annual range is from 13.73 to 24.30 inches, with quantities close to either 14 or 20 inches predominating. The study was performed for both of these rainfall totals. These figures were used in conjunction with 85th percentile, 24-hour event amounts of 0.75 for Los Angeles and 0.92 for Santa Rosa (http://ci.santa-rosa.ca.us/pworks/other/SW/SRSWManualFinalDraft.pdf), respectively, and mean annual totals of 12 and 31 inches for the respective cities to estimate 85 percentile, 24-hour event quantities of 0.77 and 0.82 inch for the 14 and 20-inch Bay Area rainfall zones, respectively.

Pre- and post-development runoff quantities were computed with selected CN values and the 0.77- and 0.82-inch rainfalls. The CN choices based on tabulated data in NRCS (1986) and professional judgment were 83 before development and 86 after land modification. Estimate runoff amounts were then divided by the rainfall totals to obtain runoff coefficients. The results were about the same for the two rainfall zones at 0.07 and 0.12 before and after development, respectively. Finally, total annual runoff volumes were estimated based on the two average annual precipitation figures.

Stormwater Runoff Pollutant Discharges

Annual pollutant mass discharges were estimated as the product of annual runoff volumes produced by the various land use and cover types and pollutant concentrations typical of those areas. Again, the 0.75-inch precipitation event was used as a basis for volumes. Stormwater pollutant data have typically been measured and reported for general land use types (e.g., single-family residential, commercial). However, an investigation of low impact development practices of the type this study sought to conduct demands data on specific land coverages. The literature offers few data on this basis. Those available and used herein were assembled by a consultant to the City of Seattle for a project in which the author participated. They appear in Attachment A (Herrera Environmental Consultants, Inc. undated).

Pollutant concentrations expected to occur typically in the mixed runoff from the several land use and cover types making up a development were estimated by mass balance; i.e., the concentrations from the different areas of the sites were combined in proportion to their contribution to the total runoff.

The Effect of Conventional Treatment BMPs on Runoff Volume, Pollutant Discharges, and Recharge Rates

The first question in analyzing how BMPs reduce runoff volumes and pollutant discharges was, What BMPs are being employed in Bay Area developments under the permit now in force? These county permits provide regulated entities with a large number of choices and few fixed requirements regarding the selection of stormwater BMPs. (See Contra Costa County NPDES Municipal Stormwater Permit, Order No. 99-058; see also Santa Clara County NPDES Municipal Stormwater Permit, Order No. 01-024, at C.3.a.). Clean Water Program Available options presumably include manufactured BMPs, such as drain inlet inserts (DIIs) and continuous deflective separation (CDS) units. Developments may also select such non-

3 http://www.census.gov/stab/ccdb/cit7140a.txt, http://www.acwd.org/dms_docs/76d0b026b60d97830492079a48b1cb88.pdf, http://www.ci.berkeley.ca.us/aboutberkeley/weather.html, http://www.usbr.gov/dataweb/dams/ca10168.htm, http://www.redwoodcity.org/about/weather.html.

proprietary devices as extended-detention basins (EDBs) and biofiltration swales and filter strips. EDBs hold water for two to three days for solids settlement before releasing whatever does not infiltrate or evaporate. Biofiltration treats runoff through various processes mediated by vegetation and soil. In a swale, runoff flows at some depth in a channel, whereas a filter strip is a broad surface over which water sheet flows. Each of these BMP types was applied to each case study, although it is not clear that these BMPs, in actuality, have been implemented consistently within the Bay Area to date.

The principal basis for the analysis of BMP performance was the California Department of Transportation's (CalTrans, 2004) BMP Retrofit Pilot Program, performed in San Diego and Los Angeles Counties. One important result of the program was that BMPs with a natural surface infiltrate and evaporate (probably, mostly infiltrate) a substantial amount of runoff, even if conditions do not appear to be favorable for an infiltration basin. On average, the EDBs, swales, and filter strips lost 40, 50 and 30 percent, respectively, of the entering flow before the discharge point. DIIs and CDS units do not contact runoff with a natural surface, and therefore do not reduce runoff volume.

The CalTrans program further determined that BMP effluent concentrations were usually a function of the influent concentrations, and equations were developed for the functional relationships in these cases. BMPs generally reduced influent concentrations proportionately more when they were high. In relatively few situations influent concentrations were constant at an "irreducible minimum" level regardless of inflow concentrations.

In analyzing the effects of BMPs on the case study runoff, the first step was to reduce the runoff volumes estimated with no BMPs by the fractions observed to be lost in the pilot study. The next task was estimating the effluent concentrations from the relationships in the CalTrans report. The final step was calculating discharge pollutant loadings as the product of the reduced volumes and predicted effluent concentrations. As before, typical pollutant concentrations in the mixed runoff were established by mass balance.

Estimating Infiltration Capacity of the Case Study Sites

Infiltrating sufficient runoff to maintain pre-development hydrologic characteristics and prevent pollutant transport is the most effective way to protect surface receiving waters. Successfully applying infiltration requires soils and hydrogeological conditions that will pass water sufficiently rapidly to avoid overly-lengthy ponding, while not allowing percolating water to reach ground-water before the soil column captures pollutants.

The study assumed that infiltration would occur in surface facilities and not in below-ground trenches. The use of trenches is certainly possible, and was judged to be an approved BMP by CalTrans after the pilot study. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff. This was accomplished by determining the infiltration capability of the pervious areas in their original condition for each development case study, and further assessing the pervious areas' infiltration capabilities if soils were modified according to low impact development practices.

The chief basis for this aspect of the work was an assessment of infiltration capacity and benefits for Los Angeles' San Fernando Valley (Chralowicz et al. 2001). The Chralowicz study posited providing 0.1-0.5 acre for infiltration basins to serve each 5 acres of contributing drainage area. At 2-3 ft deep, it was estimated that such basins could infiltrate 0.90-1.87 acre-ft/year of runoff in San Fernando Valley conditions. Soils there are generally various loam textures with infiltration rates of approximately 0.5-2.0 inches/hour. Loams are also common formations in the portion of the Bay Area covered by this report, those areas with Hydrologic

Soil Groups A, B, and C,[4] thus making the conclusions of the San Fernando Valley study applicable for these purposes. This information was used to estimate how much of each case study site's annual runoff would be infiltratable, and if the pervious portion would provide sufficient area for infiltration. For instance, if sufficient area were available, the infiltration configuration would not have to be in basin form but could be shallower and larger in surface area. This study's analyses assumed the use of bioretention areas rather than traditional infiltration basins.

Volume and Pollutant Source Reduction Strategies

As mentioned above, the essence of low impact development is reducing runoff problems before they can develop, at their sources, or exploiting the infiltration and treatment abilities of soils and vegetation. If a site's existing infiltration and treatment capabilities are inadequate to preserve pre-development hydrology and prevent runoff from causing or contributing to violations of water quality standards, then LID-based source reduction strategies can be implemented, infiltration and treatment capabilities can be upgraded, or both.

Source reduction can be accomplished through various LID techniques. Soil can be upgraded to store runoff until it can infiltrate, evaporate, or transpire from plants through compost addition. Soil amendment, as this practice is known, is a standard LID technique.

Upgraded soils are used in bioretention cells that hold runoff and effect its transfer to the subsurface zone. This standard LID tool can be used where sufficient space is available. This study analyzed whether the six development case study sites would have sufficient space to effectively reduce runoff using bioretention cells, assuming the soils and vegetation could be amended and enhanced where necessary.

Conventional pavements can be converted to porous asphalt or concrete or replaced with concrete or plastic unit pavers or grid systems. For such approaches to be most effective, the soils must be capable of infiltrating the runoff passing through, and may require renovation.

Source reduction can be enhanced by the LID practice of water harvesting, in which water from impervious surfaces is captured and stored for reuse in irrigation or gray water systems. For example, runoff from roofs and parking lots can be harvested, with the former being somewhat easier because of the possibility of avoiding pumping to use the water and fewer pollutants. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings.[5] Many successful systems of this type are in operation, such as the Natural Resources Defense Council office (Santa Monica, CA), the King County Administration Building (Seattle, WA), and two buildings on the Portland State University campus (Portland, OR). This investigation examined how water harvesting could contribute to stormwater management for case study sites where infiltration capacity, available space, or both appeared to be limited.

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[4] http://gis.ca.gov/catalog/BrowseCatalog.epl?id=108, http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

[5] New Buildings Institute, Inc., *Advanced Buildings* (2005) (http://www.poweryourdesign.com/LEEDGuide.pdf).

RESULTS OF THE ANALYSIS

1. *"Base Case" Analysis: Development without Stormwater Controls*

Comparison of Pre- and Post-Development Runoff Volumes

Table 2 presents a comparison between the estimated runoff volumes generated by the respective case study sites in the pre- and post-development conditions, assuming implementation of no stormwater controls on the developed sites. On sites dominated by impervious land cover, most of the infiltration that would recharge groundwater in the undeveloped state is expected to be lost to surface runoff after development. This greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, raise flooding risk, and transport pollutants. Only the office building, the plan for which retained substantial pervious area, would lose less than 40 percent of the site's pre-development recharge.

Table 2. Pre- and Post-Development without BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[c]	8.07	1.51	0.42	0.57	66	0.09
Post-development pervious runoff[c]	0.51	0.24	0.06	0.23	10	0.01
Post-development total runoff[c]	8.58	1.75	0.48	0.80	76	0.10
Post-development recharge[d]	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge loss (% of pre-development)	7.68 (65%)	1.50 (46%)	0.41 (49%)	0.65 (27%)	66 (45%)	0.08 (41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[c]	11.5	2.16	0.60	0.82	94	0.13
Post-development pervious runoff[c]	0.73	0.34	0.08	0.33	15	0.01
Post-development total runoff[c]	12.2	2.50	0.68	1.15	109	0.14
Post-development recharge[d]	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge loss (% of pre-development)	10.9 (65%)	2.15 (46%)	0.58 (49%)	0.91 (27%)	94 (45%)	0.11 (41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff

Pollutant Concentrations and Loadings

Table 3 presents the pollutant concentrations from the literature and loadings calculated as described for the various land use and cover types represented by the case studies. Landscaped areas are expected to release the highest TSS concentration, although relatively low TSS mass loading because of the low runoff coefficient. The highest copper concentrations and loadings are expected from parking lots. Roofs, especially commercial roofs, top the list for both zinc concentrations and loadings. Landscaping would issue by far the highest phosphorus, although access roads and driveways would contribute the highest mass loadings. With expected concentrations being equal in the two rainfall zones, mass loadings in the 20 inches/year zone would be higher than those in the 14 inches/year zone in the same proportion as the ratio of rainfall quantities.

Table 3. Pollutant Concentrations and Loadings for Case Study Land Use and Cover Types

Land Use	Concentrations				Loadings			
	TSS (mg/L)	TCu (mg/L)	TZn (mg/L)	TP (mg/L)	Lbs. TSS/ acre-year	Lbs. TCu/ acre-year	Lbs. TZn/ acre-year	Lbs. TP/ acre-year
14 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	75	0.039	0.477	0.330
Commercial roof	18	0.014	0.281	0.14	54	0.042	0.844	0.420
Access road/driveway	120	0.022	0.118	0.66	360	0.066	0.354	1.981
Parking	75	0.036	0.097	0.14	225	0.108	0.291	0.420
Walkway	25	0.013	0.059	0.11	75	0.039	0.177	0.330
Landscaping	213	0.013	0.059	2.04	81	0.005	0.022	0.774
20 Inches/Year Rainfall:								
Residential roof	25	0.013	0.159	0.11	107	0.056	0.683	0.472
Commercial roof	18	0.014	0.281	0.14	77	0.060	1.207	0.601
Access road/driveway	120	0.022	0.118	0.66	515	0.094	0.507	2.834
Parking	75	0.036	0.097	0.14	322	0.155	0.417	0.601
Walkway	25	0.013	0.059	0.11	107	0.056	0.253	0.472
Landscaping	213	0.013	0.059	2.04	135	0.008	0.037	1.291

The Basin Plan freshwater acute criteria for copper and zinc are 0.013 mg/L and 0.120 mg/L, respectively (http://www.swrcb.ca.gov/rwqcb2/basinplan/web/BP_CH3.html). All developed land uses are expected to discharge copper at or above the criterion, based on the mass balance calculations using concentrations from Table 3. Any surface release from the case study sites would just meet or violate the criterion at the point of discharge, although dilution by the receiving water would lower the concentration below the criterion at some point. Even if copper mass loadings are reduced by BMPs, any surface discharge would equal or exceed the criterion initially, but it would be easier to dilute below that level. In contrast, runoff from land covers other than roofs would not violate the acute zinc criterion. Because of this difference, the evaluation considered whether or not the zinc criterion would be exceeded in each analysis, whereas there was no point in this analysis for copper. There are no equivalent water quality criteria for TSS and TP; hence, their concentrations were not further analyzed in the different scenarios.

Table 4 shows the overall loadings, as well as zinc concentrations, expected to be delivered from the case study developments should they not be fitted with any BMPs. As Table 4 shows, all cases are forecast to exceed the 0.120 mg/L acute zinc criterion. Because of its size, the large residential development dominates the mass loading emissions.

Table 4. Case Study Pollutant Concentration and Loading Estimates without BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1254	328	119	230	14249	20
Lbs. TCu/year	0:44	0.070	0.030	0.043	3.04	0.004
Lbs. TZn/year	2.94	0.576	0.165	0.286	25.04	0.034
Lbs. TP/year	6.24	2.27	0.68	1.69	98.55	0:14
20 Inches/ Year Rainfall:						
TZn (mg/L)	0.127	0.123	0.128	0.133	0.123	0.121
Lbs. TSS/year	1864	501	180	360	21781	30
Lbs. TCu/year	0.63	0.102	0.043	0.063	4.44	0.006
Lbs. TZn/year	4.22	0.833	0.238	0.417	36.2	0.050
Lbs. TP/year	9.60	3.55	1.05	2.71	154	0.22

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home

2. *"Conventional BMP" Analysis: Effect of Basic Treatment BMPs*

Effect of Basic Treatment BMPs on Post-Development Runoff Volumes

The current set of regional permits allows regulated parties to select from a range of BMPs in order to treat or infiltrate a given quantity of annual rainfall. The administrative draft of the proposed MRP is also non-specific regarding the role of LID in satisfying permit conditions. The range of BMPs includes drain inlet inserts, CDS units, and other manufactured BMPs, detention vaults, and sand filters, all of which isolate runoff from the soil; as well as basins and biofiltration BMPs built in soil and generally having vegetation. Treatment BMPs that do not permit any runoff contact with soils discharge as much stormwater runoff as equivalent sites with no BMPs, and hence yield zero savings in recharge. As mentioned above, the CalTrans (2004) study found that BMPs with a natural surface can reduce runoff by substantial margins (30-50 percent for extended-detention basins and biofiltration).

With such a wide range of BMPs in use, runoff reduction ranging from 0 to 50 percent, and a lack of clearly ascertainable requirements, it is not possible to make a single estimate of how much recharge savings are afforded by maximal implementation of the current permits or the Municipal Regional Permit (MRP), if issued as now proposed. We made the following assumptions regarding implementation of BMPs. Assuming natural-surface BMPs perform at the average of the three types tested by CalTrans (2004), i.e., 40 percent runoff reduction, the estimate can be bounded as shown in Table 5. The table demonstrates that allowing free choice of BMPs without regard to their ability to direct water into the ground forfeits substantial groundwater recharge benefits when hardened-surface BMPs are selected. Use of soil-based conventional BMPs could cut recharge losses from half or more of the full potential to about one-quarter to one-third or less, except with the highly impervious commercial development. This analysis shows the wisdom of draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way. But as subsequent analyses showed, soil amendment can gain considerably greater benefits.

Table 5. Pre- and Post-Development with Conventional BMPs: Distribution of Surface Runoff Versus Recharge to Groundwater (annual volume in acre-ft)

Distribution	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Precipitation[b]	12.8	3.54	0.90	2.47	154	0.21
Pre-development runoff[c]	0.89	0.25	0.07	0.17	10	0.02
Pre-development recharge[d]	11.9	3.29	0.83	2.30	144	0.19
Post-development impervious runoff[e]	4.84-8.07	0.90-1.51	0.25-0.42	0.34-0.57	39-66	0.05-0.09
Post-development pervious runoff[e]	0.30-0.51	0.14-0.24	0.04-0.06	0.13-0.23	6.3-10	0.006-0.01
Post-development total runoff[e]	5.15-8.58	1.05-1.75	0.29-0.48	0.48-0.80	46-76	0.06-0.10
Post-development recharge[d, e]	4.22-7.60	1.79-2.49	0.42-0.62	1.67-2.00	78-108	0.11-0.15
Post-development recharge loss (% of pre-development)[e]	4.29-7.68 (36-65%)	0.80-1.50 (24-46%)	0.80-0.41 (26-49%)	0.30-0.65 (13-27%)	34-66 (24-45%)	0.05-0.08 (24-41%)
20 Inches/Year Rainfall:						
Precipitation[b]	18.2	5.06	1.29	3.54	220	0.30
Pre-development runoff[c]	1.28	0.35	0.10	0.24	15	0.03
Pre-development recharge[d]	16.9	4.71	1.19	3.30	205	0.27
Post-development impervious runoff[e]	6.92-11.5	1.29-2.16	0.35-0.60	0.49-0.82	56-94	0.08-0.13
Post-development pervious runoff[e]	0.44-0.73	0.20-0.34	0.05-0.08	0.19-0.33	9.0-15	0.006-0.01
Post-development total runoff[e]	7.36-12.2	1.50-2.50	0.41-0.68	0.68-1.15	65-109	0.08-0.14
Post-development recharge[d, e]	6.0-10.8	2.56-3.56	0.61-0.88	2.39-2.86	111-155	0.16-0.22
Post-development recharge loss (% of pre-development)[e]	6.1-10.9 (36-65%)	1.14-2.15 (24-46%)	0.31-0.58 (26-49%)	0.44-0.91 (13-27%)	49-94 (24-45%)	0.07-0.11 (24-41%)

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single-family home. Ranges represent 40 percent runoff volume reduction, with full site coverage by BMPs having a natural surface, to no reduction, with BMPs isolating runoff from soil.
[b] Volume of precipitation on total project area
[c] Quantity of water discharged from the site on the surface
[d] Quantity of water infiltrating the soil; the difference between precipitation and runoff [e] Ranging from the quantity with hardened bed BMPs to the quantity with soil-based BMPs

Effect of Basic Treatment BMPs on Pollutant Discharges

Table 6 presents estimates of zinc effluent concentrations and mass loadings of the various pollutants discharged from four types of conventional treatment BMPs. The loading reduction results show the CDS units always performing below 50 percent reduction for all pollutants analyzed, and most often in the vicinity of 20 percent, with zero copper reduction.

Table 6. Pollutant Concentration and Mass Loading Reduction Estimates with Conventional BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Effluent Concentrations:						
CDS TZn (mg/L)[a]	0.095	0.095	0.098	0.102	0.095	0.094
EDB TZn (mg/L)[a]	0.085	0.086	0.084	0.084	0.086	0.084
Swale TZn (mg/L)	0.055	0.054	0.055	0.056	0.054	0.053
Filter strip TZn (mg/L)	0.039	0.039	0.039	0.041	0.039	0.038
Mass Loading Reductions—14 Inches/Year Rainfall:						
CDS TSS reduction	15.7%	19.9%	22.0%	24.0%	19.9%	20.2%
CDS TCu reduction	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
CDS TZn reduction	22.7%	22.4%	22.9%	23.1%	22.4%	22.5%
CDS TP reduction	30.6%	41.5%	40.7%	45.9%	41.5%	42.0%
EDB TSS reduction	68.1%	73.7%	79.0%	81.1%	73.7%	74.3%
EDB TCu reduction	61.9%	55.7%	66.2%	63.0%	55.7%	55.8%
EDB TZn reduction	59.7%	59.6%	60.4%	61.9%	59.6%	59.8%
EDB TP reduction	61.9%	69.7%	69.1%	72.9%	69.7%	70.1%
Swale TSS reduction	68.8%	71.1%	73.1%	73.9%	71.1%	71.3%
Swale TCu reduction	72.5%	68.5%	78.2%	73.3%	68.5%	68.5%
Swale TZn reduction	78.4%	78.1%	84.3%	78.8%	78.1%	78.2%
Swale TP reduction	66.3%	70.7%	67.2%	76.2%	70.7%	71.1%
Filter strip TSS reduction	69.9%	75.4%	80.6%	82.6%	75.4%	76.0%
Filter strip TCu reduction	74.4%	69.1%	78.2%	75.4%	69.1%	69.1%
Filter strip TZn reduction	78.3%	77.9%	78.4%	78.7%	77.9%	78.1%
Filter strip TP reduction	48.4%	53.1%	63.7%	59.8%	53.1%	53.5%

Table 6 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Mass Loading Reductions—20 Inches/Year Rainfall:						
CDS TSS reduction	18.8%	25.0%	26.3%	30.5%	25.0%	25.4%
CDS TCu reduction	0.7%	1.9%	1.1%	3.0%	1.9%	2.0%
CDS TZn reduction	23.1%	23.3%	23.6%	24.7%	23.3%	23.4%
CDS TP reduction	35.4%	46.6%	44.8%	51.8%	46.6%	47.1%
EDB TSS reduction	68.8%	74.6%	79.6%	81.6%	74.6%	75.1%
EDB TCu reduction	61.8%	55.6%	66.0%	62.7%	55.6%	55.7%
EDB TZn reduction	59.6%	59.3%	60.2%	61.5%	59.3%	59.6%
EDB TP reduction	63.0%	70.4%	69.7%	73.4%	70.4%	70.7%
Swale TSS reduction	69.1%	71.4%	73.6%	74.1%	71.4%	71.6%
Swale TCu reduction	72.5%	68.4%	77.9%	73.1%	68.4%	68.5%
Swale TZn reduction	78.3%	78.0%	84.1%	78.6%	78.0%	78.1%
Swale TP reduction	67.6%	71.9%	68.2%	77.1%	71.9%	72.3%
Filter strip TSS reduction	70.6%	76.3%	81.2%	83.1%	76.3%	76.8%
Filter strip TCu reduction	74.4%	69.0%	78.0%	75.1%	69.0%	69.1%
Filter strip TZn reduction	78.2%	77.8%	78.3%	78.5%	77.8%	77.9%
Filter strip TP reduction	49.9%	54.6%	66.3%	61.0%	54.6%	55.0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home; CDS— continuous deflective separation unit; EDB—extended-detention basin

When treated with extended-detention basins, swales, or filter strips, effluents from each development case study site are expected to fall below the Basin Plan acute zinc criterion. These natural-surface BMPs, if fully implemented and well maintained, are predicted to prevent the pollutant masses generated on the six case study development sites from reaching a receiving water in both rainfall zones, which do not differ appreciably. Only total phosphorus reduction falls below 50 percent for three case studies. Otherwise, mass loading reductions range from about 60 to above 80 percent for the EDB, swale, and filter strip. These data indicate that draining impervious to pervious surfaces, even if those surfaces are not prepared in any special way, pays water quality as well as hydrologic dividends.

3. *LID Analysis*

(a) Hydrologic Analysis

The LID analysis repeats the analysis above, focusing here on the performance of LID techniques in reducing or eliminating runoff from the six development case studies. In addition to assessing the total runoff that would be expected, the analysis also considered whether LID techniques would be sufficient to attain compliance with a performance standard being considered by the Los Angeles Regional Water Quality Control Board for Ventura County, California. This standard limits EIA (Effective Impervious Area) to five percent (but our analysis further assumed EIA would be ultimately reduced to three percent). All runoff from NCIA (Not-Connected Impervious Area) was assumed to drain to vegetated surfaces.

One goal of this exercise was to identify methods that reduce runoff production in the first place. It was hypothesized that implementation of source reduction techniques could allow all of the case study sites to infiltrate substantial proportions, or all, of the developed site runoff, advancing the hydromodification mitigation objective of the Draft Permit. When runoff is dispersed into the soil instead of being rapidly collected and conveyed away, it recharges groundwater, supplementing a resource that maintains dry season stream flow and wetlands. An increased water balance can be tapped by humans for potable, irrigation, and process water supply. Additionally, runoff volume reduction would commensurately decrease pollutant mass loadings.

Accordingly, the analysis considered the practicability of more than one scenario. In one option, all roof runoff is harvested and stored for some beneficial use. A second option disperses runoff into the soil via roof downspout infiltration trenches. The former option is probably best suited to cases like large commercial and office buildings, while distribution in the soil would fit best with residences and relatively small commercial developments. The analysis was repeated with the assumptions of harvesting OFF roof runoff for some beneficial use and dispersing roof runoff from the remaining four cases in roof downspout infiltration systems.

Expected Infiltration Capacities of the Case Study Sites

The first inquiry on this subject sought to determine how much of the total annual runoff each property is expected to infiltrate, since infiltration is a basic (although not exclusive) LID technique. Based on the findings of Chralowicz et al. (2001), it was assumed that an infiltration zone of 0.1-0.5 acres in area and 2-3 ft deep would serve a drainage catchment area in the size range 0-5 acres and infiltrate 0.9-1.9 acre-ft/year. The conclusions of Chralowicz et al. (2001) were extrapolated to conservatively assume that 0.5 acre would be required to serve each additional five acres of catchment, and would infiltrate an incremental 1.4 acre-ft/year (the midpoint of the 0.9-1.9 acre-ft/year range). According to these assumptions, the following schedule of estimates applies:

Pervious Area Available for Infiltration	Catchment Served acres	Infiltration Capacity
0.5 acres	0-5 acres	1.4 acre-ft/year
1.0 acres	5-10 acres	2.8 acre-ft/year
1.5 acres	10-15 acres	4.2 acre-ft/year
(Etc.)	...	...

As a formula, infiltration capacity ≈ 2.8 x available pervious area. To apply the formula conservatively, the available area was reduced to the next lower 0.5-acre increment before multiplying by 2.8.

As shown in Table 7, in both rainfall zones all six of the sites have adequate or greater capacity to infiltrate the full annual runoff volume expected from NCIA and pervious areas where EIA is limited to three percent of the total site area. Indeed, five of the six development types have sufficient pervious area to infiltrate *all* runoff, including runoff from EIA areas. These results are based on infiltrating in the native soils with no soil amendment. For any development project at which infiltration-oriented BMPs are considered, it is important that infiltration potential be carefully assessed using site-specific soils and hydrogeologic data. In the event such an investigation reveals a marginal condition (e.g., hydraulic conductivity, spacing to groundwater) for infiltration basins, soils could be enhanced to produce bioretention zones to assist infiltration. Notably, the five case studies with far greater than necessary infiltration capacity would offer substantial flexibility in designing infiltration, allowing ponding at less than 2-3 ft depth.

Table 7. Infiltration and Runoff Volume (With 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
NCIA + pervious area runoff (acre-ft/year)	**8.20**	**1.64**	**0.45**	**0.73**	**71.3**	**0.08**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.7	0.09
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
NCIA + pervious area runoff (acre-ft/year)	**11.7**	**2.34**	**0.64**	**1.04**	**101.7**	**0.14**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration potential[c]	84%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Compare runoff production from NCIA + pervious area (row 3) with estimated infiltration capacity (row 6)

As Table 7 shows, each of the six case study sites have the capacity to infiltrate *all* or substantially all of the runoff produced onsite annually by draining impervious surfaces to pervious areas on native soils or, in some soil regimes, soils amended with organic matter. If these sites were designed as envisioned in this analysis, no runoff discharge is expected in storms as large as, and probably larger than, the design storm event—using infiltration only. Discharge would be anticipated only with exceptionally intense, large, or prolonged rainfall that saturates the ground at a faster rate than water can infiltrate or evaporate. Even runoff from the area assumed to be EIA could be infiltrated in most cases based on the amount of pervious area available in typical development projects. Therefore, this analysis shows that the EIA performance standard being considered for Ventura County, California, or one more stringent, can be met readily in development projects occurring on A, B, and C soils in the San Francisco Bay Area.

Additional Source Reduction Capabilities of the Case Study Sites: Water Harvesting Example

As noted, infiltration is one of a wide variety of LID-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other source LID measures can enhance a site's runoff retention capability. For example, soil amendment, which improves infiltration, is a standard LID technique. Water harvesting is another. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Table 8 shows the added LID implementation flexibility created by subtracting roof runoff by harvesting it or efficiently directing it into the soil through downspout dispersion systems, further demonstrating the feasibility and robust performance of LID options for reducing or eliminating runoff in most expected conditions. Specifically, all development types studied could readily infiltrate and/or retain all expected annual precipitation.

Table 8. Infiltration and Runoff Volume Reduction Analysis Including Roof Runoff Harvesting or Disposal in Infiltration Trenches (Assuming 3 Percent EIA and All NCIA Draining to Pervious Areas)

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.36	0.10	0.03	0.07	4.4	0.01
Roof runoff (acre-ft/year)	4.68	0.89	0.08	0.19	38.5	0.05
Other NCIA + pervious area runoff (acre-ft/year)	**3.52**	**0.75**	**0.37**	**0.54**	**32.7**	**0.04**
Total runoff (acre-ft/year)	8.56	1.74	0.48	0.80	75.6	0.10
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%
20 Inches/Year Rainfall:						
EIA runoff (acre-ft/year)	0.52	0.14	0.04	0.10	6.2	0.01
Roof runoff (acre-ft/year)	6.67	1.27	0.12	0.28	55.1	0.08
Other NCIA + pervious area runoff (acre-ft/year)	**5.03**	**1.07**	**0.52**	**0.76**	**46.7**	**0.06**
Total runoff (acre-ft/year)	12.2	2.48	0.68	1.14	108.0	0.15
Pervious area available for infiltration (acres)	3.66	1.67	0.39	1.61	72.7	0.10

Table 8 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
Estimated infiltration capacity (acre-ft/year)[b]	**9.8**	**4.2**	**1.4**	**4.2**	**203**	**0.28**
Infiltration capacity[c]	>100%	>100%	>100%	>100%	>100%	>100%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—single family home;
[b] Based on Chralowicz et al. (2001) according to the schedule described above
[c] Comparison of runoff production from NCIA + pervious area **(row 3)** with estimated infiltration capacity **(row 6)**

Effect of Full LID Approach on Recharge

Table 9 shows the recharge benefits of preventing roofs from generating runoff and infiltrating as much as possible of the runoff from the remainder of the case study sites. The data show that LID methods offer significant benefits relative to the baseline (no stormwater controls) in all cases. These benefits are particularly impressive in developments with relatively high site imperviousness, such as in the MFR case.

Table 9. Comparison of Water Captured Annually (in acre-ft) from Development Sites for Beneficial Use with a Full LID Approach Compared to Development With No BMPs

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
14 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	11.9	3.29	0.83	2.30	144	0.19
No BMPs—						
Post-development recharge[b] (acre-ft)	4.22	1.79	0.42	1.67	78	0.11
Post-development recharge lost (acre-ft)	7.68	1.50	0.41	0.65	66	0.08
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	11.9	3.29	0.83	2.30	144	0.19
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

Table 9 continued

	MFR[a]	Sm-SFR[a]	REST[a]	OFF[a]	Lg-SFR[a]	SINGLE[a]
20 Inches/Year Rainfall:						
Pre-development recharge[b] (acre-ft)	16.9	4.71	1.19	3.30	205	0.27
No BMPs—						
Post-development recharge[b] (acre-ft)	6.0	2.56	0.61	2.39	111	0.16
Post-development recharge lost (acre-ft)	10.9	2.15	0.58	0.91	94	0.11
Post-development % recharge lost	65%	46%	49%	27%	45%	41%
Full LID approach—						
Post-development runoff capture (acre-ft)[c]	16.9	4.71	1.19	3.30	205	0.27
Post-development recharge lost (acre-ft)	0	0	0	0	0	0
Post-development % recharge lost	0%	0%	0%	0%	0%	0%

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; REST—restaurant; OFF—office building; Lg-SFR—large-scale single-family residential; SINGLE—Single family home

[b] Quantity of water infiltrating the soil; the difference between precipitation and runoff

[c] Water either entirely infiltrated in BMPs and recharged to groundwater or partially harvested from roofs and partially infiltrated in BMPs. EIA was not distinguished from the remainder of the development, because these sites have the potential to capture all runoff.

(b) Water Quality Analysis

It was assumed that any site discharges would be subject to treatment control. For purposes of the analysis, treatment control was assumed to be provided by conventional sand filtration. This choice is appropriate for study purposes for two reasons. First, sand filters can be installed below grade, and land above can be put to other uses. Pervious area should be reserved for receiving NCIA drainage, and using sand filters would not draw land away from that service or other site uses. A second reason for the choice is that sand filter performance data equivalent to the data used in analyzing other conventional BMPs are available from the CalTrans (2004) work. Sand filters may or may not expose water to soil, depending on whether or not they have a hard bed. This analysis assumed a hard bed, meaning that no infiltration would occur and thus there would be no additional recharge in sand filters. Performance would be even better than shown in the analytical results if sand filters were built in earth.

Pollutant Discharge Reduction Through LID Techniques

The preceding analyses demonstrated that in each of the six case studies, *all* stormwater discharges could be eliminated at least under most meteorological conditions by dispersing runoff from impervious surfaces to pervious areas. Therefore, pollutant additions to receiving waters would also be eliminated.

SUMMARY AND CONCLUSIONS

This paper demonstrated that common Bay Area residential and commercial development types subject to the Municipal NPDES Permit are likely, without stormwater management, to reduce groundwater recharge from the pre-development state by approximately half in most cases to a much higher fraction with a large ratio of impervious to pervious area. With no treatment, runoff from these developments is expected to exceed Basin Plan acute copper and zinc criteria at the point of discharge and to deliver large pollutant mass loadings to receiving waters.

Conventional soil-based BMP solutions that promote and are component parts of low impact development approaches, by contrast, regain about 30-50 percent of the recharge lost in development without stormwater management in Bay Area locations having NRCS Hydrologic Soil Groups A, B, and C. It is expected the soil-based BMPs generally would release effluent that meets the acute zinc criterion at the point of discharge, although it would still exceed or just barely meet the copper limit. Excepting phosphorus, it was found that these BMPs would capture and prevent the movement to receiving waters of the majority of the pollutant loadings considered in the analysis.

It was found that by draining all site runoff to pervious areas with A, B, or C soil types, runoff can be eliminated entirely in most development categories. It follows that a three percent Effective Impervious Area standard can be met in typical developments, as well. This result was reached assuming the use of native soils or well recognized soil enhancement techniques (typically, with compost). Draining impervious surfaces onto these soils, in connection with limiting directly connected impervious area to three percent of the site total area, should eliminate storm runoff from some development types and greatly reduce it from more highly impervious types. Adding roof runoff elimination to the LID approach (by harvesting or directing it to downspout infiltration trenches) provides an additional tool, increasing flexibility and confidence that no discharge in most meteorological conditions is a feasible performance expectation. Even in the development scenarios involving the highest relative proportion of impervious surface, losses of rainfall capture for beneficial uses could be reduced from the untreated scenario when draining to pervious areas was supplemented with water harvesting. These results demonstrate the basic soundness of the concept of using LID techniques to reduce stormwater pollution in the Bay Area, and further show that limiting directly connected impervious area and draining the remainder over pervious surfaces, as contemplated by some Regional Water Boards in California, is also feasible.

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ATTACHMENT A

POLLUTANT CONCENTRATIONS FOR URBAN SOURCE AREAS (HERRERA ENVIRONMENTAL CONSULTANTS, INC. UNDATED)

Source Area	Study	Location	Sample Size (n)	TSS (mg/L)	TCu (ug/L)	TPb (ug/L)	TZn (ug/L)	TP (mg/L)	Notes
Roofs									
Residential	Steuer, et al. 1997	MI	12	36	7	25	201	0.06	2
Residential	Bannerman, et al. 1993	WI	~48	27	15	21	149	0.15	3
Residential	Waschbusch, et al. 2000	WI	25	15	n.a.	n.a.	n.a.	0.07	3
Residential	FAR 2003	NY		*19*	*20*	*21*	*312*	*0.11*	4
Residential	Gromaire, et al. 2001	France		*29*	*37*	*493*	*3422*	*n.a.*	5
Representative Residential Roof Values				**25**	**13**	**22**	**159**	**0.11**	
Commercial	Steuer, et al. 1997	MI	12	24	20	48	215	0.09	2
Commercial	Bannerman, et al. 1993	WI	~16	15	9	9	330	0.20	3
Commercial	Waschbusch, et al. 2000	WI	25	18	n.a.	n.a.	n.a.	0.13	3
Representative Commercial Roof Values				**18**	**14**	**26**	**281**	**0.14**	
Parking Areas									
Res. Driveways	Steuer, et al. 1997	MI	12	157	34	52	148	0.35	2
Res. Driveways	Bannerman, et al. 1993	WI	~32	173	17	17	107	1.16	3
Res. Driveways	Waschbusch, et al. 2000	WI	25	34	n.a.	n.a.	n.a.	0.18	3
Driveway	FAR 2003	NY		*173*	*17*		*107*	*0.56*	4
Representative Residential Driveway Values				**120**	**22**	**27**	**118**	**0.66**	
Comm./ Inst. Park. Areas	Pitt, et al. 1995	AL	16	110	116	46	110	n.a.	1
Comm. Park. Areas	Steuer, et al. 1997	MI	12	110	22	40	178	0.2	2
Com. Park. Lot	Bannerman, et al. 1993	WI	5	58	15	22	178	0.19	3
Parking Lot	Waschbusch, et al. 2000	WI	25	51	n.a.	n.a.	n.a.	0.1	3
Parking Lot	Tiefenthaler, et al. 2001	CA	5	36	28	45	293	n.a.	6
Loading Docks	Pitt, et al. 1995	AL	3	40	22	55	55	n.a.	1
Highway Rest Areas	CalTrans 2003	CA	53	*63*	*16*	*8*	*142*	*0.47*	7
Park and Ride Facilities	CalTrans 2003	CA	179	*69*	*17*	*10*	*154*	*0.33*	7
Comm./ Res. Parking	FAR 2003	NY		*27*	*51*	*28*	*139*	*0.15*	4
Representative Parking Area/Lot Values				**75**	**36**	**26**	**97**	**0.14**	

Landscaping/Lawns									
Landscaped Areas	Pitt, et al. 1995	AL	6	33	81	24	230	n.a.	1
Landscaping	FAR 2003	NY		*37*	*94*	*29*	*263*	n.a.	4
Representative Landscaping Values				**33**	**81**	**24**	**230**	**n.a.**	
Lawns - Residential	Steuer, et al. 1997	MI	12	262	n.a.	n.a.	n.a.	2.33	2
Lawns - Residential	Bannerman, et al. 1993	WI	~30	397	13	n.a.	59	2.67	3
Lawns	Waschbusch, et al. 2000	WI	25	59	n.a.	n.a.	n.a.	0.79	3
Lawns	Waschbusch, et al. 2000	WI	25	122	n.a.	n.a.	n.a.	1.61	3
Lawns - Fertilized	USGS 2002	WI	58	n.a.	n.a.	n.a.	n.a.	2.57	3
Lawns - Non-P Fertilized	USGS 2002	WI	38	n.a.	n.a.	n.a.	n.a.	1.89	3
Lawns - Unfertilized	USGS 2002	WI	19	n.a.	n.a.	n.a.	n.a.	1.73	3
Lawns	FAR 2003	NY	3	*602*	*17*	*17*	*50*	*2.1*	4
Representative Lawn Values				**213**	**13**	**n.a.**	**59**	**2.04**	

Notes:

Representative values are weighted means of collected data. Italicized values were omitted from these calculations.

1 - Grab samples from residential, commercial/institutional, and industrial rooftops. Values represent mean of DETECTED concentrations

2 - Flow-weighted composite samples, geometric mean concentrations

3 - Geometric mean concentrations

4 - Citation appears to be erroneous - original source of data is unknown. Not used to calculate representative value

5 - Median concentrations. Not used to calculate representative values due to site location and variation from other values.

6 - Mean concentrations from simulated rainfall study

7 - Mean concentrations. Not used to calculate representative values due to transportation nature of land use.

RB-AR33201

SUPPLEMENTARY INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES ("LID") FOR THE SAN FRANCISCO BAY AREA

Richard R. Horner†

ABSTRACT

The Clean Water Act NPDES permit that regulates municipal separate storm sewer systems (MS4s) in the San Francisco Bay Area, California will be reissued in 2007. The draft permit includes general provisions related to low impact development practices (LID) for certain kinds of development and redevelopment projects. Using eight representative development project case studies, based on California building records, the author investigated the practicability and relative benefits of LID options for the portion of the region having soils potentially limiting to infiltration. The principal LID option applicable in this situation is roof runoff harvesting, supplement by dispersion of the roof water in single-home sites. Other site runoff would be treated by conventional stormwater best management practices (BMPs), as specified in the permit. The results showed that effectively managing roof runoff and treating the remainder with conventional BMPS can: (1) reduce annual runoff volumes by almost half to more than 3/4, depending on land use characteristics, with much of the water saved available for a beneficial use; and (2) decrease mass loadings of pollutants to receiving waters by 63 to over 90 percent, depending on pollutant and land use.

† Richard R. Horner, Ph.D., Research Associate Professor, University of Washington Departments of Civil and Environmental Engineering and Landscape Architecture; Adjunct Associate Professor, University of Washington Center for Urban Horticulture

INTRODUCTION

Background

A report titled Initial Investigation of the Feasibility and Benefits of Low-Impact Development Practices ("LID") for the San Francisco Bay Area used six representative development project case studies, based on California building records, to investigate the practicability and relative benefits of LID options for the majority of the region having soils potentially suitable for infiltration either in their natural state or after amendment using well recognized LID techniques. The results demonstrated that: (1) LID site design and source control techniques are more effective than conventional best management practices (BMPs) in reducing runoff rates; and (2) in each of the case studies, LID methods would reduce site runoff volume and pollutant loading to zero in typical rainfall scenarios.

For a broad regional assessment of relatively large scale use of soil-based, infiltrative LID practices, the initial report covered areas having soils in Natural Resources Conservation Service (NRCS) Hydrologic Soil Groups A, B, or C as classified by the Natural Resources Conservation Service (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx). Depending on site-specific conditions, A and B soils would generally effectively infiltrate water without modification, whereas C soils could require organic amendments according to now standard LID methods. This supplementary report covers locations with group D soils, which are generally not amenable to infiltration, again depending on the specific conditions on-site. A minority but still substantial fraction of the Bay Area has group D soils (39.3, 68.0, 18.3, and 50.1 percent of the mapped areas of Alameda, Contra Costa, San Mateo, and Santa Clara Counties, respectively). Regarding any mapped soil type, it is important to keep in mind that soils vary considerably within small distances. Characteristics at specific locations can deviate greatly from those of the major mapped unit, making infiltration potential either more or less than may be expected from the mapping. The soil survey data are regarded as appropriate for use in broad-scale assessments such as underlie this and the initial report, but once site-specific implementation begins, it is important to verify site conditions.

General Assessment Methods

The assessment for group D soils reported herein emphasizes the use of LID practices appropriate in areas with relatively restrictive soils to the greatest possible extent, supplemented by conventional stormwater management practices implemented at fully practicable, high levels of effectiveness. The assessment was performed in a manner analogous to the analysis for the other soil groups and as described in the initial report. To recap briefly, with respect to each of several development case studies, three assessments were undertaken: a baseline scenario incorporating no stormwater management controls; a second scenario employing conventional BMPs; and a third development scenario employing LID stormwater management strategies. In each assessment, annual stormwater runoff volumes were estimated, as well as concentrations and mass loadings (the products of concentrations times flow volumes) of four pollutants: (1) total suspended solids (TSS), (2) total recoverable copper (TCu), (3) total recoverable zinc (TZn), and (4) total phosphorus (TP). The results of the second and third assessments were expressed in terms of the extent to which the management practices would reduce pollutant concentrations and loadings and runoff volumes, converting stormwater discharge a potential beneficial use (direct consumption or, in the case of group A, B, C soil areas, groundwater recharge).

Six case studies were selected to represent a range of urban development types considered to be representative of the Bay Area. These case studies involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a restaurant (REST), an office building (OFF), a relatively large (1000 homes) single-family residential development (Lg-SFR), and a single home (SINGLE). The land cover types for these various land uses were derived from building permit and other public records from the Bay Area or elsewhere in California.

Adaptation of Methods for Areas with Group D Soils

A key LID technique in a setting with soils relatively restrictive to infiltration is water harvesting, which can be applied at larger scales in commercial and light industrial developments and at smaller residential scales using cisterns or rain barrels. Harvesting has been successful in reducing runoff discharged to the storm drain system and conserving water in applications at all scales. For example, in downtown Seattle the King County Government Center collects enough roof runoff to supply over 60 percent of the toilet flushing and plant irrigation water requirements, saving approximately 1.4 million gallons of potable water per year (http://www.psat.wa.gov/Publications/LID_studies/rooftop_rainwater.htm; http://dnr.metrokc.gov/dnrp/ksc_tour/features/features.htm). A much smaller public building in Seattle, the Carkeek Environmental Learning Center, drains roof runoff into a 3500-gallon cistern to supply toilets (http://www.harvesth2o.com/seattle.shtml). Collecting drainage from individual dwellings for household use is a standard technique around the world, particularly in areas deficient in rainfall and without affordable alternative sources.

An additional general category of LID practices for poorly infiltrating locations, applicable especially at single homes and other relatively small-scale developments, is runoff dispersion for storage in vegetation and soil until evapotranspiration and some infiltration occurs. Section C.3.c of the California Regional Water Quality Control Board San Francisco Bay Region "Administrative Draft" NPDES Municipal Regional Stormwater Permit ("the Permit") requires all single-family home projects that create and/or replace 5,000 square feet or more of impervious surface to implement one or more stormwater lot-scale BMPs from a selection of: (1) diverting roof runoff to vegetated areas; (2) directing paved surface runoff flow to vegetated areas; and/or (3) installing driveways, patios, and walkways with pervious material such as pervious concrete or pavers. Another way of distributing and dissipating roof runoff used successfully in varied soils in the state of Washington is the downspout dispersion system, consisting of a splash block or gravel-filled trench serving to spread roof runoff over a vegetated area (Washington Department of Ecology 2005 [Volume III, Section 3.1.2]).

The basis of the group D soils assessment was harvesting roof runoff to the maximum possible degree, supplemented in smaller-scale developments by runoff dispersion methods. The report asserts that, through these LID BMPs, it is practicable to prevent the entrance of any roof runoff into the municipal storm drain system in any soils setting in the Bay Area. In group D soils, infiltration likely cannot be relied upon to reduce runoff from other portions of developments, such as walkways, driveways, parking lots, access roads, and landscaping. Some water loss would undoubtedly occur, especially through evapotranspiration and at least some infiltration of runoff generated on or directed to landscaping. The analysis presented in this report does not take account of these losses and hence is somewhat conservative in estimating benefits.

As required by the Permit, any runoff not attenuated by harvest, evapotranspiration, or infiltration would be subject to quantity and quality controls. The analysis assumes that extended-detention basins (EDBs) with water residence times up to 72 hours would provide this control. EDBs are one of several general-purpose, conventional stormwater BMPs available for this service, others being wet ponds, constructed wetlands, sand or other media filters, and biofiltration swales and filter strips. The California Department of Transportation (Caltrans, 2004) tested the performance of all of these practices in its BMP Retrofit Pilot Program, conducted in San Diego and Los Angeles Counties. The initial report investigating LID for A, B, and C soils presented estimates of benefits for EDBs, swales, and filter strips, along with continuous deflective separation (CDS) units, a practice that effectively captures only large particulate pollutants. For brevity, this follow-up report focuses on just EDBs as the supplement to LID. In performance, EDBs tend to fall between swales and filter strips for total suspended solids, slightly lower than the other two BMP types for metals, and either between the two or comparable to swales for total phosphorus.

These practices were applied to the same six case studies used in the initial analysis and described in Table 1 of the first report. Two additional case studies were defined for the assessment reported here: a sizeable commercial retail installation (COMM) and an urban redevelopment (REDEV). The hypothetical COMM scenario consists of a building with a 2-acre footprint and 500 parking spaces. Parking spaces were estimated to be 176 sq ft in area, which corresponds to 8 ft width by 22 ft length dimensions. A simple, square parking lot with roadways around the four sides and a square building with walkways also around the four sides were assumed. Roadways and walkways were taken to be 20 ft and 6 ft wide, respectively. The REDEV case was taken from an actual project in Berkeley involving a remodel of an existing structure, built originally as a corner grocery store with apartments above and a large side yard, and the addition of a new building on the same site to create a nine-unit, mixed-use, urban infill project. Table 1 summarizes the characteristics of these two case studies. The table also provides the recorded or estimated areas in each land use and cover type.

Table 1. Characteristics and Land Use and Land Cover Areas of Added Case Studies

	COMM[a]	REDEV[a]
No. buildings	1	1
Total area (ft^2)	226,529	5,451
Roof area (ft^2)	87,120	3,435
No. parking spaces	500	2 uncovered
Parking area (ft^2)	88,000	316 uncovered
Access road area (ft^2)	23,732	-
Walkway area (ft^2)	7,084	350
Driveway area (ft^2)	-	650
Landscape area (ft^2)	20,594	700

[a] COMM—retail commercial; REDEV—commercial/residential infill

The assessment for group D soils employed the same methods as the earlier analysis to estimate annual stormwater runoff volumes and pollutant discharges. Please refer to the initial report for details on those methods. The Natural Resource Conservation Service (NRCS, 1986) methodology cited in that report was applied to estimate that infiltration in group D soils would be roughly 60 percent of the amount through landscaping or the bed of a conventional BMP in C soils, which were the basis for establishing runoff coefficients in the first analysis. While that initial analysis was performed for both 14- and 20-inch average annual runoff zones, typical of different Bay Area locations, this supplementary work covered only the former condition. This simplification was made in the interest of brevity in this report, given that the first analysis showed almost no difference in conclusions between the two situations.

RESULTS OF THE ANALYSIS

Table 2 provides a comprehensive summary of the results. Rows shaded in gray compare runoff and pollutant discharges with and without treatment by CDS units, which can capture relatively large solids but have no mechanisms for dissolved substances and the finer particles. Having no soil contact and very limited residence time for evaporation, this BMP cannot reduce runoff volume at all. It can achieve some substantial reductions in TSS and TP for land uses relatively high in landscaped area but little removal of metals, especially copper.

The blue-shaded rows show the performance of conventional EDBs. In the group D soils considered in this analysis, they were estimated to reduce annual runoff volumes by 13-23 percent, the higher values for land uses with relatively small impervious footprints (OFF and REST). These BMPs can capture the majority of the long-term mass loading of most pollutants from most land uses in these soils, falling below 50 percent in reducing metals in stormwater flowing from residential developments.

Rows shaded in green present the results of applying LID BMPs appropriate for group D soils, roof runoff harvesting supplemented by dispersion in single-home land uses, plus treating the remaining runoff with EDBs. Comparing annual runoff volumes with and without LID, it can be seen that removing roof runoff from the storm drain system affords very significant benefits in reducing surface discharge and putting much of that water to productive use. Compared to directing all site runoff to EDBs, LID is expected to reduce volume by almost 10 times in the REDEV case, by about five times for the various residential land uses, 3.6 times for the large commercial development, and around twice for the OFF and REST cases. This management strategy can recover over 3/4 of the stormwater that would otherwise go down the drain in the intense redevelopment case, approximately 2/3 for the multi- and single-family residential cases, over half in the COMM development, and almost half in the office and restaurant cases with relatively small roof footprints.

Reduction of volume translates to decreases in pollutant loadings also. The combination of LID and EDB treatment is estimated to raise copper and zinc reductions to about 70 to over 90 percent in all except the developments with relatively low roof proportions (60-65 percent in these cases). TSS predictions come in at a quite consistent 75-82 percent across land uses. Total phosphorus estimates are a similarly consistent 63-71 percent, a bit higher in the highly impervious REDEV case.

Effectively managing roof runoff gives a way out of the dilemma posed by group D soils in the Bay Area. The analysis has demonstrated that harvesting this runoff stream, supplemented by ground dispersion techniques with sufficient space, shows strong promise to reduce the majority of flow inputs to municipal storm drain systems while conserving water. Moreover, this strategy can also stem the majority of solids, copper, zinc, and phosphorus transport to receiving waters.

Table 2. Runoff Volume and Pollutant Loading Reductions with Conventional and Low-Impact Development (LID) Best Management Practices (BMPs) for Eight Land Use Case Studies in Hydrologic Group D Soils

	COMM[a]	OFF[a]	REST[a]	REDEV[a]	MFR[a]	Lg-SFR[a]	Sm-SFR[a]	SINGLE
Total annual runoff with no BMPs (ac-ft)	5.29	0.80	0.47	0.12	8.57	75.66	1.74	0.10
Total annual runoff with CDS units[b] (reduction)	5.29 (0.0%)	0.80 (0.0%)	0.47 (0.0%)	0.12 (0.0%)	8.57 (0.0%)	75.66 (0.0%)	1.74 (0.0%)	0.10 (0.0%)
Total annual runoff with EDBs[b] (reduction)	4.43 (16.3%)	0.63 (21.3%)	0.36 (23.2%)	0.11 (8.1%)	7.48 (12.7%)	65.27 (13.7%)	1.50 (13.7%)	0.09 (13.3%)
Total annual runoff with LID[b] (reduction)	2.22 (58.0%)	0.44 (45.0%)	0.28 (40.4%)	0.03 (78.9%)	2.80 (67.3%)	26.72 (64.8%)	0.61 (64.8%)	0.04 (65.7%)
CDS TSS reduction[b, c]	19.4%	44.8%	33.9%	22.1%	27.1%	37.1%	37.1%	37.7%
CDS TCu reduction[b, c]	0.4%	11.0%	4.2%	0.9%	2.7%	7.3%	7.3%	7.6%
CDS TZn reduction[b, c]	25.3%	29.1%	25.5%	25.5%	24.1%	25.6%	25.6%	25.9%
CDS TP reduction[b, c]	25.9%	63.7%	54.3%	35.7%	46.7%	57.6%	57.6%	58.2%
EDB TSS reduction[b, c]	64.7%	78.1%	74.9%	66.5%	62.8%	70.3%	70.3%	70.9%
EDB TCu reduction[b, c]	57.9%	51.6%	56.4%	53.2%	51.4%	43.5%	43.5%	43.6%
EDB TZn reduction[b, c]	57.6%	49.6%	48.9%	58.1%	48.5%	47.7%	47.7%	48.0%
EDB TP reduction[b, c]	44.4%	67.6%	63.3%	52.8%	56.3%	64.4%	64.4%	64.7%
LID + EDB TSS reduction[b, c, d]	74.6%	80.3%	77.0%	81.5%	79.4%	81.3%	81.3%	81.8%
LID + EDB TCu reduction[b, c, d]	71.9%	60.3%	62.2%	82.3%	73.8%	68.9%	68.9%	69.5%
LID + EDB TZn reduction[b, c, d]	79.7%	65.1%	60.9%	92.3%	78.9%	76.4%	76.4%	77.0%
LID + EDB TP reduction[b, c, d]	63.1%	69.8%	66.0%	75.2%	69.4%	70.8%	70.8%	71.1%

[a] COMM—retail commercial; OFF—office building; REST—restaurant; REDEV—commercial/residential redevelopment; MFR—multi-family residential; Lg-SFR—large-scale single-family residential; Sm-SFR—small-scale single-family residential; SINGLE—single family home
[b] CDS— continuous deflective separation; EDBs—extended-detention basins; reduction—comparison with no BMPs
[c] TSS—total suspended solids; TCu—total recoverable copper; TZn—total recoverable zinc; TP—total phosphorus
[d] LID + EDB—roof runoff harvesting for COMM, OFF, REST, REDEV, AND MFR; harvesting supplemented by dispersion of roof runoff for Lg-SFR, Sm-SFR, and SINGLE; treatment of remaining runoff by EDBs

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REFERENCES

California Department of Transportation. 2004. BMP Retrofit Pilot Program Final Report. California Department of Transportation, Sacramento, CA.

Natural Resource Conservation Service. 1986. Urban Hydrology for Small Watersheds, Technical Release-55. U.S. Department of Agriculture, Washington, D.C.

Washington Department of Ecology. 2005. Stormwater Management Manual for Western Washington. Washington Department of Ecology, Olympia, WA. http://www.ecy.wa.gov/programs/wq/stormwater/index.html.

Post-Construction Water Balance Calculator

User may make changes from any cell that is orange or brown in color (similar to the cells to the immediate right). Cells in green are calculated for you.

(Step 1a) If you know the 85th percentile storm event for your location enter it in the box below

(Step 1b) If you can not answer 1a then select the county where the project is located (click on the cell to the right for drop-down): This will determine the average 85th percentile 24 hr. storm event for your site, which will appear under precipitation to left. — *INYO*

(Step 1c) If you would like a more percise value select the location closest to your site. If you do not recgonize any of these locations, leave this drop-down menu at location. The average value for the County will be used. — **LONE PINE COTTONWOOD PH**

Project Information		***Runoff Calculations***	
Project Name:	*Optional*	(Step 2) Indicate the Soil Type (dropdown menu to right):	*Soil Type*
Waste Discharge Identification (WDID):	*Optional*	(Step 3) Indicate the existing **dominant** non-built land Use Type (dropdown menu to right):	***Non-Built Land Use Type Pre Development***
Date:	*Optional*	(Step 4) Indicate the proposed **dominant** non-built land Use Type (dropdown menu to right):	***Non-Built Land Use Type Post Development***
Sub Drainage Area Name (from map):	*Optional*		

Runoff Curve Numbers		
Existing Runoff Curve Number		
Proposed Development Runoff Curve Number		
Design Storm		
Based on the County you indicated above, we have included the 85 percentile average 24 hr event - P85 (in)^ for your area.	**0.50**	**in**
The Amount of rainfall needed for runoff to occur (Existing runoff curve number - P from existing RCN (in)^)	**0.00**	**In**
P used for calculations (in) (the greater of the above two criteria)	**0.50**	**In**
^Available at www.cabmphandbooks.com		
Pre-Project Runoff Volume (cu ft)	**0**	**Cu.Ft.**
Project-Related Runoff Volume Increase w/o credits (cu ft)	**0**	**Cu.Ft.**
Project-Related Volume Increase with Credits (cu ft)	**0**	**Cu.Ft.**

You have achieved your minimum requirements

	Complete Either		
	Sq Ft	**Acres**	**Acres**
(Step 5) Total Project Site Area:			**0.00**
(Step 6) Sub-watershed Area:			**0.00**
Percent of total project :			

(Step 7) Sub-watershed Conditions	**Complete Either**		**Calculated Acres**
Sub-watershed Area (acres)	**Sq Ft**	**Acres**	**0.00**
Existing Rooftop Impervious Coverage			**0.00**
Existing Non-Rooftop Impervious Coverage			**0.00**
Proposed Rooftop Impervious Coverage			**0.00**
Proposed Non-Rooftop Impervious Coverage			**0.00**

Credits	**Acres**	**Square Feet**
Porous Pavement	**0.00**	**0**
Tree Planting	**0.00**	**0**
Downspout Disconnection	**0.00**	**0**
Impervious Area Disconnection	**0.00**	**0**
Green Roof	**0.00**	**0**
Stream Buffer	**0.00**	**0**
Vegetated Swales	**0.00**	**0**
Subtotal	**0.00**	**0**
Subtotal Runoff Volume Reduction Credit	**0 Cu. Ft.**	

(Step 9) Impervious Volume Reduction Credits	**Volume (cubic feet)**
Rain Barrels/Cisterns	**0 Cu. Ft.**
Soil Quality	**0 Cu. Ft.**
Subtotal Runoff Volume Reduction	**0 Cu. Ft.**
Total Runoff Volume Reduction Credit	**0 Cu. Ft.**

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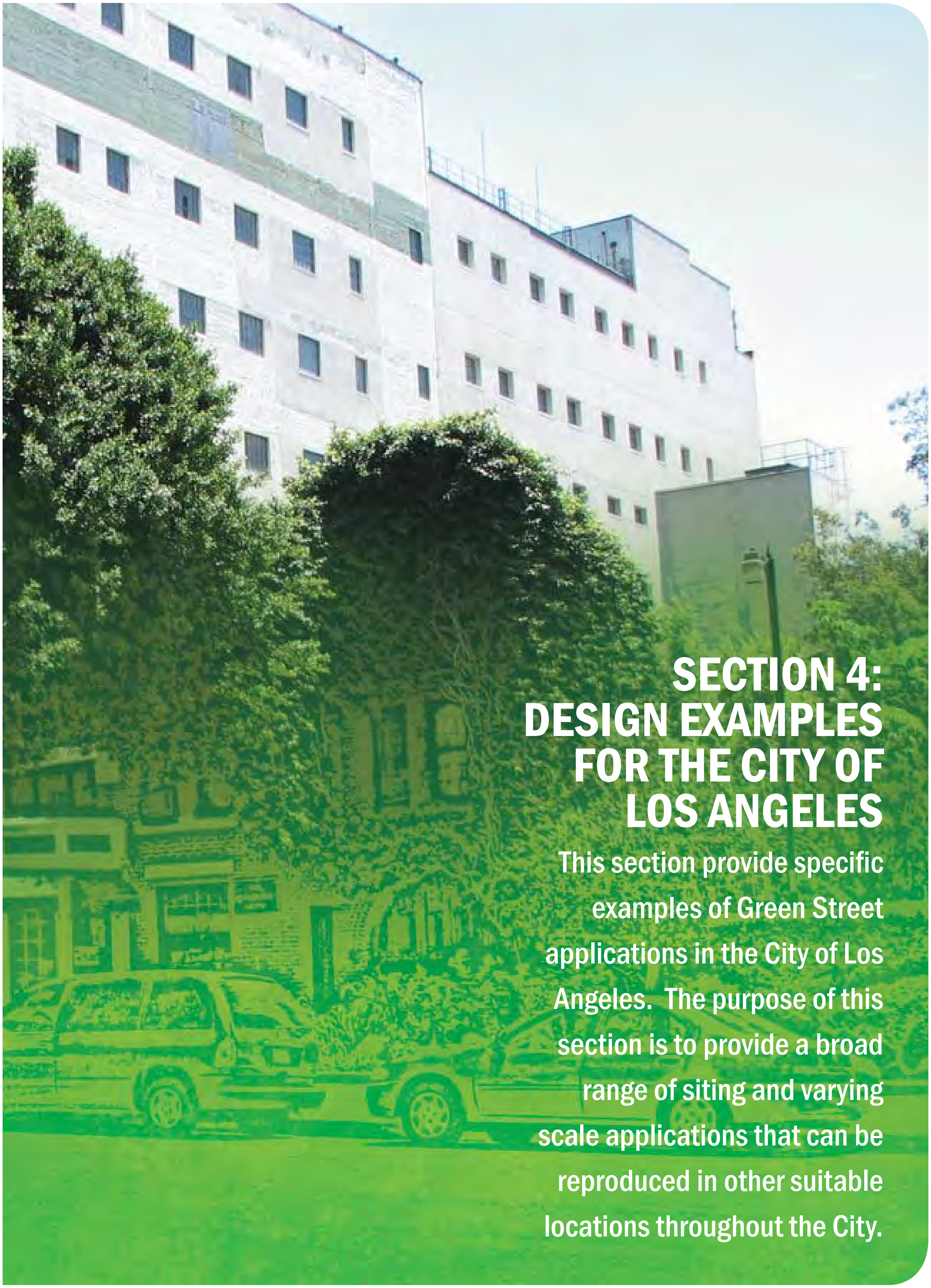

SECTION 4: DESIGN EXAMPLES FOR THE CITY OF LOS ANGELES

This section provide specific examples of Green Street applications in the City of Los Angeles. The purpose of this section is to provide a broad range of siting and varying scale applications that can be reproduced in other suitable locations throughout the City.

RB-AR33210

Section
4.1

The design scenarios presented in this section illustrate different ways that vegetated swales, planters, pervious paving, infiltration trenches, stormwater curb extensions, canopy trees, and curb inlets can be applied to diverse settings within the City of Los Angeles.

GREEN STREETS AND PARKING LOTS

The design scenarios presented in this section illustrate different ways that vegetated swales, planters, pervious paving, infiltration trenches, stormwater curb extensions, canopy trees, and curb inlets can be applied to diverse settings within the City of Los Angeles. Designers and developers are encouraged to review these examples for ideas. Several "before and after" illustrations show the potential for green streets and parking lot retrofit opportunities in Los Angeles. The goal of illustrating multiple site strategies is to give the user of this guidebook a broad range of siting and varying scale applications that can be similarly reproduced throughout the region. The examples shown include some developed projects and some conceptual projects for reference only. Whether a particular site is located in a low or high-density residential neighborhood, a commercial "main street" district, along an arterial or boulevard street, or within a small or large parking lot, there are multiple stormwater design options available.

Section
4.1.1

OROS STREET

The Oros Streetend Biofiltration Project was implemented in the Elysian Valley neighborhood of northeast Los Angeles, California, along Oros Street between Blake Avenue and the Los Angeles River. Oros Street was designed to capture stormwater runoff from private homes and the street and allow for infiltration into the soil via stormwater gardens and an infiltration basin. Other benefits include the beatification of the neighborhood with new infrastructure and ample greenscape.

The Oros Street Project was a joint project between the City of Los Angeles and North East Trees with assistance from numerous agencies and community stakeholders. This keystone project serves as a model project for the Los Angeles Stormwater Program, demonstrating that creative restoration initiatives can provide multiple benefits by improving water quality, involving stakeholders such as NET and showing the City of Los Angeles is leading the way among major United States cities in using cutting edge design to curb stormwater pollution.

Utilizing new technology, the City's Bureau of Sanitation and Bureau of Street Services constructed five Stormwater Gardens along the street's corridor. The gardens are bioretention areas in the parkway that capture and infiltrate stormwater runoff. The park also assists in the removal of pollutants, serving dual functions for the neighborhood community. Runoff from the street is collected via two newly constructed catch basins and filtered through catch basin inserts before discharging into an underground detention/infiltration basin located underneath Steelhead Park for subsequent infiltration into the ground. Ultimately, this project resulted in zero discharge of stormwater (up to the design storm capacity) and urban runoff to the adjacent Los Angeles River.

First "Green Street" in Los Angeles is Completed

A National Model of Sustainability That Cleans Water Before Entering the Los Angeles River LOS ANGELES, CA – North East Trees and Los Angeles City Council President Eric Garcetti, joined by project partners and the neighbors, officially dedicated the first "Green Street" in Los Angeles on Oros Street at the Los Angeles River in Elysian Valley.

The Oros Green Street Project was designed to capture stormwater runoff from private homes and a residential street and clean it through a series of soil filtration and vegetative bioretention treatments before it ever gets into the Los Angeles River, while simultaneously

"This project marks the first time that a neighborhood can say that it is contributing no pollutants to the Los Angeles River because the Oros Green Street Project will clean water from this neighborhood before it enters the River"
— Larry Smith, Executive Director of North East Trees.

"This project is the new gold standard for how North East Trees and our project partners can transform and complete the cycle of restoring nature's services in an urban environment." "We need green streets to have a clean river,"

"Today we're demonstrating that a major goal of the LA River Revitalization Master Plan is within our reach, thanks to the collaboration between our city and North East Trees."
— Council President Eric Garcetti.

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improving and beautifying a neighborhood with new infrastructure and greenscape. It is an eco-friendly and innovative model of sustainability that manages and cleans storm and dry weather runoff and pollutants that traditionally went directly to the stormwater system (or the Los Angeles River). "This project marks the first time that a neighborhood can say that it is contributing no pollutants to the Los Angeles River because the Oros Green Street Project will clean water from this neighborhood before it enters the River" said Larry Smith, Executive Director of North East Trees. "This project is the new gold standard for how North East Trees and our project partners can transform and complete the cycle of restoring nature's services in an urban environment."

"We need green streets to have a clean river," said Council President Eric Garcetti. "Today we're demonstrating that a major goal of the LA River Revitalization Master Plan is within our reach, thanks to the collaboration between our city and North East Trees."

The Oros Green Street Project was a collaboration mobilized by North East Trees with the City of Los Angeles, county, state and federal agencies as well as neighborhood resident stakeholders. It was funded through grants and services from the California Water Quality Control Board (over $500,000) and the City of Los Angeles' Proposition O Bond Act ($385,000) with close coordination and services from the Los Angeles Department of Public Works, Bureau of Street Services and Bureau of Sanitation. This project also marks the first Proposition O-funded project to be completed. This project also marks the first Proposition O-funded project to be completed.

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Section
4.1.2

11TH STREET

A commercial street in downtown Los Angeles at Hope Street near 11th Street was recently designed to capture runoff and infiltrate it through landscaped areas using drought tolerant plants. The purpose of the project is to capture, clean, and temporarily detain stormwater. Every 10 feet or so, the curbs are notched, leading to below-grade, rock-strewn planters filled with grasses, trees and flowers. This green street is a great example of how urban infrastructure can be converted to green infrastructure.

All three City agencies had to approve the newest infiltration planters at the privately developed Luma building, which opened on Hope Street in downtown Los Angeles in 2008. The gold-certified Leadership in Energy and Environmental Design building was co-developed by Gerding Edlen Development, a Portland, Ore., firm that has been incorporating infiltration planters in its buildings for several years.

The purpose of the project is to capture, clean, and temporarily detain stormwater.

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Section
4.1.3

RIVERDALE AVENUE

The Riverdale Avenue Green Street project was proposed with the goal of establishing a City standard to promote infiltration of street runoff and to promote runoff management.

Rendering of Riverdale Avenue Green Street Project

In the past year, the Green Streets Committee developed a draft pilot project list and selection criteria, and obtained funding from the Coastal Conservancy for a pilot project on Riverdale Avenue in Elysian Park. The Riverdale Avenue Green Street project was proposed with the goal of establishing a City standard to promote infiltration of street runoff and to promote runoff management. This project will demonstrate the use of storm water planters to treat and infiltrate storm water runoff, thereby providing water quality and flood control benefits. A primary goal of this project is to create a model for a new standard of residential street design to reduce the amount of storm water and urban runoff from streets.

The project will reconstruct the existing parkways on both sides of Riversdale Avenue between Crystal Street and its terminus at the south side of the Los Angeles River. The proposed parkway swales will be able to capture and treat urban runoff from 14.6 acres of residential land with the dual benefit of irrigating the parkway plants and infiltrating the street runoff and thereby protecting the Los Angeles River from the pollutants in storm water and urban runoff. Additionally, the planters will improve the existing urban streetscape by replacing grass parking strips with drought tolerant, native landscaping. The project will include signage to explain the purpose of the infiltration swales and the need to protect the Los Angeles River from polluted urban and storm water runoff.

BIMINI SLOUGH

Section
4.1.4

In this part of Los Angeles, parks are in short supply, and there are 1,000 residents for every one-third of an acre of green space.

Project location

The Bimini “Slough” Ecology Park Project (pronounced "slew"), meaning that it is low land, i.e. a marsh area where runoff water from surrounding hills collects on a rainy day. The 20,000 square feet park covers what was previously Second Street between South Bimini Place and Juanita Avenue (near the intersection of Vermont Avenue and Third Street). In this part of Los Angeles, parks are in short supply, and there are 1,000 residents for every one-third of an acre of green space. This park is the Bresee Foundation's gift to the community.

Project Description

The Bimini Slough Ecology Park was completed in 2004 to be enjoyed by all those living in the neighborhood near the Bresee Community Center. This park, previously one city block, was restored to the natural Sacatella Creek that years ago flowed through here before the city grew and its waters were diverted. The Project addresses not only the need for green space, but also serves as a model for addressing key environmental issues.

The park was designed to highlight this characteristic and incorporate into it several features beneficial to the environment. The Project consists of three primary components:

- A state-of-the-art drip irrigation system, which will minimize water usage;
- A selection of plants and trees native to the area which will provide color and require little water; and;
- A bio-filtration vegetated 180-ft swale. Helped by its vegetation and trash interceptor, the swale will serve as a filter for storm water runoff and will eliminate pollutants from the water before it enters the ocean.

Targeted Pollutants

The Project will treat runoff from the surrounding community and targets the following pollutants:

- Bacteria - Trash
- Metals - Oil & Grease

GREEN PARKING LOTS

Section
4.1.5

Green parking lots reduce runoff that is discharged into local water bodies by using permeable paving and natural drainage landscapes.

Project Funding

The Project was a gift from the Breese Foundation with in-kind services from the Metropolitan Water District, City of Los Angeles, Department of Public Works, Bureau of Sanitation, and North East Trees.

Green parking refers to several techniques applied together to reduce the contribution of parking lots to the total impervious cover in a lot. Green parking lots reduce runoff that is discharged into local water bodies by using permeable paving and natural drainage landscapes. From a stormwater perspective, application of green parking techniques in the right combination can dramatically reduce impervious cover and consequently, the amount of stormwater runoff. Green parking lot techniques include setting maximums for the number of parking lots created, minimizing the dimensions of parking lot spaces, utilizing alternative pavers in overflow parking areas, using bioretention areas to treat stormwater, and encouraging shared parking.

Utilizing alternative pavers is an effective green parking technique. They can replace conventional asphalt or concrete in both new developments and redevelopment projects. Alternative pavers can range from medium to relatively high effectiveness in meeting stormwater quality goals. The different types of alternative pavers include gravel, cobbles, wood mulch, brick, grass pavers, turf blocks, natural stone, pervious concrete, and porous asphalt. In general, alternate pavers require proper installation and more maintenance than conventional asphalt or concrete. (Refer to permeable paving fact sheets in the guidelines).

Bioretention areas can effectively treat stormwater in a parking lot. Stormwater is directed into a shallow, landscape area and temporarily detained. The runoff then filters down through the bed of the facility and is infiltrated into the subsurface or collected into an underdrain pipe for discharge into a stream or another stormwater facility. Bioretention facilities can be attractively integrated into landscaped areas and can be maintained by commercial landscaping firms. (Refer to bioretention-related fact sheets in the guidelines).

5 Steps Toward A Green Parking Lot

1. Determine native soil infiltration rate.
2. Determine the direction of stormwater flow and where it needs to be collected.
3. Determine opportunities for incorporating permeable pavement and natural drainage landscapes.
4. Determine the required dimensions for natural drainage landscape areas and ensure that the receiving area is sufficient and practical.
5. Identify location of overflow structure and where the structure is to be connected to the storm drain system.

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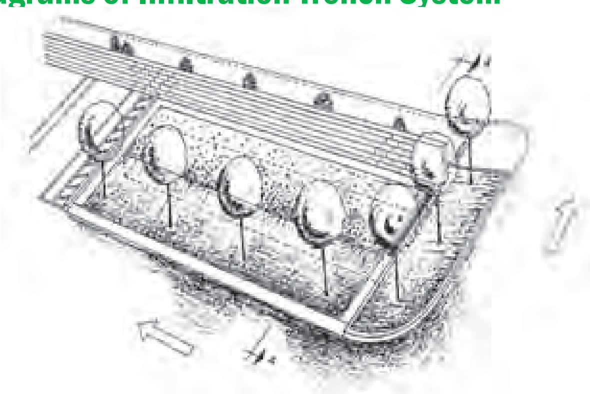
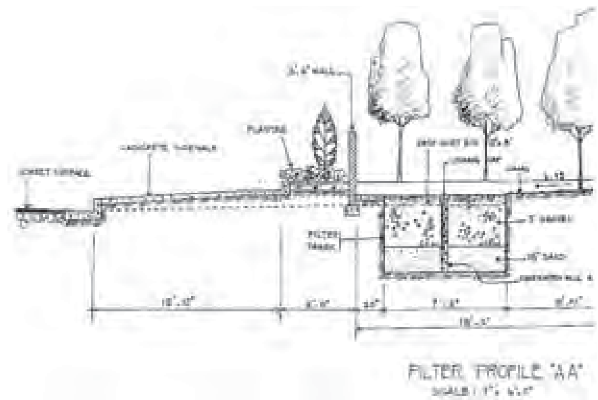
A green parking lot can prevent pollution at the source, remove pollutants before runoff is discharged, control discharge rates of stormwater runoff, and provide a pleasant parking experience. Green parking lots may save capital and maintenance costs and will enhance protection of downstream water bodies.

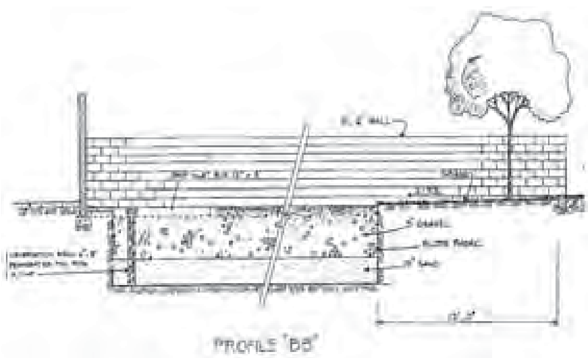
Venice Parking Lot

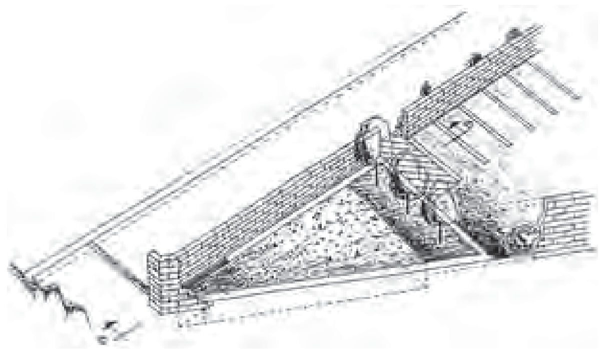
An infiltration trench system was implemented in a city parking lot at the intersection of Venice Blvd and Dell Ave in the Venice Beach Area. There were nine infiltration trenches constructed in this 1.5 acre parking lot. The system captures and infiltrates the beach parking lot runoff measuring 5,253 cubic feet or 39,295 gallons. The dimensions of the trench are: 15′ l X 5.3′ w X 4.5′ d; it includes a gravel bed as well as a sand filter.

Diagrams of Infiltration Trench System







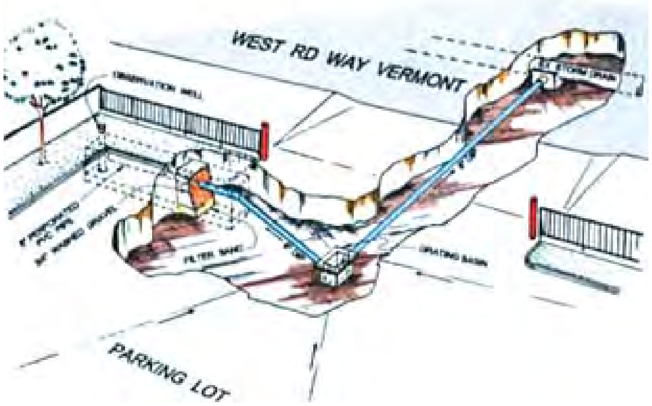


Construction of the Infiltration Trench

Finished Infiltration Trench

Constituent Parking Lot

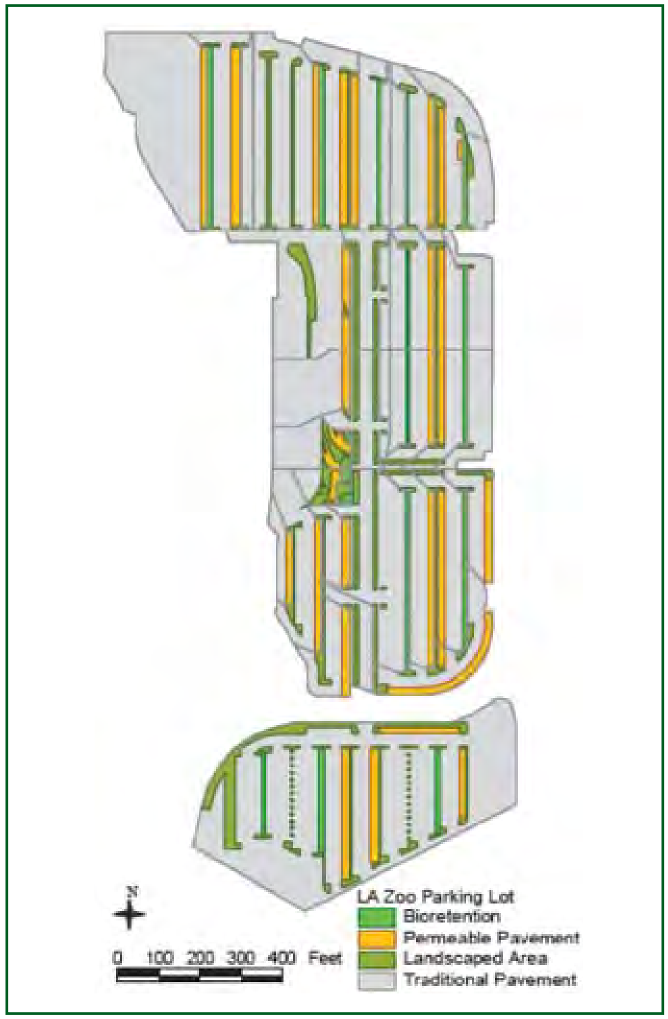
Another infiltration trench example can be found in the Constituency Center parking lot in Los Angeles City Council District 8.



LA Zoo Parking Lot

The Los Angeles Zoo Parking Lot Project is a Proposition O project that involves water quality improvement and sustainable design. The 134-acre Los Angeles Zoo, located in the northeast corner of Griffith Park, is owned and operated by the City of Los Angeles. The zoo's main parking lot consists of 33 acres of impervious, failing asphalt concrete pavement. Surface water from the parking lot and Zoo Drive flows to a storm drain that empties directly into the Los Angeles River. This water has the potential to contribute trash, heavy metals, pathogens, total suspended solids, oil and grease, and gasoline to the Los Angeles River Watershed.

The Zoo Parking Lot Project will renovate the Zoo's existing main parking lot to provide additional infiltration, runoff reduction, and pollutant loading control through implementation of Low Impact Development (LID) concepts and Best Management Practices (BMPs). Low impact development concepts and BMPs that will be incorporated into the project include permeable pavement and bioretention cells.



The permeable pavement will filter the storm water to remove pollutants before being discharged to the existing underground storm water system. The bioretention cells will provide the same filter removal process as the permeable pavement with underground storage, but will incorporate native plants above the surface that will aid in evapotranspiration of the stormwater. Landscaping will be provided to meet the City's goal of one tree per four parking stalls. Native and naturalized vegetation will be implemented so that the parking lot blends well with the Zoo and its surroundings. The Los Angeles Zoo Parking Lot Project can even assist in the revival of Griffith Park, which was affected by recent wildfires.

In addition, the project will provide a "first exhibit" educational experience, improve the parking lot circulation and repair the parking lot surfaces. The goal of the project is to become the Zoo's first exhibit achieving a "Demonstration on Environmental Sustainability." It will act as a model that can be

Section

4.1.6

GRAND AVENUE TREE WELLS

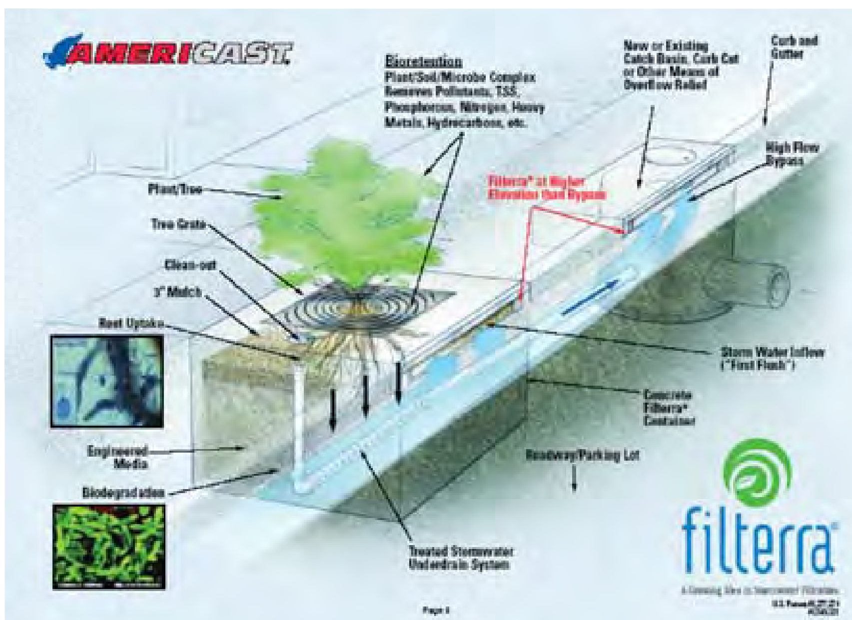
The Grand Avenue Tree Well project targets a 5-acre high-density residential and commercial corridor in the Venice area by installing seven stormwater bioretention filtration BMPs.

replicated throughout the City, multiplying the Los Angeles Zoo Parking Lot's water quality benefits many times over.

The Grand Avenue Tree Well project targets a 5-acre high-density residential and commercial corridor in the Venice area by installing seven stormwater bioretention filtration BMPs. The project site is considered a "hot spot" in Santa Monica Bay Watershed. Dry weather flow and a portion of the wet weather flow along Abbot Kinney Blvd and Grand Ave. will be diverted and treated using the Filterra Stormwater Bioretention Filtration System® before it enters the storm drain, thus eliminating trash, bacteria, metals, and TSS discharges to the Bay.

Goals

- Reduces the size and cost of downstream stormwater control facilities by infiltrating stormwater in upland areas.
- Reduce downstream flooding and protect stream bank integrity
- Reduce downstream pollutant loading
- Increases beneficial and recreational uses of receiving waterbodies
- Reduce potential for human safety and health risk



In general, Bioretention Systems can be described as shallow, landscaped depressions commonly located in parking lot islands or within small pockets in residential areas that receive stormwater runoff. Stormwater flows into the bioretention area, ponds on the surface, and gradually infiltrates into the soil bed. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George's County, MD, 1993). Filtered runoff can either be allowed to infiltrate into the surrounding soil (functioning as an infiltration basin or rainwater garden), or collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters (functioning like a surface sand filter). Runoff from larger storms is generally diverted past the area to the storm drain system.

Incorporate the Concept of "Green" BMPs

- The project is consistent with the Low Impact Development (LID) concept by incorporating distributed small-scale green BMPs as opposed to a large conventional structural BMP.
- Consistent with the Mayor's million tree initiatives by incorporating trees/plans into the stormwater quality treatment system.
- Consistent with the "Green Street" initiative by providing landscape along street corridors and increasing the aesthetics values for the area.

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SECTION 4.2: GREEN ALLEYS

Simple infrastructure changes such as using permeable pavement or adding bioswales in alleys will reduce urban runoff, recharge groundwater, and improve water quality in streams, rivers, and coastal waters.

Section
4.2.1

HATTERAS/EMELITA STREET RENDERING

Simple infrastructure changes such as using permeable pavement or adding bioswales in alleys will reduce urban runoff, recharge groundwater, and improve water quality in streams, rivers, and coastal waters. The following pictures illustrate the potential to transform an existing Los Angeles alley after green infrastructure principles are applied:

The Los Angeles Department of City Planning's Urban Design Studio recently prepared a report for green alleys entitled, "An Exploration of Green Alleys for Los Angeles for the Green Streets Committee." The case studies examined in this report explored the potential to green two alleys in the North Hollywood area of Los Angeles.

In the following scenario, permeable pavers and Grasscrete creates an inviting "Hollywood driveway." (Grasscrete is an interlocking concrete system with grass that grows between it, able to withstand the weight of garbage trucks as well as traffic from the residential parking areas.)

Existing conditions, alley east of Vineland Avenue between Hatteras and Emelita Streets in Los Angeles

Rendering of the greened alley, featuring a "Hollywood driveway" with Grasscrete and permeable pavement, as well as drought-resistant landscaping and energy efficient streetlights.

The alley is also planted with drought-resistant landscaping on the left, which further helps filter stormwater runoff. Additionally, to encourage non-automotive traffic down the alley, energy-efficient pedestrian scale streetlights have been added.

Simple infrastructure changes such as using permeable pavement or adding bioswales in alleys will reduce urban runoff, recharge groundwater, and improve water quality in streams, rivers, and coastal waters.

Section
4.3

CANOPY TREES

In 2008, the Million Trees Los Angeles initiative engaged tens of thousands of individuals, businesses, and community groups in tree planting and maintenance — increasing L.A.'s annual tree planting tenfold and creating a legacy of environmental activism.

Million Trees Los Angeles: A City Of Los Angeles Green Initiative

In September 2006, Mayor Antonio Villaraigosa announced his plan to plant one million trees over several years. In 2008, the Million Trees Los Angeles initiative engaged tens of thousands of individuals, businesses, and community groups in tree planting and maintenance -- increasing L.A.'s annual tree planting tenfold and creating a legacy of environmental activism. Many of the trees have been planted in parkways, creating green streets across the City. In 2009, The City of Los Angeles received an Environmental Award from the U.S. EPA's Pacific Southwest office in recognition of this program.

Keystone Projects

Balboa Boulevard Signature Project - An MTLA signature planting project was completed, this time along Balboa Boulevard, a major San Fernando Valley transportation corridor. The area received 78 street trees of various species, such as crape myrtle, sweet shade, gingko and atlas cedar. The project will benefit area residents and students that go to Birmingham High School, Mulholland Middle School, the West Valley Special Education Center, and the Hi Tech High School. The Balboa Boulevard signature project was made possible by the collaborative effort of MTLA, the Air Quality Management District (AQMD), and the Los Angeles Conservation Corps.

Jefferson Boulevard Signature Project

As part of the Mayor's South Los Angeles Day of Service on September 20th, 47 more trees were planted in the South Los Angeles area, particularly along Jefferson Boulevard from Crenshaw Boulevard to Hillcrest Drive. The partnership of MTLA, AQMD and the Koreatown Youth and Community Center is responsible for the Jefferson Boulevard signature project.

million treesLA

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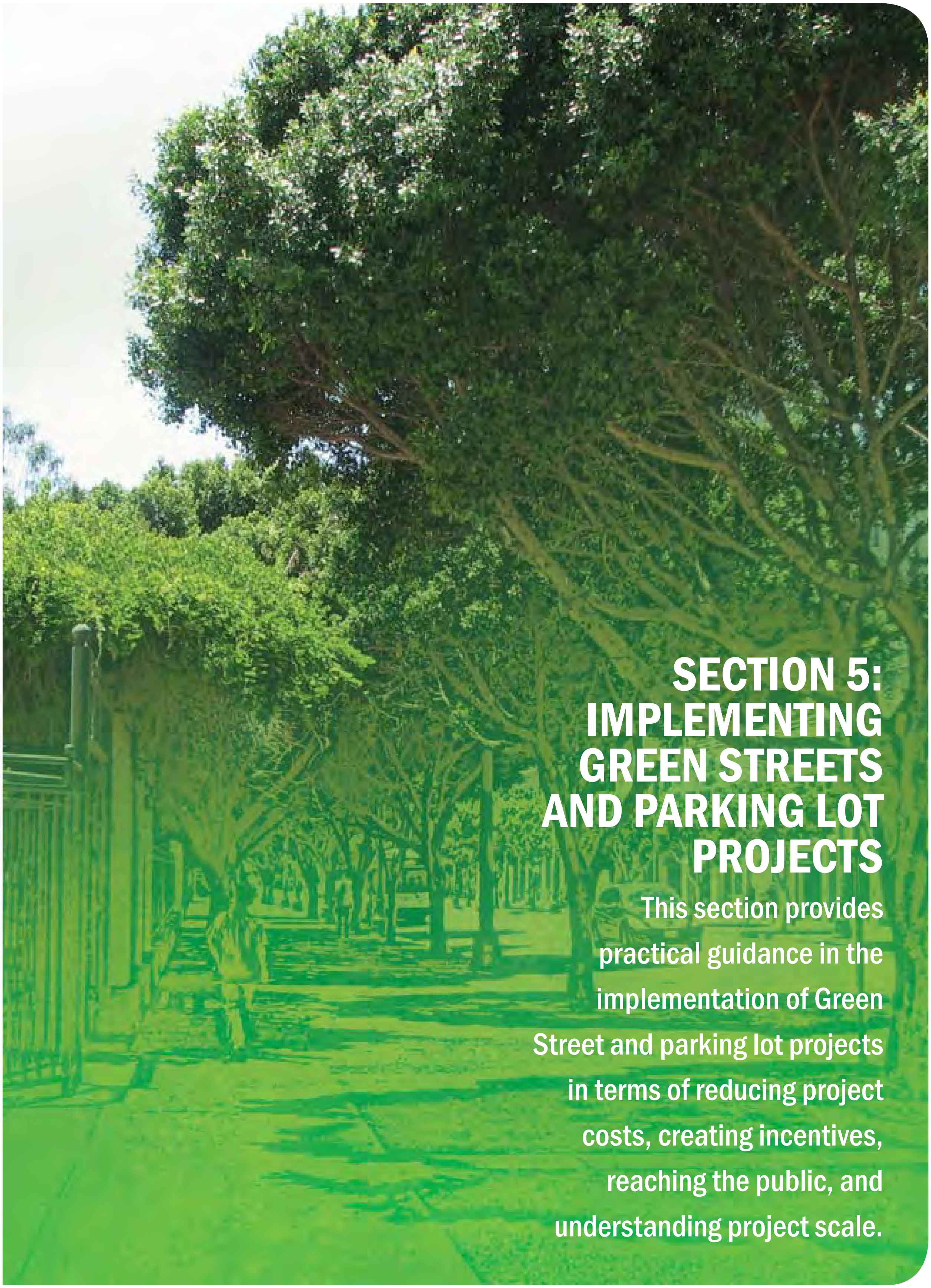

SECTION 5: IMPLEMENTING GREEN STREETS AND PARKING LOT PROJECTS

This section provides practical guidance in the implementation of Green Street and parking lot projects in terms of reducing project costs, creating incentives, reaching the public, and understanding project scale.

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SECTION 5 IMPLEMENTING GREEN STREETS AND PARKING LOT PROJECTS

It is anticipated that the Bureaus of Sanitation, Street Services and Engineering, as well as the Community Redevelopment Agency, will include green streets elements into all new and pending street capital improvement projects involving parkways, sidewalk or median construction or reconstruction.

Following implementation of the design guidelines, it is anticipated that the Bureaus of Sanitation, Street Services and Engineering, as well as the Community Redevelopment Agency, will include green streets elements into all new and pending street capital improvement projects involving parkways, sidewalk or median construction or reconstruction. The City Planning Department will incorporate Green Streets policy and concepts into the General/Community Plans. In this section of the Green Streets Guidelines, specific methods to implement green streets and parking lots into the City of Los Angeles are explored. Topics covered include reducing implementation costs, creating incentive programs, providing public education and outreach, and choosing demonstration projects.

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Section
5.1

REDUCING PROJECT COSTS

The City of Los Angeles has numerous opportunities to retrofit the existing built environment, therefore, the overall goal should be to reduce costs as much as possible and to deliver additional stormwater related benefits when applying design solutions. In general, retrofitting green streets and parking projects is more costly than implementing new development projects simply because the former has site constraints that must be addressed. For example, there are often extra costs associated with removing existing concrete or asphalt in order to make way for new green space. In some cases, using a "green" approach might cost more, but the ancillary benefits (such as traffic calming, improved neighborhood aesthetics, and a safer pedestrian environment) often outweigh the costs. The following describes four ways to reduce costs when implementing green street and parking lot projects:

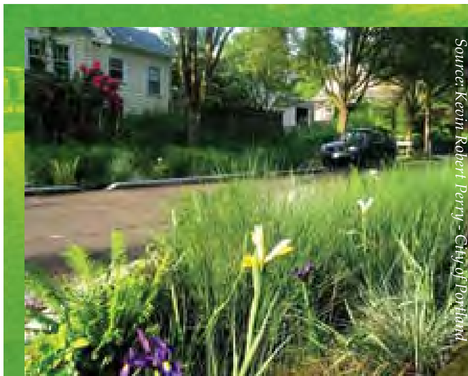

Figure 5.1: NE Siskiyou Green Street in Portland, Oregon avoided alterations to the existing storm pipe infrastructure and was therefore built cost-effectively.

Minimize Existing Impacts

One way to reduce construction costs is to minimize the impact to the existing storm drain infrastructure as much as possible and maintain existing storm drain inlet locations. Altering drain inlet locations and installing new storm drains at intersections can be very cost prohibitive in some projects. In many cases, stormwater facilities constructed up-gradient of existing storm drain inlets may require little, if any, alteration to infrastructure. Many green streets projects in Portland, Oregon were built inexpensively because they minimized impacts to the existing piped infrastructure. For example, the NE Siskiyou Green Street project installed two stormwater curb extensions just upstream of the existing stormwater drain inlets and never touched the existing storm infrastructure. By avoiding any such impact, the project's overall costs were reduced significantly.

Look for High-Opportunity Projects

When searching for cost effective green street projects, look for candidate sites that have minimal site constraints and maximum space for stormwater facilities. In some cases, available landscape space can be easily regraded and planted to provide stormwater management. In other cases, there are streets and parking lots that have excess asphalt area that can be converted into a stormwater facility at minimal cost. High-opportunity projects also include street and parking lot projects that have willing stakeholders, agencies, owners, or neighbors that can help provide advocacy or funding for a particular project.

Combine Green Streets with Other Street Improvements

Continual capital improvements are needed to maintain street longevity. Asphalt paving often needs to be replaced; curbs, sidewalks, and utility lines need to be repaired; and overall traffic/pedestrian improvements are constantly being planned. The most opportune time to incorporate a green street element is when a street is already planned and budgeted for improvement. Coordinating the efforts between regular street

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improvements and green street improvements can help reduce the cost of green street implementation by achieving positive economies of scale. In many situations, green street projects can be integrated and budgeted as part of solutions for local traffic problems. For example, stormwater curb extensions can help narrow street widths, provide traffic calming benefits, and potentially be paid for by a non-green street-related budget.

Keep Design Solutions Simple

During the design phase of green street and parking lot projects, it is important to keep the design as simple as possible. Highly engineered design solutions can often increase project costs. Green streets should rely on a natural, landscape-approach to stormwater management. A component that is often over-designed in green street and parking lot construction is the means by which water gets in and out of landscape stormwater facilities. Overdesigned inlet structures not only increase project costs, but they often detract from the aesthetics of a project. Keeping the design simple and allowing water to surface flow in and out of stormwater facilities will help keep costs more manageable. Likewise, using only surface overflow to an existing downstream storm drain inlet, when possible, can simplify a project's design and greatly reduce costs. Another effective cost saving strategy is to limit the amount of imported hardscape materials. For example, it may seem advantageous to use deeper concrete walls to facilitate greater ponding depth, but the marginal benefit compared to shallower stormwater facilities, which require fewer resources, may not justify the additional expense. With larger construction projects, the designer should balance the total cut and fill on a project. It can be expensive to excavate, haul, and dispose of excess soil.

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Section
5.2
CREATING INCENTIVES

There are several options for creating incentives for municipalities and property owners to retrofit green streets or parking lots.

There are several options for creating incentives for municipalities and property owners to retrofit green streets or parking lots. As described below, these incentives can be classified into three different categories: reward-based incentives, mandate-based incentives, and community-based incentives.

Reward-based Incentives

Reward-based incentives compensate a developer or property owner for incorporating green street and parking lot elements into their project. This type of incentive may include utility fee discounts, tax benefits, project grant funding, or even expedited review of development proposals. Reward-based incentives are particularly applicable to private development associated with parking lot projects. However, when private development occurs in conjunction with public streets, reward-based incentives can also apply. An example of a reward-based incentive is the City of Portland's Clean River Rewards Discount Program that allows up to a 35% reduction in residential or commercial stormwater utility fees for employing certain landscape-based stormwater management strategies on-site.

Mandate-based Incentives

This type of incentive require a developer or property owner to employ green street and/or parking lot strategies or their on-site stormwater management fee will be levied or increased. Mandate-based incentives can result in a more wide-spread application of green street and parking lot projects, but they can also set a more negative tone to a positive effort. Mandate-based incentives may also create a burden for municipal staff by creating a larger green street and parking lot program than originally anticipated.

Community-based Incentives

Many neighborhoods and business districts see the value of "greening" their environment in terms of improving quality of life, increasing property values, and increasing business profits. Local neighborhoods are often willing to combine resources and help pay for a green street project, or agree to undertake long-term maintenance, or simply provide advocacy for a municipality's green street efforts. One way to bring to bear full community resources is to form a community benefit district. Such an entity is comprised of a network of businesses and other property owners within a defined area who voluntarily agree to pay additional property tax in order to finance capital improvements and services that enhance, but do not replace, those provided by the city. Alternatively, parking benefit districts serve the same function, but derive their funding from on-street parking meters or non-resident parking passes. General problem-solving is another common form of community-based incentives. For example, green street and parking lot projects have the potential to reduce neighborhood flooding, provide traffic calming, and provide pedestrian safety benefits. Communities are more inclined to endorse and provide incentives toward green street projects when they are part of a more comprehensive solution to neighborhood problems.

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Section

5.3 PUBLIC EDUCATION AND OUTREACH

Source: Nevue Ngai Associates

Figure 5.2: A green street public workshop describes several options for retrofitting a boulevard

One of the best tools for successful stormwater management is educating the general public. There is a lot of confusion and misconceptions about using various stormwater management strategies. People sometimes think of stormwater facilities as "swamps" or "mosquito nests" and are unaware of well-designed stormwater facility examples. Likewise, people may not realize well-designed stormwater facilities can look just as good as conventional landscapes. Therefore, it is important to show the general public specific examples of successful demonstration projects (local or otherwise) in order to assure them that stormwater facilities can help protect the environment and can also provide a unique and attractive neighborhood amenity. There are several ways to promote stormwater education and outreach, such as:

- Conduct public tours of successful stormwater projects built in the local area, including field trip tours for school children who would like to learn more about environmental sustainability.
- Offer public meetings/workshops on the topic of sustainable stormwater management. Provide specific education materials that explain how well-designed stormwater facilities should not allow any prolonged periods of standing water that promote mosquito breeding.
- Send out brochures or provide fact sheets that describe different ways to manage stormwater runoff.
- Install interpretative signs for key stormwater demonstration projects. The signs should describe the particular elements of a project and where to find more information.

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DEMONSTRATION PROJECT APPROACHES

Section
5.4

Green street and parking lot demonstration projects can be selected and designed using one or a combination of three approaches. Depending on the approach taken, demonstration projects can range from small to large, retrofit to new construction, and simple to complex.

Strategic Approach

This approach locates stormwater facilities intermittently, but strategically, to provide the most efficient level of stormwater management. Because this approach uses smaller facilities, it tends to be the least expensive to construct and maintain. This approach is widely used for retrofitting existing streets. One example of this approach is the SW 12th Avenue Green Street in Portland, Oregon (Figure 5-3).

Opportunity Approach

This approach locates stormwater facilities in areas where there are very few constraints and that offer high demonstration value. By using this approach, under-utilized landscape or impervious areas are converted into stormwater facilities of any size. One example of this approach is the five rain gardens located along NE Sandy Boulevard in Portland, Oregon (Figure 5-4).

Full-Integration Approach

This green street approach integrates the entire street frontage for stormwater management. A full-integration approach offers the most stormwater management benefits, but it is usually the most expensive to build and maintain. This approach is most compatible with new construction projects or if a street is planned to be completely rebuilt. An example of this approach is the Street Edge Alternatives in Seattle, Washington (Figure 5-5).

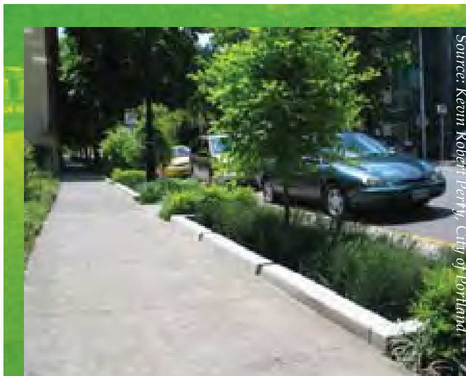

Figure 5-3: Portland's SW 12th Avenue Green Street project utilizes a strategic approach in placing smaller stormwater facilities intermittently along the streetscape

Figure 5-4: The five rain garden projects located along NE Sandy Boulevard in Portland are located where the site constraints were minimal

Figure 5-5: When a street is completely reconstructed, such as the Street Edge Alternatives (SEA) Streets in Seattle, Washington, the project uses a full-integration approach.

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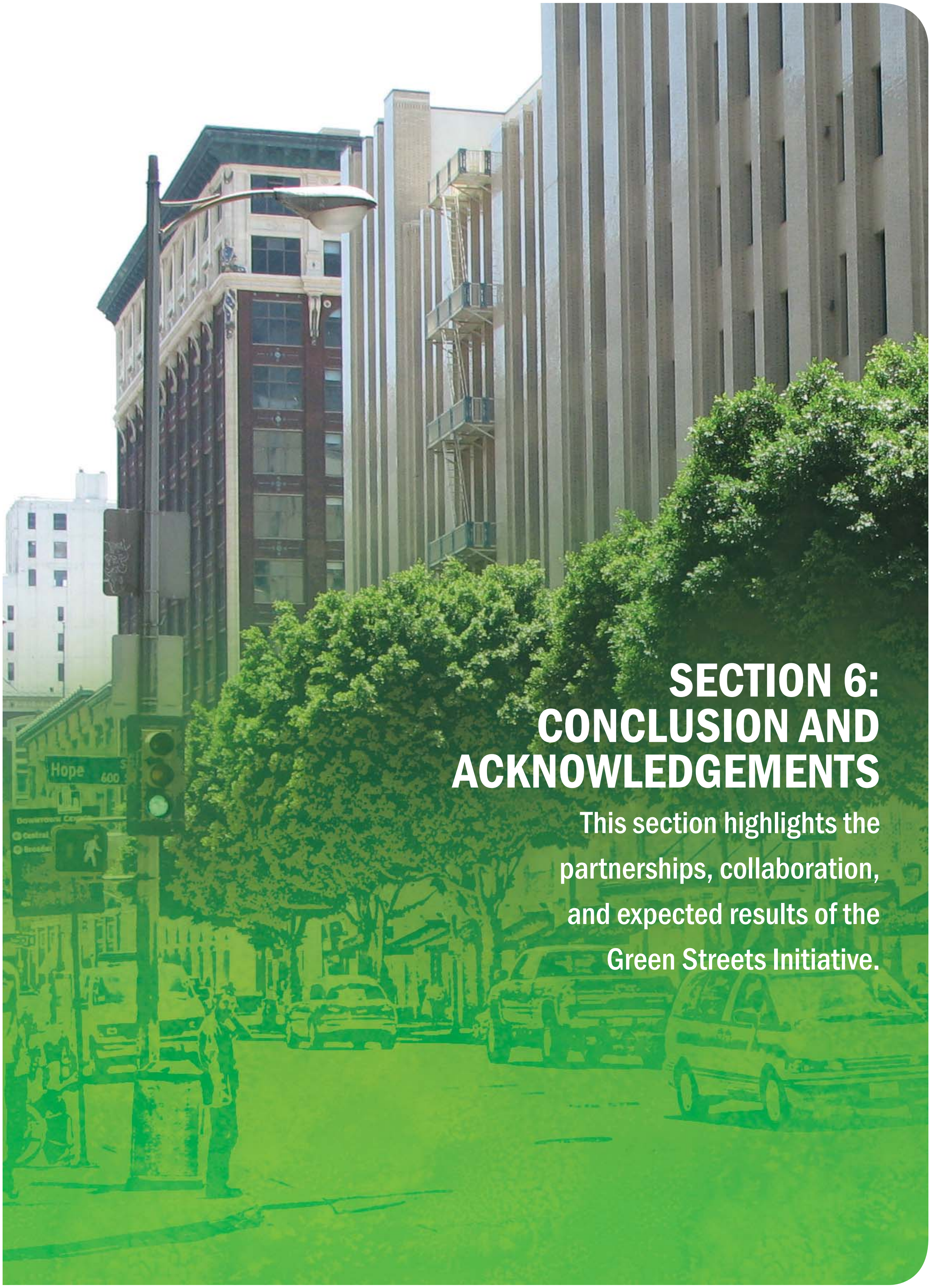
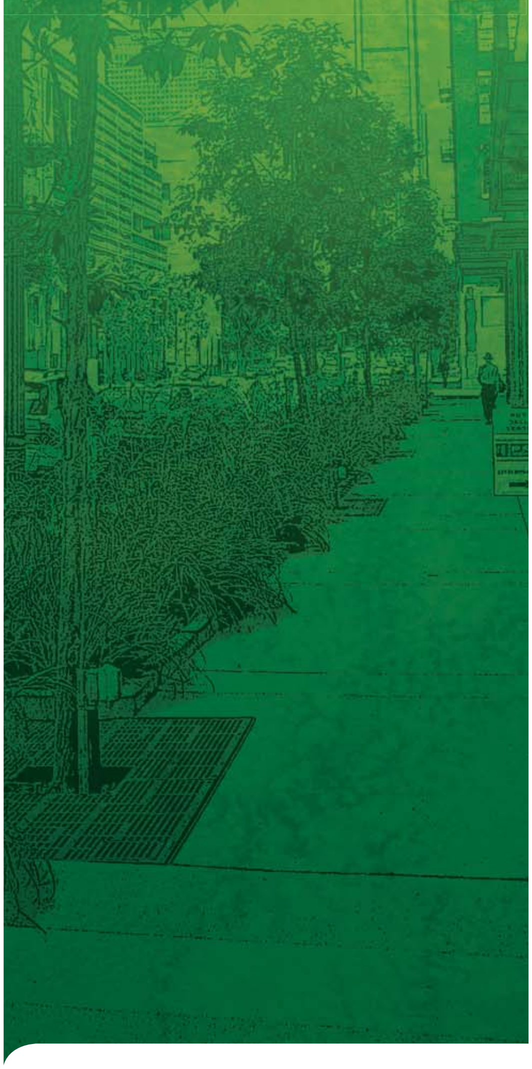


SECTION 6: CONCLUSION AND ACKNOWLEDGEMENTS

This section highlights the partnerships, collaboration, and expected results of the Green Streets Initiative.

SECTION 6: CONCLUSION AND ACKNOWLEDGEMENTS

The success of a Green Streets Initiative requires a partnership between all implementing departments, including Bureaus of Sanitation, Engineering, and Street Services.



Conclusion

The success of the Green Streets Initiative requires a partnership between all implementing departments, including the Department of Public Works' Bureaus of Sanitation, Engineering, and Street Services; the Departments of City Planning, Environmental Affairs, Water and Power, and Transportation; and the Community Redevelopment Agency. Next steps in implementing a Green Streets Initiative in Los Angeles include completion of successful demonstration projects. The City's capital improvement program for new roadway construction projects would typically employ traditional end-of-line treatment systems which could require large amounts of land. The Green Streets Initiative takes an alternate approach to the traditional structural treatment systems by exploring public right-of-ways where infiltration swales or other types of pervious surfaces can be constructed to collect, retain, or detain storm water runoff. This "Green Streets" approach embraces a more regional, sustainable solution with multiple beneficial uses and is consistent with the Low Impact Development (LID) concepts, which looks at and identify opportunity sites within the upper watershed to implement small scale, low cost solutions. In addition, it is expected that the new Los Angeles County NPDES Permit will require storm water mitigation for roadway construction projects.

This initiative will also help conserve the City's limiting and ever-decreasing water supply. Water use in the City of Los Angeles in the 2007-2008 fiscal year exceeded 650,000 acre-feet. While demand continues to grow, recent drought years have put a tremendous strain on the City's water supply. To address this problem, the City's Department of Water & Power implemented a plan to enhance storm water capture and expand ground water storage. This Green Street initiative will help the City achieve water conservation goals identified in the plan.

The Green Street Initiative will address the new NPDES Permit requirements, reduce stormwater runoff, improve water quality, supplement the City's water supply via groundwater recharge (where applicable), improve air quality through reduction of heat island effects from street pavement, and provide a more aesthetically pleasing environment.

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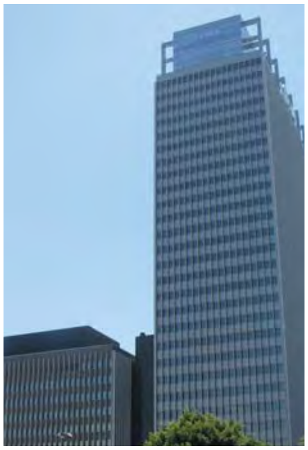

Acknowledgments

The Green Streets Initiative program appreciates all who contributed to this guidebook standard, which was developed by the City of Los Angeles Bureau of Sanitation with guidance from the Board of Public Works, the Green Streets Committee, and input from the Public Works and Energy and Environment Committees of the Los Angeles City Council. A special thanks to the following organizations and individuals for their contributions to the City of Los Angeles Rainwater Harvesting Program:

City of Los Angeles Bureau of Sanitation
Executive Management:
Enrique Zaldivar - Director

Traci Minamide - Chief Operating Officer

Varouj Abkian - Assistant Director

Adel Hagekhalil - Assistant Director

Alex Helou - Assistant Director

Shahram Kharaghani, Program Manager, Watershed Protection Division

City of Los Angeles Bureau of Sanitation
Watershed Protection Division:
Rainwater Harvesting Program Team

Wing Tam, Assistant Division Manager

Steven Nikaido, Civil Engineer

Peter Tonthat, Associate Civil Engineer

Majid Sadeghi, Associate Environmental Engineer

Laura Hunter, Environmental Specialist

City of Los Angeles Community Redevelopment Agency
Karen Yamamoto, Senior Planner

CDM Consultant Team
Wendy Katagi, Samson Debela, Jeff DiMatteo

Geosyntec Consultant Team
Ken Susilo, Lisa Austin, Megan Patterson, Avianne Louie

Ah'be Landscape Architects Consultant Team
Calvin Abe, Martha Williams, Megan Horn

KPF Consultant Team
Tricia Johns

Community Reviewers:
Heal the Bay
Mark Gold, Kirsten James, Meredith McCarthy

Los Angeles & San Gabriel Rivers Watershed Council
Nancy Steele, Edward Belden

City of Los Angeles Bureau of Engineering
Michael Kantor, Michael Brown, Steve Chen, Jeffery Jolley, Mark Chmielowiec, Jeong Park, Patrick Lee

City of Los Angeles Bureau of Street Services
Hugh Lee, Lance Oishi, Robert Gutierrez

City of Los Angeles Department of Water and Power
Tom Erb, Andy Niknafs, Mark Hanna

The River Project
Melanie Winter

The Surfrider Foundation
Paul Herzog

TreePeople
Andy Lipkis, Rebecca Drayse, Deborah Weinstein, Edith Ben-Horin, David O'Donnell, Jason Schmidt, Lisa Cahill

The City of Los Angeles would also like to thank San Mateo County and the City of Portland for granting their permission to incorporate by reference from their Green Streets documents. Their vision, commitment, and leadership in implementing outstanding green street and parking lot projects have been instrumental in the development of this guide and inspiring the Green Streets Initiative to pursue its own sustainable stormwater management efforts. More information can be found about the San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook at: http://www.flowstobay.org/ms_sustainable_streets.php and City of Portland Green Street Program: http://www.portlandonline.com/bes/index.cfm?c=44407

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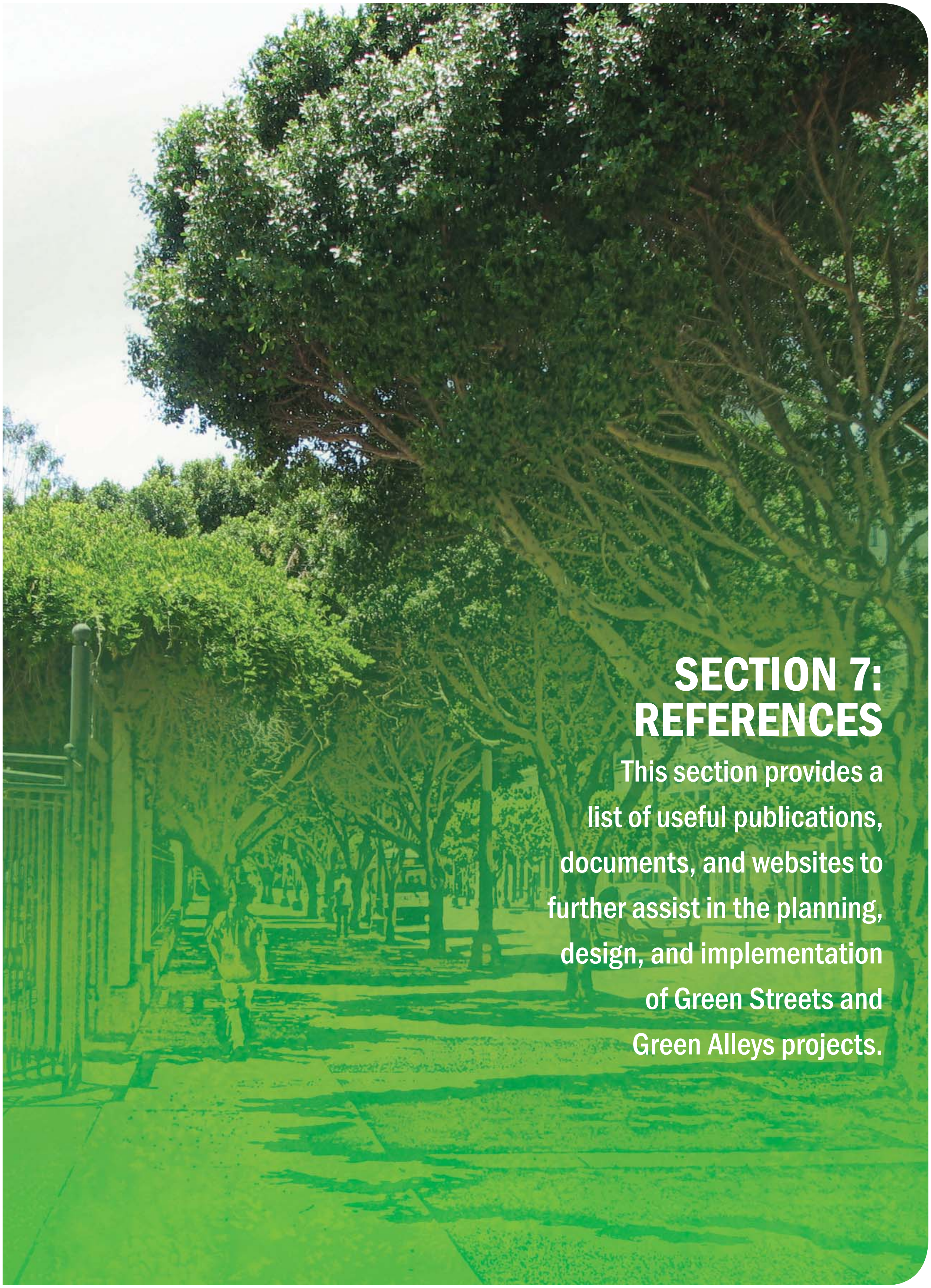

SECTION 7: REFERENCES

This section provides a list of useful publications, documents, and websites to further assist in the planning, design, and implementation of Green Streets and Green Alleys projects.

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SECTION
7.1

USEFUL PUBLICATIONS AND DOCUMENTS

First "Green Street" in Los Angeles is Completed. North East Trees
http://www.lacity.org/COUNCIL/cd13/cd13press/cd13cd13press13247327_07262007.pdf
Resource was used for an understanding of the Oros Green Street Project.

Green Streets Cross-Bureau Team Report Phase 2. City of Portland, Bureau of Environmental Services. 2007.
http://www.portlandonline.com/bes
Resource was incorporate into this Los Angeles green street guidelines document.

San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook. San Mateo Countywide Water Pollution Prevention Program. 2009.
http://www.flowstobay.org/ms_sustainable_streets.php
Resource was incorporated into this Los Angeles green street guidelines document.

Seattle Right-of-Way Improvements Manual. City of Seattle.
http://www.seattle.gov/transportation/rowmanual/manual/
Resource was used for its chapter 6 streetscape design guidelines.

Seattle Permits – Green Parking Lots
http://www.seattle.gov/DPD/Publications/CAM/CAM515.pdf
Resource was used for the Green Parking Lot subsection.

Stormwater Best Management Practice Handbook: New Development and Redevelopment. California Stormwater Quality Association. 2003.
http://www.cabmphandbooks.com
Resource was used for pervious pavement, infiltration trench, and vegetated swale BMPs.

Transforming Alleys into Green Infrastructure for Los Angeles. USC Center for Sustainable Studies. 2009.
Resource was used for Green Alley section.

Urban Hydrology and Storm Water Management. Villanova University, College of Engineering. Traver, Robert. 2007
Resource was used for pervious pavement and infiltration trench BMPs.

USEFUL WEBSITES

SECTION
7.2

Angelus Block Co. INC.
http://www.angelusblock.com
Resource was used for Green Alley section.

Methodology for Prioritizing Structural BMP Implementation
http://www.labmpmethod.com
Resource was used as guidance for strategic storm water quality project planning.

PaverSearch
http://www.paverseach.com
Resource was used for Green Alley section.

PermaPave USA Corp.
http://www.permapave.com
Resource was used for Green Alley section.

RUBBERSIDEWALKS, INC.
http://www.rubbersidewalks.com
Resource was used for pervious pavement section.

Soil Stabilization Products Company, INC.
http://www.sspco.com
Resource was used for Green Alley section.

The Low Impact Development Center, Inc.
http://www.lowimpactdevelopment.org
Resource was used for guidance to develop low impact BMPs such as pervious pavements and tree canopy.

The Stormwater Manager's Resource Center
http://www.stormwatercenter.net/
Resource was used for the Green Parking Lot subsection.

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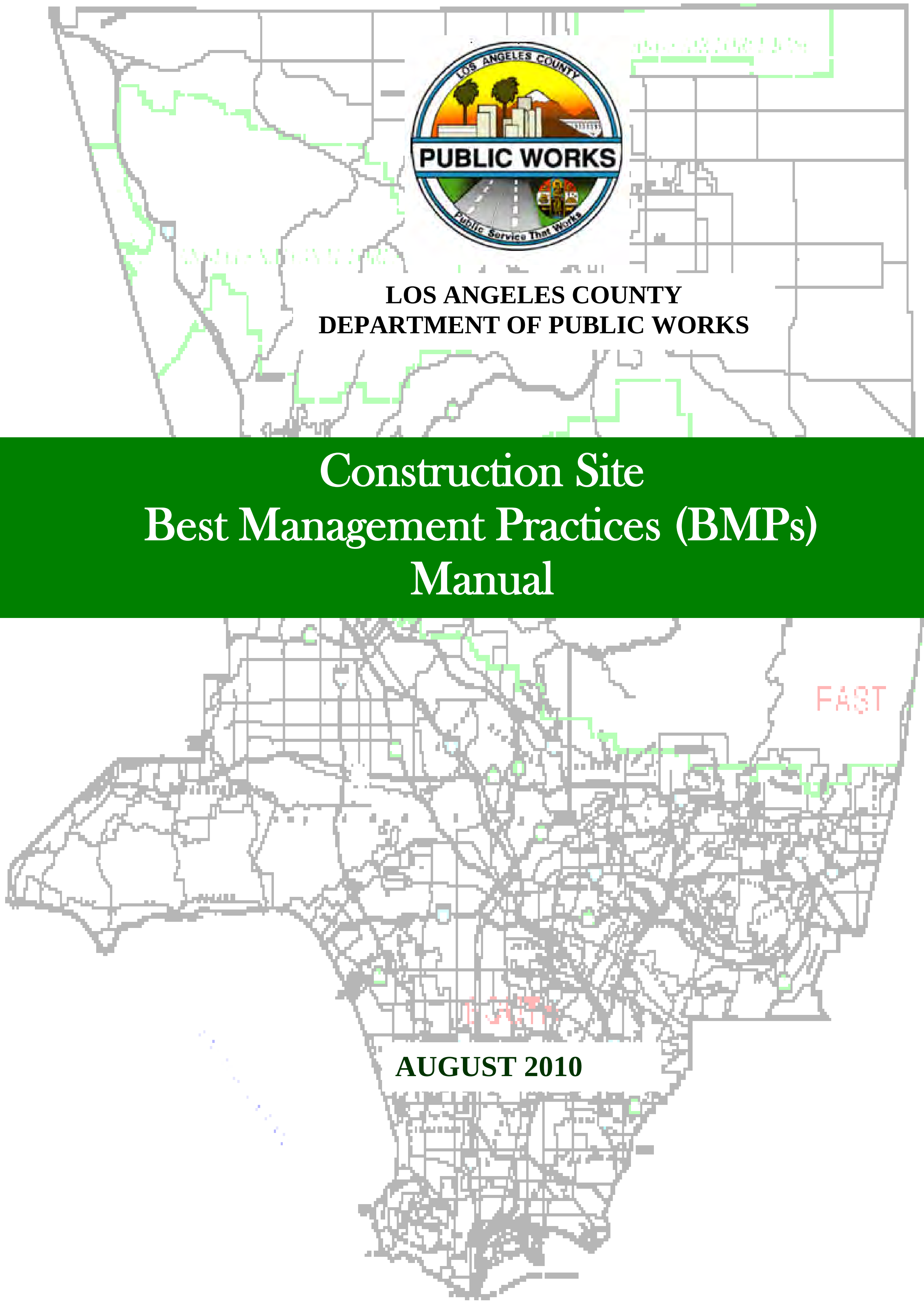

LOS ANGELES COUNTY
DEPARTMENT OF PUBLIC WORKS

Construction Site Best Management Practices (BMPs) Manual

AUGUST 2010

RB-AR33239

Construction Site Best Management Practices (BMP) Manual

Prepared By:
Los Angeles County Department of Public Works
Construction Division
Environmental Compliance Unit
Oscar R. Enriquez – Section Head
Technical Review:
John Gleason
Chris Jones
Ernie Mansfield

References:

Los Angeles County Department of Public Works,
Construction Site Best Management Practices (BMPs) Manual, September 2007.

State Water Resources Control Board (SWRCB) Order No. 2009-0009-DWQ, National Pollutant Discharge Elimination System (NPDES) General Permit No. CAS000002, Waste Discharge Requirements (WDRs) for Discharges of Storm Water Runoff Associated with Construction and Land Disturbance Activities, September 2, 2009.

Regional Water Quality Control Board (RWQCB), Los Angeles Region, Order No. 01-182; NPDES Permit No. CAS004001 Municipal Storm Water and Urban Runoff Discharges within the County of Los Angeles, and Incorporated Cities Therein, December 13, 2001.

State of California Department of Transportation,
Storm Water Quality Handbooks, Construction Site Best Management Practices (BMPs) Manual, March 2003.

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RB-AR33241

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Appendices

SECTION 1

INTRODUCTION

1.1 Introduction

The Construction Site Best Management Practices (BMP) Manual (BMP Manual) has been prepared by the Los Angeles County Department of Public Works (LACDPW) Construction Division to assist Contractors in the process of selection and implementation of construction site BMPs. This BMP Manual includes the LACDPW requirements for the implementation of construction site BMPs. As site conditions change or as deemed necessary, LACDPW may impose additional construction site BMPs for contractor activities. Additional BMPs may be included in the project's contract Special Provisions or may be required by the LACDPW Engineer (Engineer).

LACDPW has developed a program to control runoff from construction sites. The program requires Contractors to implement an effective combination of BMPs to protect water quality as identified in Table 1-1.

Table 1-1

Water Quality Protection Requirements

Category	Requirements	BMP Section of Manual
Soil Stabilization	Erosion from disturbed soil and concentrated flows shall be prevented by implementing appropriate BMPs, such as limiting grading and excavation during the wet season, diverting run-on, controlling runoff, slowing and spreading flows, breaking up disturbed areas with linear barriers and covering erosion susceptible areas.	Section 3
Sediment Control	Sediment shall not be discharged offsite, to the storm drain system or receiving waters. Sediments generated on the project shall be retained by implementing appropriate BMPs.	Section 4
Wind Erosion Control	Prevent wind erosion and dust by applying water or other dust palliatives or by covering as necessary.	Section 5
Tracking Control	Prevent or reduce tracking of sediment and prevent sediment from discharging to paved surfaces, offsite or entering storm drains or watercourses.	Section 6
Non-Storm Water	Non-storm water shall be retained on the construction site and shall be prevented from discharging to the	Section 7

Management	ground, offsite, or entering storm drains or watercourses. BMPs will be implemented to prevent non-storm water discharges.	
Waste Management & Material Pollution Control	Construction-related materials and waste shall be protected from contact with precipitation and run-on and runoff. Spills, leaks or residues shall be cleaned up immediately and all materials and waste shall be prevented from coming in contact with water or from being discharged to the ground, or discharged from the site or to the storm drain system.	Section 8

1.2 Organization of this BMP Manual

The organization of this BMP Manual is as follows:

- Section 1: Introduction – identifies the purpose and use of this BMP Manual, including a brief discussion of the regulatory framework and permits associated with the LACDPW storm water pollution prevention program.

- Section 2: Selecting and Implementing BMPs – provides the process for the selection and implementation of construction site BMPs.

- Section 3: Temporary Soil Stabilization – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Temporary Soil Stabilization BMPs and Concentrated Flow Conveyance BMPs.

- Section 4: Temporary Sediment Control – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Temporary Sediment Control BMPs.

- Section 5: Wind Erosion Control – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Wind Erosion Control BMPs.

- Section 6: Tracking Control – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Tracking Control BMPs.

- Section 7: Non-Storm Water Management – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Non-Storm Water Management BMPs.

- Section 8: Waste Management and Material Pollution Control – provides a list, appropriate application, limitations, standards and specifications, and inspection and maintenance of Waste Management and Material Pollution Control BMPs.

- Appendix A provides a list and definitions of frequently used abbreviations, acronyms, and terms used in this BMP Manual.

- Appendix B has the LACDPW BMP Checklist with instructions.

- Appendix C has the LACDPW Notice of BMP Noncompliance form with instructions.

The Contractor shall know and fully comply with the applicable provisions of the contract Special Provisions, Construction Site BMP Manual and SWPPP Preparation Manual (if a SWPPP is required by contract Special Provisions), Permits, and Federal, State, and local regulations that govern the Contractor's operations and storm water discharges from the construction site.

This BMP Manual refers to the Engineer repeatedly. The Engineer is the LACDPW authorized representative on site (Engineer, Inspector, or LACDPW consultant).

1.3 Regulations and Permits

In 1972, the Federal Water Pollution Control Act (also referred to as the Clean Water Act) (CWA) was amended to provide that the discharge of pollutants to waters of the United States from any point source is unlawful unless the discharge is in compliance with an NPDES permit. In 1987, the CWA was amended to establish a framework for regulating municipal and industrial storm water discharges under the NPDES Program. In 1990, the U.S. Environmental Protection Agency (USEPA) published final regulations that establish storm water permit application requirements for specified categories of industries. In 2003, the Phase II regulations became effective for small construction sites. The regulations provide that discharges of storm water to waters of the United States from construction projects that encompass one acre or more of soil disturbance are effectively prohibited unless the discharge is in compliance with an NPDES Permit.

The Regional Water Quality Control Board (RWQCB) regulates the discharge of storm water from municipalities and activities within their jurisdiction including construction. Part of the RWQCB Los Angeles Region regulations requires the County to have adequate enforcement capabilities for controlling storm water runoff. Los Angeles County Code Chapter 12.80.630 Storm Water and Pollution Runoff Control fulfills the requirement of the RWQCB for enforceable regulations.

The State Water Resources Control Board (SWRCB) issued the Small Municipal Separate Storm Sewer System (MS4) Permit (Small MS4 Permit) effective August 8, 2003 which will impact the County's unincorporated areas in the Antelope Valley. LACDPW requires the Antelope Valley portions of Los Angeles County to comply with the same requirements for Construction Site Storm Water Runoff Control as the rest of the County.

1.3.1 General Permit

The SWRCB has elected to adopt one statewide General Permit that will apply to all storm water discharges associated with construction activity.

In 2009, the SWRCB re-issued *National Pollutant Discharge Elimination System (NPDES) Permit No. CAS000002 under Order No. 2009-0009-DWQ, Waste Discharge Requirements for Discharges of Storm Water Runoff Associated with Construction and Land Disturbance Activities* (Construction General Permit) that requires all dischargers where construction activities disturb one or more acres to comply with the Construction General Permit and develop and implement a Storm Water Pollution Prevention Plan (SWPPP). For construction sites that disturb one or more acres, refer to the LACDPW "Storm Water Pollution Prevention Plan (SWPPP) Preparation Manual."

1.3.2 Municipal Permit

On December 13, 2001, the RWQCB, Los Angeles Region, adopted Order No. 01-182, NPDES Permit No. CAS004001, Waste Discharge Requirements for Municipal Storm Water and Urban Runoff Discharges within the County of Los Angeles, and Incorporated Cities Therein (MS4 Permit). This Permit was issued to the Los Angeles County Flood Control District, the County of Los Angeles, and 84 cities within the county; and requires the preparation and implementation of a storm water pollution prevention program to control runoff from construction sites within its jurisdiction. The MS4 Permit jurisdiction includes all areas of Los Angeles County except the northern (Antelope Valley) area. This BMP Manual is part of the LACDPW program to control runoff from all construction sites within Los Angeles County including the Antelope Valley.

1.3.3 Los Angeles County Code

The Contractor is subject to enforcement action by Chapter 12.80 of the Los Angeles County Code (12.80.630) that states, *"Any person, firm, corporation, municipality or district or any officer or agent of any firm corporation, municipality or district violating any provision of this chapter shall be guilty of a misdemeanor. Such violation shall be punishable by a fine of not more than $1,000 or by imprisonment in the county jail for a period not to exceed six months, or by both fine and imprisonment. Each day during any portion of which such violation is committed, continued or permitted shall constitute a separate offense and shall be punishable as such (Ord. 98-0021§1(part), 1998)."* LACDPW applies this code to all their construction sites.

SECTION 2

SELECTING AND IMPLEMENTING BMPS

This Section provides instructions to assist Contractors in the selection and implementation of construction site BMPs. The requirements in this BMP Manual reflect the LACDPW minimum requirements. LACDPW may impose additional construction site BMPs as necessary to adequately protect water quality and comply with storm water pollution prevention regulations. Additional BMPs may be included in the project's contract Special Provisions or required in the field by the Engineer.

Construction site BMPs are required to be implemented on a year-round basis during construction activities, including during any temporary suspension of work.

2.1 Minimum BMP Requirements

Table 2-1 lists the Construction Site BMPs approved for use on LACDPW construction sites. The minimum BMPs identified on Table 2-1 shall be implemented on all LACDPW construction sites.

Table 2-1
Construction Site BMPs(1)

ID	BMP Name	Minimum Requirement
Temporary Soil Stabilization		
SS-1	Scheduling	X
SS-2	Preservation of Existing Vegetation	X
SS-3	Hydraulic Mulch(2)	
SS-4	Hydroseeding(2)	
SS-5	Soil Binders(2)	
SS-6	Straw Mulch(2)	
SS-7	Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats(2)	
SS-8	Wood Mulching(2)	
SS-9	Earth Dikes/Drainage Swales & Lined Ditches	
SS-10	Outlet Protection/Velocity Dissipation Devices	
SS-11	Slope Drains	
SS-12	Streambank Stabilization	
Temporary Sediment Control		
SC-1	Silt Fence	X(3)
SC-2	Sediment/Desilting Basin	
SC-3	Sediment Trap	
SC-4	Check Dam	
SC-5	Fiber Rolls(4)	X(3)

SC-6	Gravel Bag Berm[4]	X[3]
SC-7	Street Sweeping and Vacuuming	X
SC-8	Sandbag Barrier	X[3]
SC-9	Straw Bale Barrier	
SC-10	Storm Drain Protection	X
Wind Erosion Control		
WE-1	Wind Erosion Control[5]	X
Tracking Control		
TC-1	Stabilized Construction Entrance/Exit	X
TC-2	Stabilized Construction Roadway	
TC-3	Entrance/Outlet Tire Wash	
Non-Storm Water Management		
NS-1	Water Conservation Practices	X
NS-2	Dewatering Operations[6]	X
NS-3	Paving and Grinding Operations	X
NS-4	Temporary Stream Crossing	
NS-5	Clear Water Diversion	
NS-6	Illicit Connection/Illegal Discharge Detection and Reporting	X
NS-7	Potable Water/Irrigation	X
NS-8	Vehicle Equipment Cleaning	X
NS-9	Vehicle Equipment Fueling	X
NS-10	Vehicle Equipment Maintenance	X
NS-11	Pile Driving Operations	
NS-12	Concrete Curing	
NS-13	Material and Equipment Use Over Water	
NS-14	Concrete Finishing	
NS-15	Structure Demolition Over or Adjacent to Water	
NS-16	Temporary Batch Plant	
Waste Management and Material Pollution Control		
WM-1	Material Delivery and Storage	X
WM-2	Material Use	X
WM-3	Stockpile Management	X
WM-4	Spill Prevention and Control	X
WM-5	Solid Waste Management	X
WM-6	Hazardous Waste Management[7]	X
WM-7	Contaminated Soil Management	
WM-8	Concrete Waste Management	X
WM-9	Sanitary/Septic Waste Management	X
WM-10	Liquid Waste Management[8]	X

(1) This table indicates minimum required BMPs. Additional BMPs may be required as a result of actual field conditions, Contractor activities, or construction operations.
(2) The Contractor shall select and implement one or a combination of soil stabilization BMPs.

(3) The Contractor shall implement one or a combination of BMPs for prevention of sediment discharges along the perimeter of the Project site.

(4) One or a combination of BMPs is required to break up the sheet flow lengths (grade breaks for exposed soil).

(5) The Contractor shall implement effective wind erosion and dust control BMPs in conformance with the requirements of the jurisdictional air quality regulatory agency.

(6) Required for discharging accumulated precipitation. Separate permits are required for groundwater dewatering.

(7) Required for vehicles and equipment fueling, cleaning or maintenance, or other construction activities on the Construction site if waste is generated.

(8) Required for prevention of potential sewage spills as well as for inclusion in any plan for emergency spill cleanup and response.

Table 2-2, "Storm Water Pollution Controls for Construction Activities" is a guide for selection of storm water BMPs. The table is based on Construction activity categories. The Contractor shall use Table 2-2 to select additional BMPs based on the types of construction activities to be conducted on the construction site.

Table 2-2
Storm Water Pollution Controls for Construction Activities

Storm Water Best Management Practices	BMP No.	Site Preparation/ Earthmoving: Clearing & Grubbing	Site Preparation/ Earthmoving: Earthwork	Construction of Underground Structures: Foundations	Construction of Underground Structures: Conduits (Open Cut)	Construction of Underground Structures: Drilling	Construction of Underground Structures: Tunnels	Construction of Above Ground Structures: Wood Frame	Construction of Above Ground Structures: Structural Steel	Construction of Above Ground Structures: Masonry & Concrete	Construction of Roadways, Walkways & Parking Lots: Concrete	Construction of Roadways, Walkways & Parking Lots: Asphalt	Construction of Roadways, Walkways & Parking Lots: Base & Subgrade	Construction in Waterways: Channel Improvement	Construction in Waterways: Water/Sediment Impoundment	Construction in Waterways: Construction Over Water	Construction in Waterways: In Waterway	Construction in Waterways: Adjacent to Water	Planting & Landscaping: Irrigation	Planting & Landscaping: Seeding & Sodding	Planting & Landscaping: Mulching	Planting & Landscaping: Planting
Temporary Soil Stabilization																						
Scheduling	SS-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Preservation of Existing Vegetation	SS-2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Hydraulic Mulch	SS-3	X	X		X														X X	X		X
Hydroseeding	SS-4	X	X		X														X X	X		X
Soil Binders	SS-5	X	X		X														X X	X		X
Straw Mulch	SS-6	X	X		X														X X	X		X
Geotextiles, Plastic Covers & Erosion Control Blankets/Mats	SS-7	X	X		X														X X	X		X
Wood Mulch	SS-8	X	X		X														X X	X		X
Earth Dikes/Drainage Swales & Ditches	SS-9	X	X	X	X						X	X	X	X	X	X	X	X				
Outlet Protection/Velocity Dissipation Devices	SS-10	X	X								X	X	X	X	X	X	X	X				
Slope Drains	SS-11	X	X											X	X	X	X	X	X			
Streambank Stabilization	SS-12													X			X					
Temporary Sediment Control																						
Silt Fence	SC-1	X	X	X	X			X	X X	X X			X	X	X	X	X	X		X	X	X
Desilting Basin	SC-2	X	X	X	X			X	X X	X X			X	X	X	X	X	X		X	X	X
Sediment Trap	SC-3	X	X	X	X	X	X			X X	X		X	X	X	X	X	X				
Check Dam	SC-4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Fiber Rolls	SC-5	X	X	X	X	X	X			X X	X											
Gravel Bag Berm	SC-6	X	X	X	X	X	X							X	X							
Street Sweeping & Vacuuming	SC-7	X	X	X	X	X	X	X	X X	X X			X	X		X	X					
Sand Bag Barrier	SC-8	X	X		X					X	X	X		X	X	X X		X X	X X			X
Straw Bale Barrier	SC-9	X	X		X									X	X	X	X	X				
Storm Drain Inlet Protection	SC-10	X	X		X					X	X	X		X	X	X	X	X				

Table 2-2 (continued)
Storm Water Pollution Controls for Construction Activities

Storm Water Best Management Practices	BMP No.	Site Preparation/ Earthmoving		Construction of Underground Structures				Construction of Above Ground Structures			Construction of Roadways, Walkways & Parking Lots			Construction in Waterways					Planting & Landscaping			
		Clearing & Grubbing	Earthwork	Foundations	Conduits (Open Cut)	Drilling	Tunnels	Wood Frame	Structural Steel	Masonry & Concrete	Concrete	Asphalt	Base & Subgrade	Channel Improvement	Water/Sediment Impoundment	Construction Over Water	In Waterway	Adjacent to Water	Irrigation	Seeding & Sodding	Mulching	Planting
Wind Erosion																						
Wind Erosion Control	WE-1		X	X	X	X	X							X	X	X	X	X				
Tracking Control																						
Stabilized Construction Entrance/Exit	TC-1	X	X	X	X						X	X	X	X	X		X	X				
Stabilized Construction Roadway	TC-2	X	X	X	X						X	X	X	X	X	X	X	X				
Entrance/Exit Tire Wash	TC-3	X	X		X						X	X	X	X	X		X	X				
Non-Storm Water Management																						
Water Conservation Practices	NS-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Paving & Grinding Operations	NS-3									X	X	X										
Temporary Stream Crossing	NS-4	X	X	X	X	X	X							X	X							
Clear Water Diversion	NS-5			X	X		X			X	X			X		X	X		X			
Illicit Connection/Illegal Discharge	NS-6	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Potable Water/Irrigation	NS-7																		X	X	X	X
Vehicle and Equipment Cleaning	NS-8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Vehicle and Equipment Fueling	NS-9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Vehicle and Equipment Maintenance	NS-10	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Pile Driving Operation	NS-11			X																		
Concrete Curing	NS-12									X	X											
Material and Equipment Use Over Water	NS-13															X						
Concrete Finishing	NS-14									X	X											
Structure Demolition/Removal Over or Adjacent to Waters	NS-15													X		X		X				
Temporary Batch Plants	NS-16									X	X	X										

Table 2-2 (continued)
Storm Water Pollution Controls for Construction Activities

Storm Water Best Management Practices	BMP No.	Site Preparation/ Earthmoving: Clearing & Grubbing	Site Preparation/ Earthmoving: Earthwork	Construction of Underground Structures: Foundations	Construction of Underground Structures: Conduits (Open Cut)	Construction of Underground Structures: Drilling	Construction of Underground Structures: Tunnels	Construction of Above Ground Structures: Wood Frame	Construction of Above Ground Structures: Structural Steel	Construction of Above Ground Structures: Masonry & Concrete	Construction of Roadways, Walkways & Parking Lots: Concrete	Construction of Roadways, Walkways & Parking Lots: Asphalt	Construction of Roadways, Walkways & Parking Lots: Base & Subgrade	Construction in Waterways: Channel Improvement	Construction in Waterways: Water/Sediment Impoundment	Construction in Waterways: Construction Over Water	Construction in Waterways: In Waterway	Construction in Waterways: Adjacent to Water	Planting & Landscaping: Irrigation	Planting & Landscaping: Seeding & Sodding	Planting & Landscaping: Mulching	Planting & Landscaping: Planting
Waste Management & Material Pollution Control																						
Material Delivery & Storage	WM-1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Material Use	WM-2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X X		X X	X X			X
Stockpile Management	WM-3	X	X	X	X	X	X				X	X	X	X	X	X		X				
Spill Prevention & Control	WM-4					X	X			X	X			X	X	X	X	X	X			
Solid Waste Management	WM-5	X	X					X	X	X	X	X	X	X	X	X X		X X	X X			X
Hazardous Waste Management	WM-6		X		X	X	X		X													
Contaminated Soil Management	WM-7		X		X	X	X						X									
Concrete Waste Management	WM-8			X		X	X	X	X X	X X				X		X		X				
Sanitary/Septic Waste Management	WM-9	X	X					X	X	X	X	X	X	X	X	X X		X X	X X			X
Liquid Waste Management	WM-10					X	X			X	X			X	X	X X		X X	X X			X

2.2 BMP Inspections and Checklist

To ensure the proper implementation and functioning of water pollution control practices, the Contractor shall regularly inspect and maintain the construction site for the water pollution control practices as follows:

- At a minimum once every week.
- Within 48 hours prior to a qualifying rain event (1/2 inch or more of precipitation with a 48 hour or greater period between rain events);
- Within 48 hours after a qualifying rain event
- At least every 24 hours during extended precipitation events.

Detailed instructions for conducting inspections and filling out the BMP Checklist are included in Appendix B.

2.3 BMP Noncompliance and Enforcement Actions

Corrective actions may be required to comply with the SWPPP or contract Special Provisions. The corrective actions identified on the BMP Checklist are required to be completed by the end of the day that the inspection was performed and documented. If the corrective actions identified on the BMP Checklist are not completed by the end of the day, enforcement actions of the contract Special Provisions will be triggered. One of the enforcement tools is the Notice of BMP Noncompliance Form (Appendix C).

When the Engineer identifies that one or more of the BMPs have not been properly implemented and maintained, the Notice of BMP Noncompliance form may be implemented:

1. Part 1 of the Notice of BMP Noncompliance Form will be completed to identify the date of noncompliance, (A) BMP Description, (B) Location, (C) Recommended corrective action(s), and (D) Date Corrective Action to be Completed (within 2 working days).
2. A copy of the form will be given to the Contractor.
3. When the corrective action is completed by the Contractor, the completion date will be entered in Column (E) "Date Corrective Action Completed."
4. If the corrective action is completed by the specified date, "Yes" will be checked in Column (F) Corrective action completed within 2 days.
5. If the corrective action is not completed by the specified date, the Engineer will check "No" in Column (F) indicating the corrective action was not completed within two days, and immediately notify the Environmental Compliance Unit (ECU).
6. Part 2 of the form will be completed if a corrective action was not completed within two days. Contractual Sanctions will be implemented on a daily basis until the recommended corrective action is completed to the satisfaction of the Engineer and the ECU. The date will be written in Column (E) once the corrective action is completed.

> Noncompliance for the same violation will result in immediate monetary penalty without allowing 2 days for compliance. It is noted that this form is only one tool and it is up to the Engineer whether additional enforcement is necessary including immediate fines. For example, discharge of concrete waste may result in immediate monetary penalty.

The LACDPW, as a permittee, is subject to enforcement action by the SWRCB, Environmental Protection Agency, private citizens, and citizen groups. The LACDPW will assess the Contractor a penalty of $1,000 for each calendar day that the Contractor does not fully implement or comply with the provisions set forth in Section 7-8.6 "Water Pollution Control," of the contract Special Provisions, including but not limited to, compliance with the applicable provisions of the Special Provisions, manuals, permits and Federal, State and local regulations. The Contractor shall be responsible for the costs and for liabilities imposed by law as a result of the Contractor's failure to comply with the provisions. Costs and liabilities include, but are not limited to: fines, penalties, and damages, whether assessed against the LACDPW or the Contractor, including those levied under the Federal Clean Water Act and the State Porter Cologne Water Quality Act. In addition the LACDPW will deduct from payments due the Contractor, the total amount of any legal fees, staff costs, and consultant fees as a result of the Contractor's noncompliance with these provisions.

SECTION 3

TEMPORARY SOIL STABILIZATION BMPs

3.1 Temporary Soil Stabilization

Temporary soil stabilization is erosion control that consists of protecting or covering exposed areas of soil or stockpiles to minimize erosion by implementing at least one, or any combination, of the BMPs shown on Table 3-1. Provide effective soil cover for inactive areas and all finished slopes, open space, utility backfill, and completed lots and inactive portions thereof. Implement appropriate erosion control BMPs (runoff control and soil stabilization) in conjunction with sediment control BMPs for areas under active construction.

3.2 Temporary Concentrated Flow Conveyance Controls

Temporary concentrated flow conveyance controls are erosion controls that consist of BMPs used to intercept, divert, convey and discharge concentrated flows to minimize erosion from within the construction site and downstream of the construction site. Temporary concentrated flow conveyance controls are required to effectively manage all run-on, all runoff within the site and all runoff that discharges from the site. Run-on from offsite shall be directed away from all disturbed areas.

Table 3-1
Temporary Soil Stabilization BMPs

ID	BMP Name
SS-1	Scheduling
SS-2	Preservation of Existing Vegetation
SS-3	Hydraulic Mulch
SS-4	Hydroseeding
SS-5	Soil Binders
SS-6	Straw Mulch
SS-7	Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats
SS-8	Wood Mulching
Temporary Concentrated Flow Conveyance	
SS-9	Earth Dikes/Drainage Swales & Lined Ditches
SS-10	Outlet Protection/Velocity Dissipation Devices
SS-11	Slope Drains
SS-12	Streambank Stabilization

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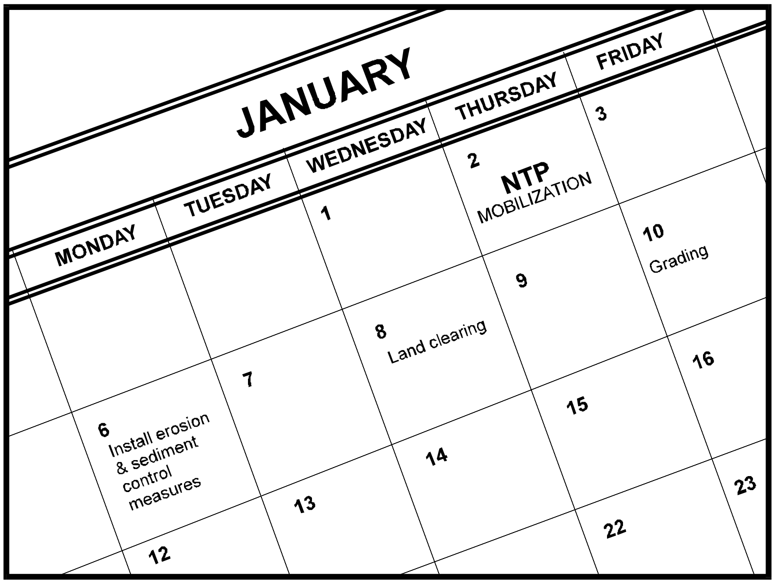
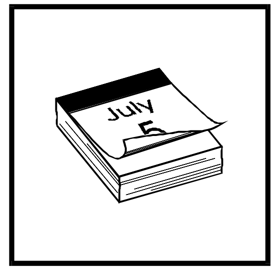
Scheduling

SS-1





Standard Symbol

BMP Objectives

- Soil Stabilization
- Sediment Control
- Tracking Control
- Wind Erosion Control
- Non-Storm Water Management
- Materials and Waste Management

Definition and Purpose

This best management practice (BMP) involves sequencing of construction activities with the implementation of construction site BMPs such as temporary soil stabilization (erosion control) and temporary sediment control measures. The purpose is to reduce the amount and duration of soil exposed to erosion by wind, rain, runoff and vehicle tracking, and to perform the construction activities and control practices in accordance with the planned schedule.

Appropriate Applications

Scheduling and planning the project are the very first steps in an effective storm water program and are required for every construction project.

Limitations

None identified.

Standards and Specifications

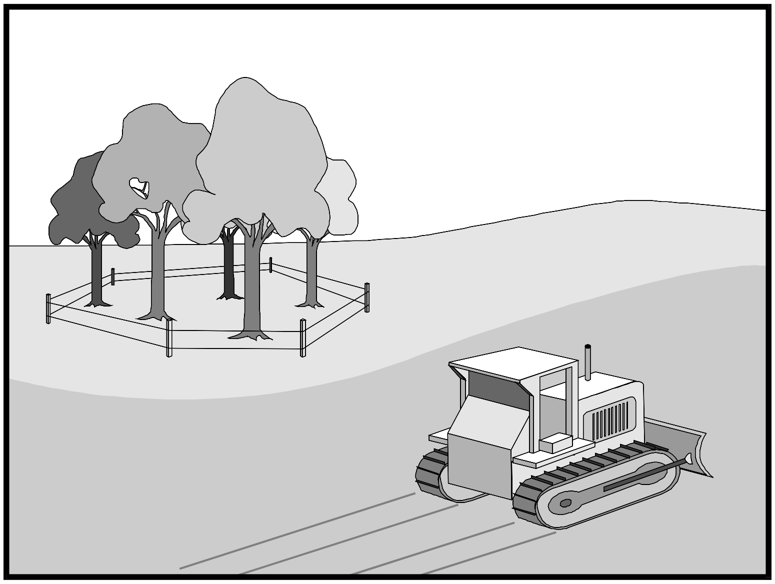
- Construction sequencing shall be scheduled to minimize land disturbance for all projects throughout the year. Appropriate BMPs shall be implemented on a year round basis. The construction schedule shall be reflected in the SWPPP implementation of BMPs.
- Schedule year around implementation and deployment of:
  - Temporary soil stabilization BMPs.
  - Temporary sediment control BMPs.
  - Tracking control BMPs.
  - Wind erosion control BMPs.
  - Non-storm water BMPs.
  - Waste management and materials pollution control BMPs.

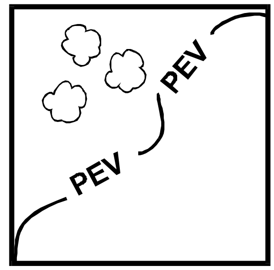
- Develop the sequencing and timetable for the start and completion of each item such as site clearing and grubbing, grading, excavation, paving, pouring foundations, installing utilities, etc., to minimize the soil disturbing activities during the rainy season.
- Schedule major grading operations for the non-rainy season when practical.
- Stabilize non-active areas within 14 days from the cessation of soil-disturbing activities or one day prior to the onset of precipitation, whichever occurs first.
- Monitor the weather forecast for rainfall.
- When rainfall is predicted, adjust the construction schedule to allow the implementation of soil stabilization and sediment controls and sediment treatment controls on all disturbed areas prior to the onset of rain.
- Be prepared year-round to deploy soil stabilization and sediment control practices. Erosion may be caused during the non-rainy season by unseasonal rainfall, wind, and vehicle tracking. Keep the site stabilized year-round, and retain and maintain sediment tapping devices in operational condition.
- Incorporate staged seeding and re-vegetation of graded slopes as work progresses according to the contract Special Provisions or as directed by the Engineer.
- Apply and maintain temporary erosion and sediment controls to all areas until permanent stabilization has been established.

Maintenance and Inspection

- Review and update project site weekly.
- Verify that work is progressing in accordance with the schedule. If progress deviates, take corrective actions.
- Amend the schedule when changes are warranted or when directed by the Engineer.

Preservation of Existing Vegetation SS-2





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Preservation of existing vegetation is the identification and protection of desirable vegetation that provides erosion and sediment control benefits.

Appropriate Applications

- Preserve existing vegetation at areas on a site where no construction activity is required by the contract Special Provisions.
- On a year-round basis, temporary fencing shall be installed at the limits clearing and grubbing operations and other soil-disturbing activities. The temporary fencing shall be installed prior to commencement of clearing and grubbing operations and other soil-disturbing activities
- Clearing and grubbing operations shall be staged to preserve existing vegetation.

Limitations

Protection of existing vegetation requires planning, and may limit the area available for construction activities.

Standards and Specifications

Do NOT drive over vegetation or store materials on vegetation or otherwise disturb vegetation outside construction project boundaries shown on the project plans.

Schedule

- The Contractor shall not prune or remove any trees for any reason during the nesting season (see contract Special Provisions) for migratory non-game native bird species, including raptors.
- If approved by the Engineer, the Contractor may prune or remove any trees during the nesting season. The Contractor will coordinate with the Agency to provide all required bird surveys to detect any protected native birds in the trees to be removed and other suitable nesting habitat.

- If a protected native bird is found, the Agency will delay all clearance/construction disturbance activities in suitable nesting habitat or continue the surveys in order to locate any nests. If an active nest is located, clearance/construction disturbance activities shall be delayed until the nest is vacated and juveniles have fledged and when there is no evidence of a second attempt at nesting. Limits of construction to avoid a nest shall be established in the field by the Agency.

- Refer to contract Special Provisions for any other provisions or requirements for the preservation vegetation.

Design and Layout

- Mark areas to be preserved with temporary fencing.

- Minimize the disturbed areas by locating temporary roadways, stockpiles and layouts areas to avoid stands of trees, shrubs, and grass. Follow existing contours to reduce cutting and filling.

Installation

- Construction materials, equipment storage, and parking areas shall be located where they will not cause root compaction.

- Keep equipment away from trees to prevent trunk and root damage.

- Maintain existing irrigation systems.

- Employees and subcontractors shall be trained to perverse protective devices. No heavy equipment, vehicular traffic, or storage piles of any construction materials shall be permitted within the drip line of any tree to be remain. Removed trees shall not be felled, pushed, or pulled into any retained trees. No toxic or construction materials (including paint, acid, nails, gypsum board, chemicals, fuels, and lubricants) shall be stored within 50 feet of the drip line of any retained trees, nor disposed of in any way which would impact vegetation.

Trenching and Tunneling

- Trenching shall be as far away from tree trunks as possible, usually outside of the tree drip line or canopy. Curve trenches around trees to avoid large roots or root concentrations. If roots are encountered, consider tunneling under them. When trenching and/or tunneling near or under trees to be retained, tunnels shall be at least 18 inches below the ground surface, and not below the tree center to minimize impact on the roots.

- Tree roots shall not be left exposed to air; they shall be covered with soil as soon as possible, protected, and kept moistened with wet burlap or peat moss until the tunnel and/or trench can be completed.

- The ends of damaged or cut roots shall be cut off smoothly.
- Trenches and tunnels shall be backfilled as soon as possible. Careful backfilling andcompacting will eliminate air spaces in the soil which can damage roots.
- After all other work is complete, fences and barriers shall be removed last. This is because protected trees may be destroyed by carelessness during the final cleanup and landscaping.

Maintenance and Inspection

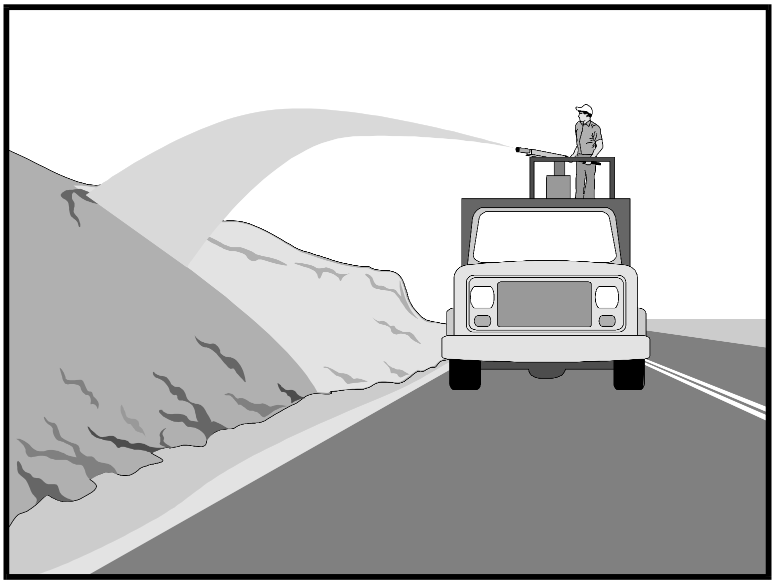
During construction, the limits of disturbance shall remain clearly marked at all times. Irrigation or maintenance of existing vegetation shall conform to the requirements in the landscaping plan. If damage to protected trees still occurs, maintenance guidelines described below shall be followed:

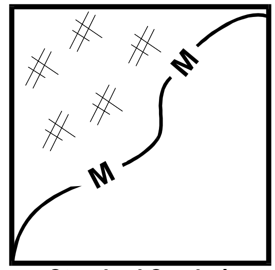
- Verify that protective measures remain in place. Restore damaged protection measures immediately
- Serious tree injuries shall be attended to by an arborist.
- Damage to the crown, trunk, or root system of a retained tree shall be repaired immediately.
- Trench as far from tree trunks as possible, usually outside of the tree drip line or canopy. Curve trenches around trees to avoid large roots or root concentrations. If roots are encountered, consider tunneling under them. When trenching or tunneling near or under trees to be retained, place tunnels at least 18 in. below the ground surface, and not below the tree center to minimize impact on the roots.
- Do not leave tree roots exposed to air. Cover exposed roots with soil as soon as possible. If soil covering is not practical, protect exposed roots with wet burlap or peat moss until the tunnel or trench is ready for backfill.
- Cleanly remove the ends of damaged roots with a smooth cut.
- Remove any trees intended for retention if those trees are damaged seriously enough to affect their survival, as determined by the Engineer. If replacement is required, the new tree shall be of similar species, as required by the contract special provisions or as directed by the Engineer.
- If bark damage occurs, cut back all loosened bark into the undamaged area, with the cut tapered at the top and bottom and drainage provided at the base of the wood. Limit cutting the undamaged area as much as possible.
- Aerate soil that has been compacted over a trees root zone by punching holes 12 in. deep with an iron bar, and moving the bar back and forth until the soil is loosened. Place holes 18 in. apart throughout the area of compacted soil under the tree crown.

- Fertilization
  - Fertilize stressed or damaged broadleaf trees to aid recovery.
  - Fertilize trees in the late fall or early spring.
  - Apply fertilizer to the soil over the feeder roots and in accordance with label instructions, but never closer than 3 ft to the trunk. Increase the fertilized area by one-fourth of the crown area for conifers that have extended root systems.
  - Discontinue the application of any erodible landscape material within 2 days before a forecasted rain event or during periods of precipitation.
  - Follow WM-1 for storage of fertilizers.
- Retain protective measures until all other construction activity is complete to avoid damage during site cleanup and stabilization.
- Inspect existing vegetation weekly and before and after every rainfall events. During extended rainfall events, inspect existing vegetation at least once every 24 hours.

Hydraulic Mulch

SS-3





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Hydraulic mulch consists of applying a mixture of shredded wood fiber or a hydraulic matrix and a stabilizing emulsion or tackifier with hydroseeding equipment, which temporarily protects exposed soil from erosion by raindrop impact or wind. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Hydraulic mulch is applied to disturbed areas requiring temporary protection until permanent vegetation is established or to disturbed areas that must be re-disturbed following a period of inactivity.

Limitations

- Wood fiber hydraulic mulches are generally short-lived (only last a part of a growing season) and need 24 hours to dry before rainfall occurs to be effective.
- Paper mulches alone are not permitted. Paper mulch is allowed if in combination with other mulch such as wood.
- Avoid use in areas where the mulch would be incompatible with immediate future earthwork activities and would have to be removed.

Standards and Specifications

- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching type roller or by track walking. Track walking shall only be used where other methods are impractical.
- Avoid mulch over-spray onto the roadway, sidewalks, lined drainage channels, and existing vegetation.
- Selection of hydraulic mulches by the Contractor must be approved by the Engineer.

Hydraulic Mulch

- Wood fiber mulch can be applied alone or as a component of hydraulic matrices. Wood fiber mulch shall be applied per manufacture's recommendations typically at the rate of 2,000 to 4,000 lb/ac. This type of mulch is manufactured from wood or wood waste from lumber mills or from urban sources.

Hydraulic Matrices

- Hydraulic matrices include a mixture of wood fiber mulch and tackifier applied as slurry. It is typically applied at the rate of 2,000 to 4,000 lb/ac with 5-10% by weight of a stabilizing emulsion or tackifier (e.g., guar, psyllium, acrylic copolymer, polyacrylamide).

Bonded Fiber Matrix

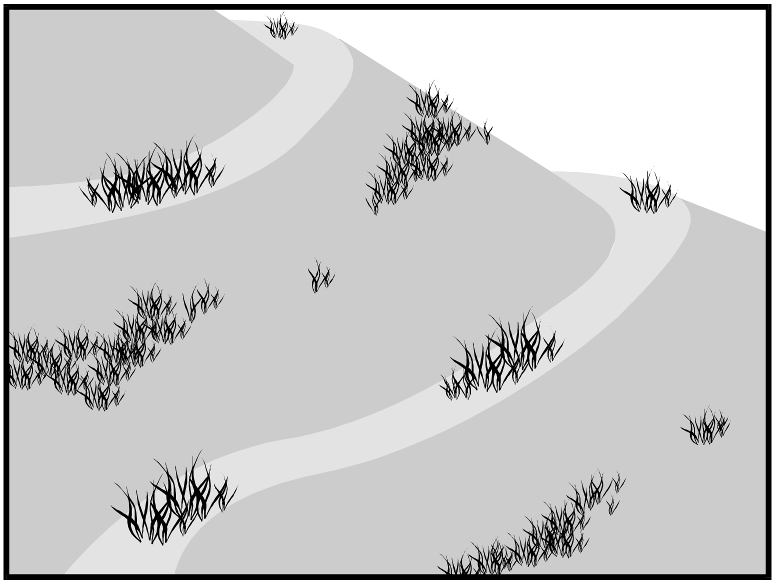
- Bonded fiber matrix (BFM) is a hydraulically-applied system of fibers and adhesives that upon drying forms an erosion-resistant blanket that promotes vegetation, and prevents soil erosion. BFMs are typically applied at rates from 3,000 to 4,500 lb/ac based on the manufacturer's recommendation. The biodegradable BFM is composed of materials that are 100% biodegradable. The binder in the BFM should also be biodegradable and should not dissolve or disperse upon re-wetting. Typically, biodegradable BFMs should not be applied immediately before, during or immediately after rainfall if the soil is saturated. Depending on the product, BFMs require 12 to 24 hours to dry to become effective.

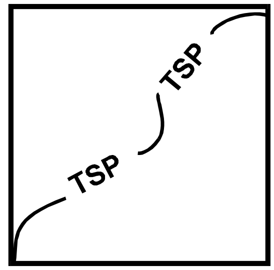
Maintenance and Inspections

- Inspect hydraulic mulched slopes and areas weekly and before and after every rainfall events. During extended rainfall events, inspect hydraulic mulched slopes and areas at least once every 24 hours.
- Maintain an unbroken, temporary mulched ground cover throughout the period of construction when the soils are not being reworked.
- The Contractor is responsible for maintaining all slopes to prevent erosion for the duration of the project or per the contract Special Provisions.

Hydroseeding

SS-4





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Hydroseeding typically consists of applying a mixture of wood fiber, seed, fertilizer, and stabilizing emulsion with hydro-seeding equipment, which temporarily protects exposed soils from erosion by water and wind.

Appropriate Applications

- Hydroseeding is applied on disturbed soil areas requiring temporary protection until permanent vegetation is established or disturbed soil areas that must be re-disturbed following an extended period of inactivity.
- Hydroseeding mix shall be per the contract Special Provisions or approved by the Engineer.

Limitations

- Hydroseeding may be used alone only when there is sufficient time in the season to ensure adequate vegetation establishment and erosion control. Otherwise, hydroseeding must be used in conjunction with a soil binder or mulching (i.e., straw mulch), refer to BMP SS-5, Table 1 for options.
- Steep slopes are difficult to protect with temporary seeding.
- Temporary seeding may not be appropriate in dry periods without supplemental irrigation.
- Temporary vegetation may have to be removed before permanent vegetation is applied.
- Temporary vegetation is not appropriate for short-term inactivity.

Standards and Specifications

To select appropriate hydroseeding mixtures, an evaluation of site conditions shall be performed with respect to:

- Soil conditions
- Site topography
- Season and climate
- Vegetation types
- Maintenance requirements
- Sensitive adjacent areas
- Water availability
- Plans for permanent vegetation

The following steps shall be followed for implementation:

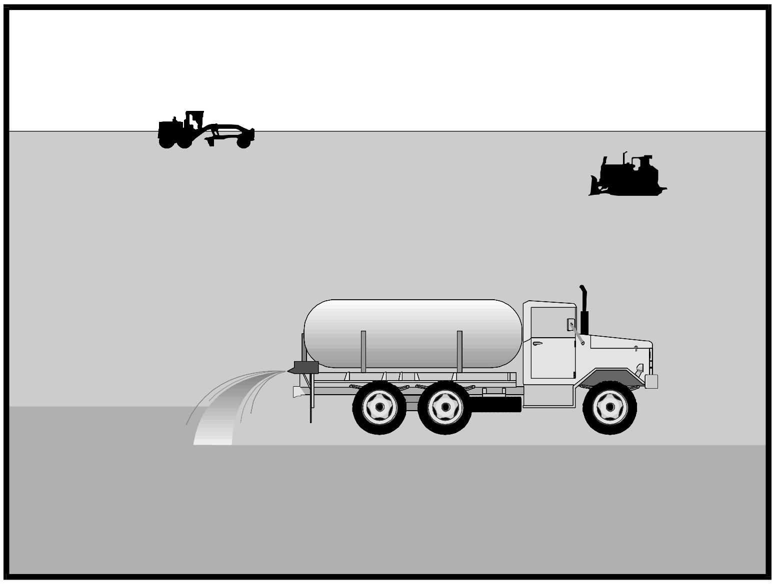
- Hydroseeding can be accomplished using a multiple-step or one-step process. The multiple-step process ensures maximum direct contact of the seeds to soil. When the one-step process is used to apply the mixture of fiber, seed, etc., the seed rate shall be increased to compensate for all seeds not having direct contact with the soil.
- Prior to application, roughen the slope, fill area, or area to be seeded with the furrows trending along the contours. Rolling with a crimping or punching type roller or track walking is required on all slopes prior to hydroseeding.
- Apply a straw mulch to keep seeds in place and to moderate soil moisture and temperature until the seeds germinate and grow.
- All seeds shall be in conformance with the California State Seed Law of the Department of Agriculture. Each seed bag shall be delivered to the site sealed and clearly marked as to species, purity, percent germination, dealer's guarantee, and dates of test; provide the Engineer with such documentation. The container shall be labeled to clearly reflect the amount of Pure Live Seed (PLS) contained.
- Commercial fertilizer shall conform to the requirements of the California Food and Agricultural Code. Fertilizer shall be in pellet or granular form.
- Follow-up applications shall be made as needed to cover bare spots, and to maintain adequate soil protection.
- Avoid over-spray onto the travel way, sidewalks, lined drainage channels, and existing vegetation.

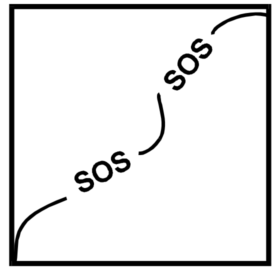
Maintenance and Inspection

- Inspect hydroseeded slopes and areas weekly and before and after every rainfall events. During extended rainfall events, inspect hydroseeded slopes and areas at least once every 24 hours.
- All seeded areas shall be inspected for failures and re-seeded, fertilized, and mulched within the planting season, using not less than half the original application rates. Any temporary revegetation efforts that do not provide adequate cover must be reapplied as required by the Engineer.
- The Contractor is responsible for maintaining all slopes to prevent erosionfor the duration of the project or per the contract Special Provisions.

Soil Binders

SS-5





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Soil binders consist of applying and maintaining a soil stabilizer to exposed soil surfaces. Soil binders are materials applied to the soil surface to temporarily prevent water-induced erosion of exposed soils on construction sites. Soil binders also provide temporary dust, wind, and soil stabilization (erosion control) benefits. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

Soil binders are typically applied to disturbed areas requiring short-term temporary protection. Because soil binders can often be incorporated into the work, they may be a good choice for areas where grading activities will soon resume. Application on stockpiles to prevent water and wind erosion is an additional appropriate use.

Limitations

- Soil binders are temporary in nature and may need reapplication.
- Soil binders require a minimum curing time until fully effective which may be 24 hours or longer. Soil binders may need reapplication after a storm event.
- Soil binders will generally experience spot failures during heavy rainfall events. If runoff penetrates the soil at the top of a slope treated with a soil binder, it is likely that the runoff will undercut the stabilized soil layer.
- Soil binders do not hold up to pedestrian or vehicular traffic across treated areas.
- Some soil binders are incompatible with existing vegetation.
- Soil binders may not penetrate soil surfaces made up primarily of silt and clay, particularly when compacted.
- Performance of soil binders depends on temperature, humidity, and traffic across treated areas.

Standards and Specifications

General Considerations

- Soil binder shall be approved by the Engineer prior to application.
- Site-specific soil types will dictate the appropriate soil binders to be used.
- A soil binder shall be environmentally benign (non-toxic to plant and animal life), easy to apply, easy to maintain, economical, and shall not stain paved or painted surfaces.
- Avoid over-spray onto the travel way, sidewalks, lined drainage channels, and existing vegetation.

Soil Binders Applications

After selecting an appropriate soil binder, the untreated soil surface must be prepared before applying the soil binder. The untreated soil surface must contain sufficient moisture to assist the agent in achieving uniform distribution. In general, the following steps shall be followed:

- Follow manufacturer's recommendations for application rates, pre-wetting of application area, and cleaning of equipment after use.
- Prior to application, roughen embankment and fill areas by rolling with a crimping or punching type roller or by track walking. Track walking shall only be used where rolling is impractical. Crown or slope ground to avoid ponding.
- Consider the drying time for the selected soil binder and apply with sufficient time before anticipated rainfall. Soil binders shall not be applied during or immediately before rainfall.
- Soil binders shall not be applied to frozen soil, areas with standing water, under freezing or rainy conditions, or when the air temperature is below 4oC (40^oF) during the curing period.
- More than one treatment is often necessary, although the second treatment may be diluted or have a lower application rate.
- Generally, soil binders require a minimum curing time before they are fully effective. Refer to manufacturer's recommendations for specific cure times.
- Uniformly pre-wet ground at a rate of 0.03 to 0.3 gal/yd^2 or according to manufacturer's recommendations. In low humidity, reactivate chemicals by re-wetting with water at a rate of 0.1 to 0.2 gal/yd^2.
- Apply soil binder solution under pressure. Overlap spry pattern by 6 to 12 inches.
- Allow treated area to cure for the time recommended by the manufacturer; typically, at least 24 hours.

Selecting a Soil Binder

Properties of common soil binders used for erosion control are provided in Table 1. Use Table 1 to select an appropriate soil binder.

Factors to consider when selecting a soil binder include the following:

- Suitability to situation - Consider where the soil binder will be applied; determine if it needs a high resistance to leaching or abrasion, and whether it needs to be compatible with any existing vegetation. Determine the length of time soil stabilization will be needed, and if the soil binder will be placed in an area where it will degrade rapidly. In general, slope steepness is not a discriminating factor for the listed soil binders.

- Soil types and surface materials - Fines and moisture content are key properties of surface materials. Consider a soil binder's ability to penetrate, leaching potential, and ability to form a surface crust on the surface materials.

- Frequency of application - The frequency of application can be affected by subgrade conditions, surface type, climate, and maintenance schedule. Frequent applications could lead to high costs. Application frequency may be minimized if the soil binder has good penetration, low evaporation, and good longevity. Consider also that frequent application will require frequent equipment clean-up.

After considering the above factors, the soil binders in Table 1 will be generally appropriate as follows:

Plant-Material Based (Short Lived)

-*Guar:* Guar is a non-toxic, biodegradable, natural galactomannan-based hydrocolloid treated with dispersent agents for easy field mixing. It shall be diluted at the rate of 1 to 5 lb per 100 gallons of water, depending on application machine capacity. Recommended minimum application rates are as follows:

Application Rates for Guar Soil Stabilizer

Slope (V:H):	Flat	1:4	1:3	1:2	1:1
lb/ac	40	45	50	60	70

-*Psyllium:* Psyllium is composed of the finely ground muciloid coating of plantago seeds that is applied as a dry powder or in a wet slurry to the surface of the soil. It dries to form a firm but rewettable membrane that binds soil particles together but permits germination and growth of seed. Psyllium requires 12 to 18 hours drying time. Psyllium shall be applied at a rate of 80 to 200 lb/ac, with enough water in solution to allow for a uniform slurry flow.

-*Starch:* Starch is non-ionic, cold-water soluble (pre-gelatinized) granular cornstarch. The material is mixed with water and applied at the rate of 150 lb/ac. Approximate drying time is 9 to 12 hours.

Plant-Material Based (Long Lived)

-*Pitch and Rosin Emulsion:* Generally, a non-ionic pitch and rosin emulsion has a minimum solids content of 48%. The rosin shall be a minimum of 26% of the total solids content. The soil stabilizer shall be non-corrosive, water-dilutable emulsion that upon application cures to a water insoluble binding and cementing agent. For soil erosion control applications, the emulsion is diluted and shall be applied as follows:

For clayey soil:	5 parts water to 1 part emulsion
For sandy soil:	10 parts water to 1 part emulsion

Application can be by water truck or hydraulic seeder with the emulsion/product mixture applied at the rate specified by the manufacturer. Approximate drying time is 19 to 24 hours.

Polymeric Emulsion Blends

-*Acrylic Copolymers and Polymers:* Polymeric soil stabilizers shall consist of a liquid or solid polymer or copolymer with an acrylic base that contains a minimum of 55% solids. The polymeric compound shall be handled and mixed in a manner that will not cause foaming or shall contain an anti-foaming agent. The polymeric emulsion shall not exceed its shelf life or expiration date; manufacturers shall provide the expiration date. Polymeric soil stabilizer shall be readily miscible in water, non-injurious to seed or animal life, non-flammable, shall provide surface soil stabilization for various soil types without totally inhibiting water infiltration, and shall not re-emulsify when cured. The applied compound shall air cure within a maximum of 36 to 48 hours. Liquid copolymer shall be diluted at a rate of 10 parts water to 1 part polymer and applied to soil at a rate of 1,175 gal/ac.

-*Liquid Polymers of Methacrylates and Acrylates:* This material consists of a tackifier/sealer that is a liquid polymer of methacrylates and acrylates. It is an aqueous 100% acrylic emulsion blend of 40% solids by volume that is free from styrene, acetate, vinyl, ethoxylated surfactants or silicates. For soil stabilization applications, it is diluted with water in accordance with manufacturer's recommendations, and applied with a hydraulic seeder at the rate of 20 gal/ac. Drying time is 12 to 18 hours after application.

-*Copolymers of Sodium Acrylates and Acrylamides:* These materials are non-toxic, dry powders that are copolymers of sodium acrylate and acrylamide. They are mixed with water and applied to the soil surface for erosion control at rates that are determined by slope gradient:

Slope Gradient (V:H)	lb/ac
Flat to 1:5	3-5
1:5 to 1:3	5-10
1:2 to 1:1	10-20

-*Poly-Acrylamide and Copolymer of Acrylamide:* Linear copolymer polyacrylamide is packaged as a dry-flowable solid. When used as a stand-alone stabilizer, it is diluted at a rate of 1 lb/100 gal of water and applied at the rate of 5 lb/ac.

-*Hydro-Colloid Polymers:* Hydro-Colloid Polymers are various combinations of dry-flowable poly-acrylamides, copolymers and hydro-colloid polymers that are mixed with water and applied to the soil surface at rates of 53 to 62 lb/ac. Drying times are 0 to 4 hours.

Maintenance and Inspection

- Inspect slopes stabilized with soil binders weekly and before and after every rainfall events. During extended rainfall events, inspect slopes stabilized with soil binders at least once every 24 hours.
- Reapplying the selected soil binder may be needed for proper maintenance. High traffic areas shall be inspected daily, and lower traffic areas shall be inspected weekly.
- The Contractor is responsible for maintaining all slopes to prevent erosion for the duration of the project or per the contract Special Provisions.
- Maintain an unbroken, temporary stabilized area while disturbed soil areas are nonactive. Repair any damaged stabilized area and re-apply soil binder to exposed areas.

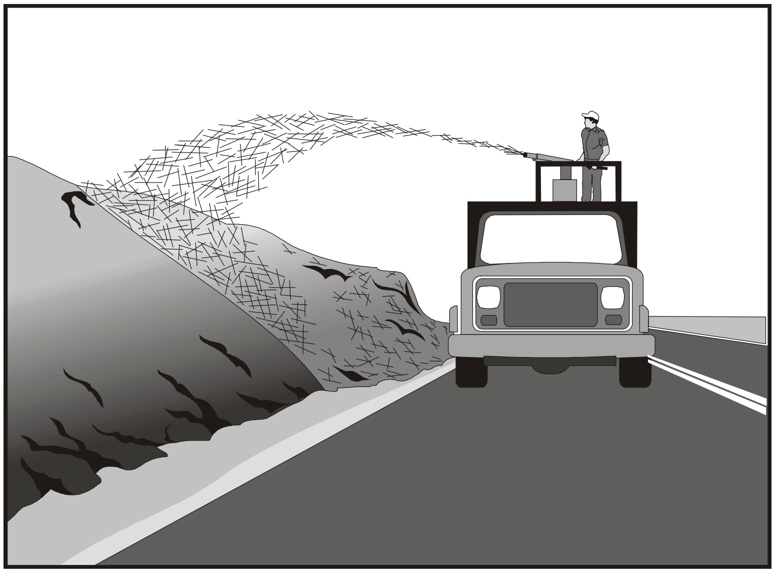
Chemicals	Plant Material Based (Short Lived)	Plant Material Based (Long Lived)	Polymeric Emulsion Blends
Relative Cost	Low	Low	Low
Resistance to Leaching	High	High	Low to Moderate
Resistance to Abrasion	Moderate	Low	Moderate to High
Longevity	Short to Medium	Medium	Medium to Long
Minimum Curing Time before Rain	9 to 18 hours	19 to 24 hours	0 to 24 hours
Compatibility with Existing Vegetation	Good	Poor	Poor
Mode of Degradation	Biodegradable	Biodegradable	Photodegradable/ Chemically Degradable
Labor Intensive	No	No	No
Specialized Application Equipment	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher	Water Truck or Hydraulic Mulcher
Liquid/Powder	Powder	Liquid	Liquid/Powder
Surface Crusting	Yes, but dissolves on rewetting	Yes	Yes, but dissolves on rewetting
Clean-Up	Water	Water	Water
Erosion Control Application Rate	Varies (1)	Varies (1)	Varies (1)

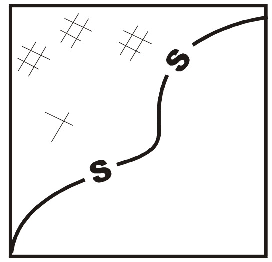
(1) Dependant on product, soil type, and slope inclination

RB-AR33272

Straw Mulch

SS-6





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Straw mulch consists of placing a uniform layer of straw and incorporating it into the soil with a studded roller or anchoring it with a stabilizing emulsion. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

- Straw mulch is typically used for soil stabilization as a temporary surface cover on disturbed areas until soils can be prepared for revegetation and permanent vegetation is established.
- Also typically used in combination with temporary and/or permanent seeding strategies to enhance plant establishment.

Limitations

- Use of Straw Mulch shall be approved by Engineer
- There is a potential for introduction of weed-seed and unwanted plant material.
- When straw blowers are used to apply straw mulch, the treatment areas must be within 150 feet of a road or surface capable of supporting trucks.
- Mulch may have to be removed prior to permanent seeding or soil stabilization.
- "Punching" of straw does not work in loose sandy soils or very compact soils.

Standards and Specifications

- Straw shall be derived from wheat, rice, or barley.
- A tackifier is the preferred method for anchoring straw mulch to the soil on slopes.
- Crimping, punch roller-type rollers, or track-walking may also be used to incorporate straw mulch into the soil on slopes. Track walking shall only be used where other methods are impractical.
- Avoid placing straw onto the travel way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- Straw mulch with tackifier shall not be applied during or immediately before rainfall.

Application Procedures

- Apply loose straw per contract Special Provisions, or at a minimum rate of 4,000 lb/ac, either by machine or by hand distribution.
- If stabilizing emulsion will be used to anchor the straw mulch in lieu of incorporation, roughen embankment or fill areas by rolling with a crimping or punching-type roller or by track walking before placing the straw mulch. Track walking should only be used where rolling is impractical.
- The straw mulch must be evenly distributed on the soil surface.
- Anchor the mulch in place by using a tackifier or by “punching” it into the soil mechanically (incorporating).
- A tackifier acts to glue the straw fibers together and to the soil surface. The tackifier shall be selected based on longevity and ability to hold the fibers in place.A tackifier is typically applied at a rate of 125 lb/ac. In windy conditions, the rates are typically 178 lb/ac.
- Methods for holding the straw mulch in place depend upon the slope steepness, accessibility, soil conditions and longevity. Install straw mulch into the soil as follows:
  - On small areas, a spade or shovel can be used.
  - On slopes with soils, which are stable enough and of sufficient gradient to safely support construction equipment without contributing to compaction and instability problems, straw can be “punched” into the ground using a knife-blade roller or a straight bladed coulter, known commercially as a “crimper.”
  - On small areas and/or steep slopes, straw can also be held in place using plastic netting or jute. The netting shall be held in place using 11 gauge wire staples, geotextile pins or wooden stakes. Refer to BMP SS-7, “Geotextiles, Plastic Covers and Erosion Control Blankets/Mats.”

Maintenance and Inspections

- The key consideration in maintenance and inspection is that the straw needs to last long enough to achieve erosion control objectives.
- Inspect areas stabilized with straw mulch weekly and before and after every rainfall events. During extended rainfall events, inspect areas stabilized with straw mulch at least once every 24 hours.
- Maintain an unbroken, temporary mulched ground cover while disturbed soil areas are non-active. Repair any damaged ground cover and re-mulch exposed areas.
- Reapplication of straw mulch and tackifier may be required by the Engineer to maintain effective soil stabilization over disturbed areas and slopes.
- The Contractor is responsible for maintaining all slopes to prevent erosionfor the duration of the project or per the contract Special Provisions.

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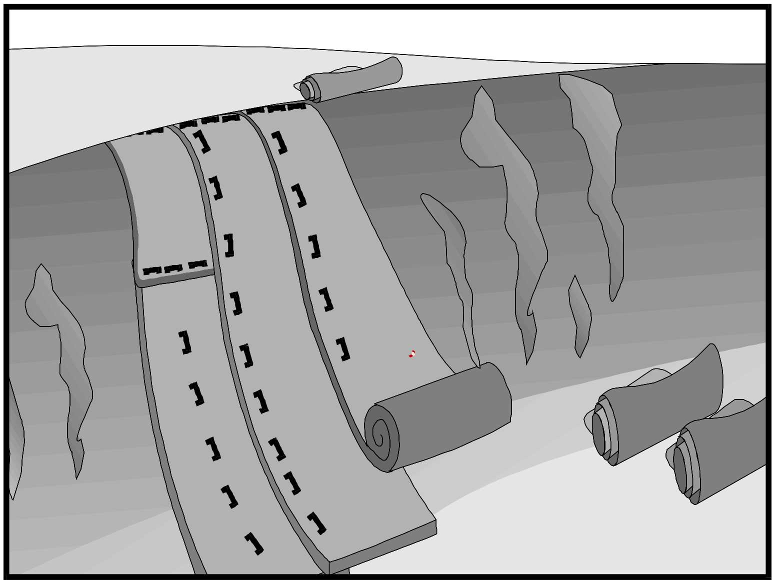
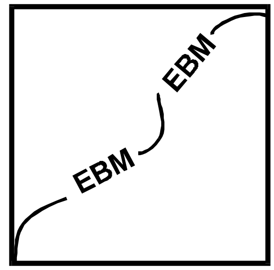
Geotextiles, Mats, Plastic Covers and Erosion Control Blankets

SS-7





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

This Best Management Practice (BMP) involves the placement of geotextiles, mats, plastic covers, or erosion control blankets to stabilize disturbed soil areas and protect soils from erosion by wind or water. This is one of five temporary soil stabilization alternatives to consider.

Appropriate Applications

These measures are used when disturbed soils may be particularly difficult to stabilize, including the following situations:

- Steep slopes, generally steeper than 1:3 (V:H).
- Slopes where the erosion potential is high, adjacent to water bodies, or Environmentally Sensitive Areas (ESAs).
- Slopes and disturbed soils where mulch must be anchored.
- Disturbed areas where plants are slow to develop.
- Channels with high flow velocities.
- Stockpiles.

Limitations

- Blankets and mats are more expensive than other erosion control measures, due to labor and material costs. This usually limits their application to areas inaccessible to hydraulic equipment, or where other measures are not applicable, such as channels.
- Blankets and mats are generally not suitable for excessively rocky sites, or areas where the final vegetation will be mowed (since staples and netting can catch in mowers).
- Blankets and mats must be removed and disposed of prior to application of permanent soil stabilization measures.

- Plastic sheeting is easily vandalized, easily torn, photodegradable, and must be disposed of as solid waste.
- Plastic results in 100% runoff, which may cause serious erosion problems in the areas receiving the increased flow.
- The use of plastic shall be limited to covering stockpiles, or very small graded areas for short periods of time (such as through one imminent storm event), until alternative measures, such as seeding and mulching, may be installed.
- Geotextiles, mats, plastic covers, and erosion control covers have maximum flow rate limitations; consult the manufacturer for proper selection.

Standards and Specifications

Material Selection

There are many types of erosion control blankets and mats, and selection of the appropriate type shall be based on the specific type of application and site conditions.

Geotextiles

- Material shall be a woven polypropylene fabric with minimum thickness of 0.06 inch, minimum width of 12 ft and shall have minimum tensile strength of 150 lbs (warp), 80 lbs (fill) in conformance with the requirements in ASTM Designation: D 4632. The permittivity of the fabric shall be approximately 0.07 sec^{-1} in conformance with the requirements in ASTM Designation: D4491. The fabric shall have an ultraviolet (UV) stability of 70 percent in conformance with the requirements in ASTM designation: D4355. Geotextile blankets shall be secured in place with wire staples or sandbags and by keying into tops of slopes and edges to prevent infiltration of surface waters under the geotextile. Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.

Plastic Covers

- Plastic sheeting shall have a minimum thickness of 6 mils, and shall be keyed in at the top of the slope and firmly held in place with sandbags or other weights placed no more than 10 ft apart. Seams are typically taped or weighted down their entire length, and there shall be and overlap of at least 12 to 24 inches at all seams. Edges shall be embedded a minimum of 6 inches in soil.

Erosion Control Blankets/Mats

- Biodegradable rolled erosion control products (RECPs) are typically composed of jute fibers, curled wood fibers, straw, coconut fiber, or a combination of these materials. For an RECP to be considered 100% biodegradable, the netting, sewing or adhesive system that holds the biodegradable mulch fibers together must also be biodegradable.

– **Jute** is a natural fiber that is made into a yarn, which is loosely woven into a biodegradable mesh. It is designed to be used in conjunction with vegetation and has limited longevity. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Excelsior (curled wood fiber)** blanket material shall consist of machine produced mats of curled wood excelsior with 80 percent of the fiber 6 inches or longer. The excelsior blanket shall be of consistent thickness. The wood fiber shall be evenly distributed over the entire area of the blanket. The top surface of the blanket shall be covered with a photodegradable extruded plastic mesh. The blanket shall be smolder resistant without the use of chemical additives and shall be non-toxic and non-injurious to plant and animal life. Excelsior blanket shall be furnished in rolled strips, a minimum of 48 inches wide, and shall have an average weight of 0.8 lb/yd^2, ±10 percent, at the time of manufacture. Excelsior blankets shall be secured in place with wire staples. Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.

– **Straw blanket** shall be machine-produced mats of straw with a lightweight biodegradable netting top layer. The straw shall be attached to the netting with biodegradable thread or glue strips. The straw blanket shall be of consistent thickness. The straw shall be evenly distributed over the entire area of the blanket. Straw blanket shall be furnished in rolled strips a minimum of 6.5 ft wide, a minimum of 80 ft long and a minimum of 0.5 lb/yd^2. Straw blankets shall be secured in place with wire staples. Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.

– **Wood fiber blanket** is composed of biodegradable fiber mulch with extruded plastic netting held together with adhesives. The material is designed to enhance revegetation. The material is furnished in rolled strips, which shall be secured to the ground with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Coconut fiber blanket** shall be machine-produced mats of 100% coconut fiber with biodegradable netting on the top and bottom. The coconut fiber shall be attached to the netting with biodegradable thread or glue strips. The coconut fiber blanket shall be of consistent thickness. The coconut fiber shall be evenly distributed over the entire area of the blanket. Coconut fiber blanket shall be furnished in rolled strips with a minimum of 6.5 ft wide, a minimum of 80 ft long and a minimum of 0.5 lb/yd^2. Coconut fiber blankets shall be secured in place with wire staples. Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.

– **Coconut fiber mesh** is a thin permeable membrane made from coconut or corn fiber that is spun into a yarn and woven into a biodegradable mat. It is designed to be used in conjunction with vegetation and typically has longevity of several years. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Straw coconut fiber blanket** shall be machine-produced mats of 70% straw and 30% coconut fiber with a biodegradable netting top layer and a biodegradable bottom net. The straw and coconut fiber shall be attached to the netting with biodegradable thread or glue strips. The straw coconut fiber blanket shall be of consistent thickness. The straw and coconut fiber shall be evenly distributed over the entire area of the blanket. Straw coconut fiber blanket shall be furnished in rolled strips a minimum of 6.5 ft wide, a minimum of 80 ft long and a minimum of 0.5 lb/yd^2. Straw coconut fiber blankets shall be secured in place with wire staples. Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.

- Non-biodegradable RECPs are typically composed of polypropylene, polyethylene, nylon or other synthetic fibers. In some cases, a combination of biodegradable and synthetic fibers is used to construct the RECP. Netting used to hold these fibers together is typically non-biodegradable as well.

– **Plastic netting** is a lightweight biaxially-oriented netting designed for securing loose mulches like straw to soil surfaces to establish vegetation. The netting is photodegradable. The netting is supplied in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Plastic mesh** is an open-weave geotextile that is composed of an extruded synthetic fiber woven into a mesh with an opening size of less than 0.2 inch. It is used with revegetation or may be used to secure loose fiber such as straw to the ground. The material is supplied in rolled strips, which shall be secured to the soil with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Synthetic fiber with netting** is a mat that is composed of durable synthetic fibers treated to resist chemicals and ultraviolet light. The mat is a dense, three-dimensional mesh of synthetic (typically polyolefin) fibers stitched between two polypropylene nets. The mats are designed to be revegetated and provide a permanent composite system of soil, roots, and geomatrix. The material is furnished in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Bonded synthetic fibers** consist of a three-dimensional geomatrix nylon (or other synthetic) matting. Typically it has more than 90% open area, which facilitates root growth. Its tough root-reinforcing system anchors vegetation and protects against hydraulic lift and shear forces created by high volume discharges. It can be installed over prepared soil, followed by seeding into the mat. Once vegetated, it becomes an invisible composite system of soil, roots, and geomatrix. The material is furnished in rolled strips that shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

– **Combination synthetic and biodegradable RECPs** consist of biodegradable fibers, such as wood fiber or coconut fiber, with a heavy polypropylene net stitched to the top and a high-strength continuous-filament geomatrix or net stitched to the bottom. The material is designed to enhance revegetation. The material is furnished in rolled strips, which shall be secured with U-shaped staples or stakes in accordance with manufacturers' recommendations.

Site Preparation

- Proper site preparation is essential to ensure complete contact of the blanket or matting with the soil.
- Grade and shape the area of installation.
- Remove all rocks, clods, vegetation or other obstructions so that the installed blankets or mats will have complete, direct contact with the soil.
- Prepare seedbed by loosening 2 in. to 3 in. of topsoil.

Seeding

Seed the area before blanket installation for erosion control and revegetation. Seeding after mat installation is often specified for turf reinforcement application. When seeding prior to blanket installation, all check slots and other areas disturbed during installation must be re-seeded. Where soil filling is specified, seed the matting and the entire disturbed area after installation and prior to filling the mat with soil.

Anchoring

- U-shaped wire staples, metal geotextile stake pins or triangular wooden stakes can be used to anchor mats and blankets to the ground surface.
- Staples shall be made of 11 gauge steel wire and shall be U-shaped with 8-inch legs and 2-inch crown.
- Metal stake pins shall be 0.188 in. diameter steel with a 1.5 in. steel washer at the head of the pin.
- Wire staples and metal stakes shall be driven flush to the soil surface.
- All anchors shall be 6 in. to 18 in. long and have sufficient ground penetration to resist pullout. Longer anchors may be required for loose soils.

Installation on Slopes

Installation shall be in accordance with the manufacturer's recommendations. In general, these will be as follows:

- Begin at the top of the slope and anchor the blanket in a 6 in. deep by 6 in. wide trench. Backfill the trench and tamp earth firmly.
- Unroll the blanket down slope in the direction of water flow.
- Overlap the edges of adjacent parallel rolls 2 in. to 3 in. and staple every 3 ft.
- When blankets must be spliced, place blankets end over end (shingle style) with 6 in. overlap. Staple through overlapped area, approximately 12 in. apart.
- Lay blankets loosely and maintain direct contact with the soil. Do not stretch.
- Staple blankets sufficiently to anchor blanket and maintain contact with the soil. Staples shall be placed down the center and staggered with the staples placed along the edges. Steep slopes, 1:1 (V:H) to 1:2 (V:H), require a minimum of 2 staples/yd^2. Moderate slopes, 1:2 (V:H) to 1:3 (V:H), require a minimum of 1½ staples/yd^2, placing 1 staple/yd on centers. Gentle slopes require a minimum of 1 staple/yd^2.

Installation in Channels

Installation shall be in accordance with the manufacturer's recommendations. In general, these will be as follows:

- Dig initial anchor trench 12 in. deep and 6 in. wide across the channel at the lower end of the project area.
- Excavate intermittent check slots, 6 in. deep and 6 in. wide across the channel at 25 ft to 30 ft intervals along the channels.
- Cut longitudinal channel anchor slots 4 in. deep and 4 in. wide along each side of the installation to bury edges of matting, whenever possible extend matting 2 in. to 3 in. above the crest of the channel side slopes.
- Beginning at the downstream end and in the center of the channel, place the initial end of the first roll in the anchor trench and secure with fastening devices at 12 in. intervals. Note: matting will initially be upside down in anchor trench.
- In the same manner, position adjacent rolls in anchor trench, overlapping the preceding roll a minimum of 3 in.
- Secure these initial ends of mats with anchors at 12 in. intervals, backfill and compact soil.

- Unroll center strip of matting upstream. Stop at next check slot or terminal anchor trench. Unroll adjacent mats upstream in similar fashion, maintaining a 3 in. overlap.

- Fold and secure all rolls of matting snugly into all transverse check slots. Lay mat in the bottom of the slot then fold back against it. Anchor through both layers of mat at 12 in. intervals, then backfill and compact soil. Continue rolling all mat widths upstream to the next check slot or terminal anchor trench.

- Alternate method for non-critical installations: Place two rows of anchors on 6 in. centers at 25 ft to 30 ft intervals in lieu of excavated check slots.

- Shingle-lap spliced ends by a minimum of 12 in. apart on 12 in. intervals.

- Place edges of outside mats in previously excavated longitudinal slots, anchor using prescribed staple pattern, backfill and compact soil.

- Anchor, fill and compact upstream end of mat in a 12 in. by 6 in. terminal trench.

- Secure mat to ground surface using U-shaped wire staples, geotextile pins, or wooden stakes.

- Seed and fill turf reinforcement matting with soil, if specified.

Soil Filling (if specified for turf reinforcement)

- Always consult the manufacturer's recommendations for installation.

- Do not drive tracked or heavy equipment over mat.

- Avoid any traffic over matting if loose or wet soil conditions exist.

- Use shovels, rakes or brooms for fine grading and touch up.

- Smooth out soil filling, just exposing top netting of mat.

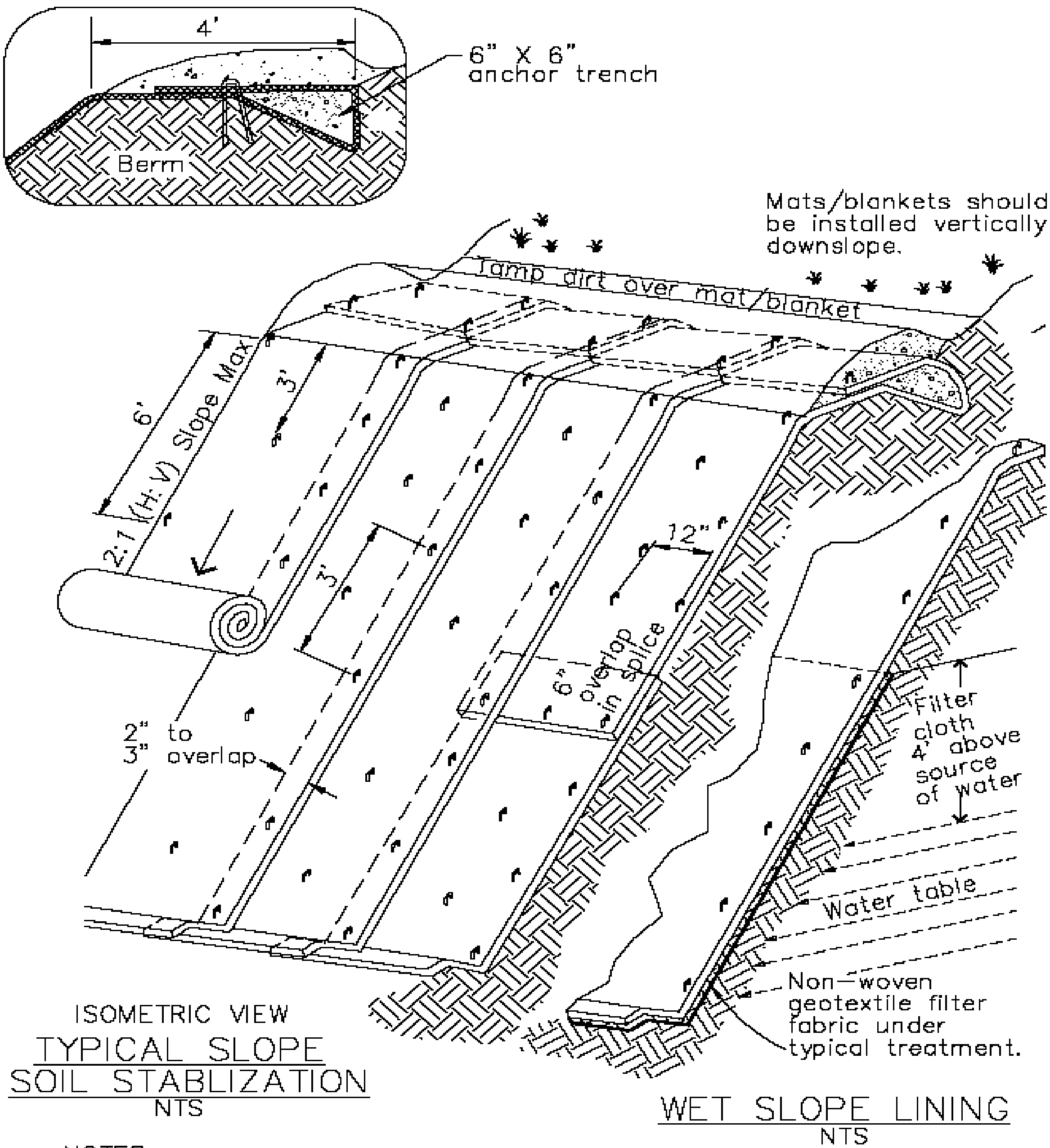
Temporary Soil Stabilization Removal

- When no longer required for the work, temporary soil stabilization shall become the property of the Contractor. Temporary soil stabilization removed from the project site shall be disposed of in conformance with all applicable laws and regulations. If approved by the Engineer, the contractor may leave the temporary soil stabilizer in place.

Maintenance and Inspection

Areas treated with temporary soil stabilization shall be maintained to provide adequate erosion control. Temporary soil stabilization shall be reapplied or replaced on exposed soils when area becomes exposed or exhibits visible erosion.

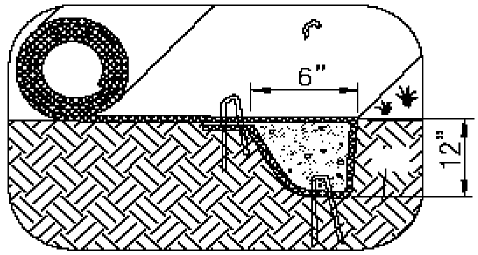
- Inspect all slopes and areas stabilized with geotextiles, mats, plastic covers, or erosion control blankets weekly and before and after every rainfall events. During extended rainfall events, inspect all slopes and areas stabilized with geotextiles, mats, plastic covers, or erosion control blankets at least once every 24 hours.
- Any failures shall be repaired immediately. If washout or breakage occurs, the material shall be re-installed after repairing the damage to the slope.



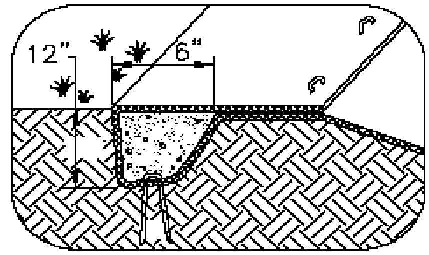
NOTES:

1. Slope surface shall be free of rocks, clods, sticks and grass. Mats/blankets shall have good soil contact.
2. Lay blankets loosely and stake or staple to maintain direct contact with the soil. Do not stretch.
3. Install per manufacturer's recommendations

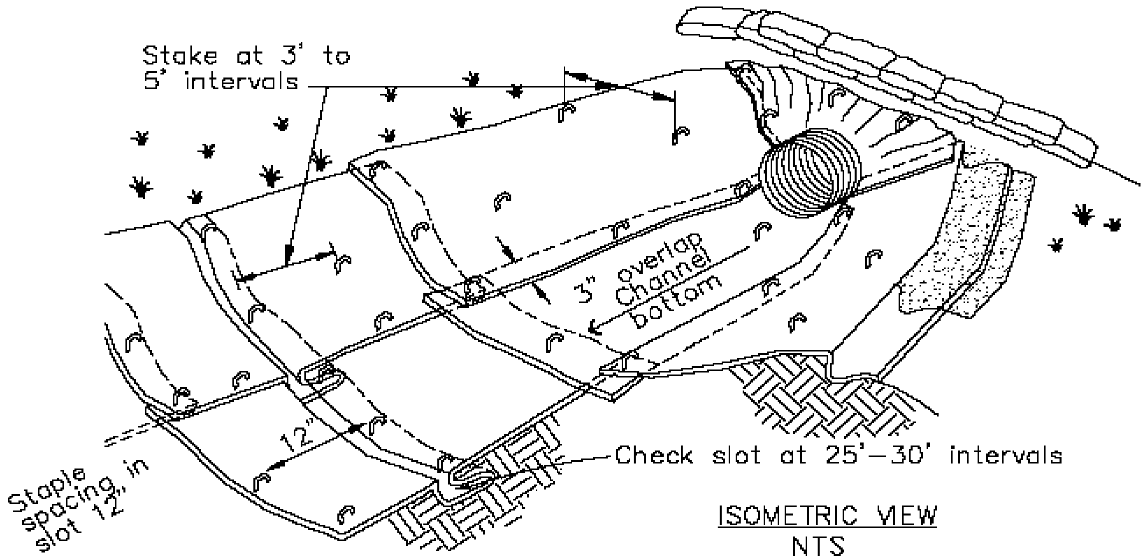
TYPICAL INSTALLATION DETAIL



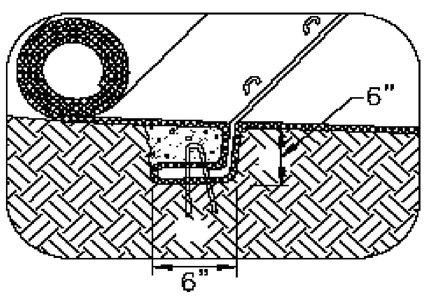
INITIAL CHANNEL ANCHOR TRENCH
NTS



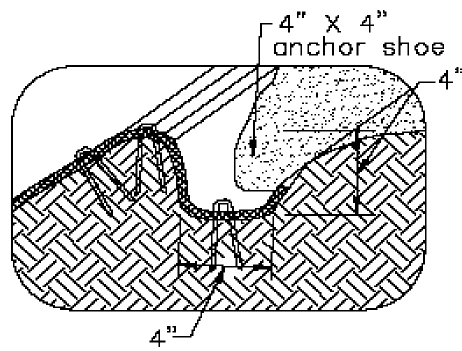
TERMINAL SLOPE AND CHANNEL ANCHOR TRENCH
NTS



ISOMETRIC VIEW
NTS



INTERMITTENT CHECK SLOT
NTS



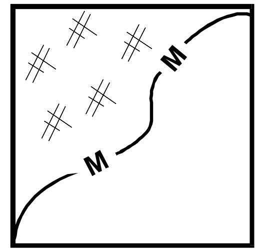
LONGITUDINAL ANCHOR TRENCH
NTS

NOTES:
1. Check slots to be constructed per manufacturers specifications.
2. Staking or stapling layout per manufacturers specifications.
3. Install per manufacturer's recommendations

TYPICAL INSTALLATION DETAIL

Wood Mulching

SS-8



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Wood mulching consists of applying a mixture of shredded wood mulch, bark or compost. Wood mulch is mostly applicable to landscape projects.

The primary function of wood mulching is to reduce erosion by protecting bare soil from rainfall impact, increasing infiltration, and reducing runoff.

Appropriate Applications

Wood mulching is considered a temporary soil stabilization (erosion control) alternative in the following situations:

- As a stand-alone temporary surface cover on disturbed areas until soils can be prepared for revegetation and permanent vegetative cover can be established.
- As short term, non-vegetative ground cover on slopes to reduce rainfall impact, decrease the velocity of sheet flow, settle out sediment and reduce wind erosion.

Limitations

- Shredded wood does not withstand concentrated flows and is prone to sheet erosion.
- Green material has the potential for the presence of unwanted weeds and other plant materials. Delivery system is primarily by manual labor, although pneumatic application equipment is available.

Standards and Specifications

Mulch Selection

There are many types of mulches, and selection of the appropriate type shall be based on the type of application and site conditions. Prior to use of wood mulches, there shall be concurrence with the Engineer since some mulch use on construction projects may not be compatible with planned or future projects. Selection of wood mulches by the Contractor must be approved by the Engineer.

Application Procedures

Prior to application, after existing vegetation has been removed, roughen embankment and fill areas by rolling with a punching-type roller or by track walking. The construction-application procedures for mulches vary significantly depending upon the type of mulching method specified. Two (2) methods are highlighted here:

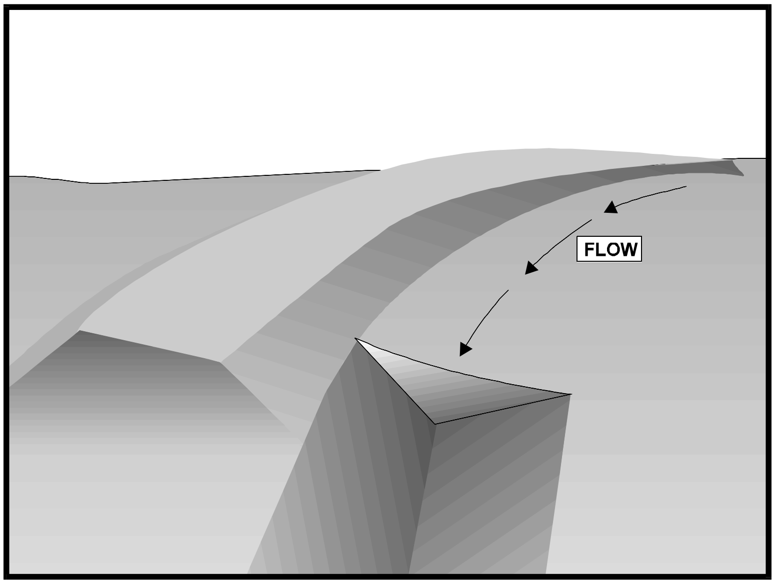
- Green Material: This type of mulch is produced by recycling vegetation trimmings such as grass, shredded shrubs and trees. Methods of application are generally by hand, although pneumatic methods are available. Mulch shall be composted to kill weed seeds.
  - It can be used as a temporary ground cover with or without seeding.
  - The green material shall be evenly distributed on site to a depth of not more than 2 in.
- Shredded Wood: Suitable for ground cover in ornamental or revegetated plantings.
  - Shredded wood/bark is conditionally suitable; see note under limitations.
  - Shall be distributed by hand (although pneumatic methods may be available).
  - The mulch shall be evenly distributed across the soil surface to a depth of 2 in. to 3 in.
- Avoid mulch placement onto the traveled way, sidewalks, lined drainage channels, sound walls, and existing vegetation.
- All material must be removed before re-starting work on the slopes.

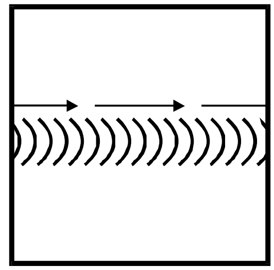
Maintenance and Inspection

- Inspect areas stabilized with wood mulch weekly and before and after every rainfall events. During extended rainfall events, inspect areas stabilized with wood mulch at least once every 24 hours.
- Wood mulch needs to last long enough to achieve erosion-control objectives. If the mulch is applied as a stand-alone erosion control method over disturbed areas (without seed), it shall last the length of time the site will remain barren or until final re-grading and revegetation.
- Where vegetation is not the ultimate cover, such as ornamental and landscape applications of bark or wood chips, inspection and maintenance shall focus on longevity and integrity of the mulch.

Earth Dikes/Drainage Swales and Lined Ditches

SS-9





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

These are structures that intercept, divert and convey surface run-on, generally sheet flow, to prevent erosion.

Appropriate Applications

- Earth dikes/drainage swales and lined ditches may be used to:
  - Convey surface runoff down sloping land.
  - Intercept and divert runoff to avoid sheet flow over sloped surfaces.
  - Divert and direct runoff towards a stabilized watercourse, drainage pipe or channel. Surface water diversion in streambeds or channels shall be in compliance with the contract Special Provisions and regulatory permits.
  - Intercept runoff from paved surfaces.
- Earth dikes/drainage swales and lined ditches also may be used:
  - Below steep grades where runoff begins to concentrate.
  - Along roadways and facility improvements subject to flood drainage.
  - At the top of slopes to divert run-on from adjacent or undisturbed slopes.
  - At bottom and mid-slope locations to intercept sheet flow and convey concentrated flows.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Engineer.

Earth Dikes/Drainage Swales and Lined Ditches

Limitations

- Earth dikes/drainage swales and lined ditches are not suitable as sediment trapping devices.
- May be necessary to use other soil stabilization and sediment controls, such as check dams, plastics, and blankets, to prevent scour and erosion in newly graded dikes, swales and ditches.

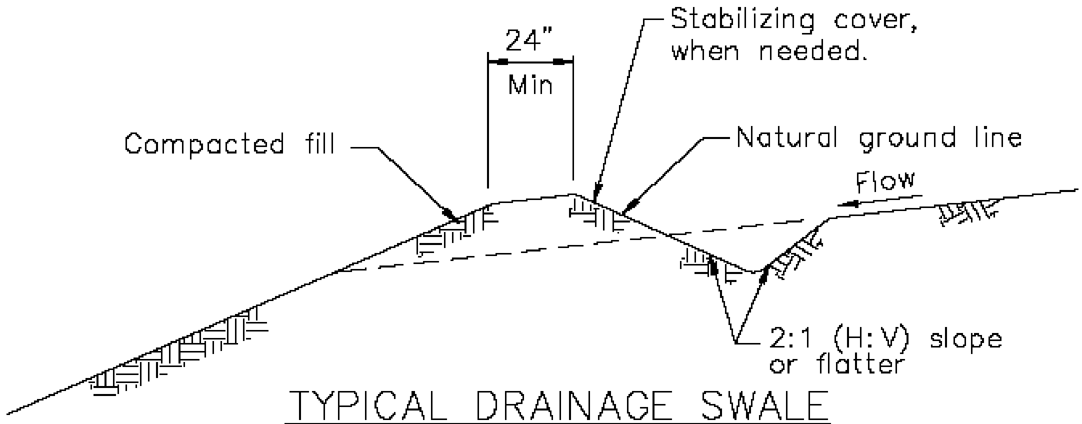
Standards and Specifications

- Care must be applied to correctly size and locate earth dikes, drainage swales and lined ditches. Excessively steep, unlined dikes and swales are subject to erosion and gully formation.
- Conveyances shall be stabilized.
- Use a lined ditch for high flow velocities.
- Select flow velocity based on careful evaluation of the risks due to erosion of the measure, soil types, over topping, flow backups, washout, and drainage flow patterns for each project site.
- Compact any fills to prevent unequal settlement.
- Do not divert runoff from the construction project onto other property.
- When possible, install and utilize permanent dikes, swales and ditches early in the construction process.
- Provide stabilized outlets. Refer to SS-10, "Outlet Protection/Velocity/ Dissipation Devices."

Maintenance and Inspections

- Inspect earth dikes, drainage swales and lined ditches weekly and before and after every rainfall events. During extended rainfall events, inspect earth dikes, drainage swales and lined ditches at least once every 24 hours.
- Inspect ditches and berms for washouts. Replace lost riprap, damaged linings or soil stabilizers as needed.
- Inspect channel linings, embankments, and beds of ditches and berms for erosion and accumulation of debris and sediment. Remove debris and sediment, and repair linings and embankments as needed or as directed by the Engineer.
- Temporary conveyances shall be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.

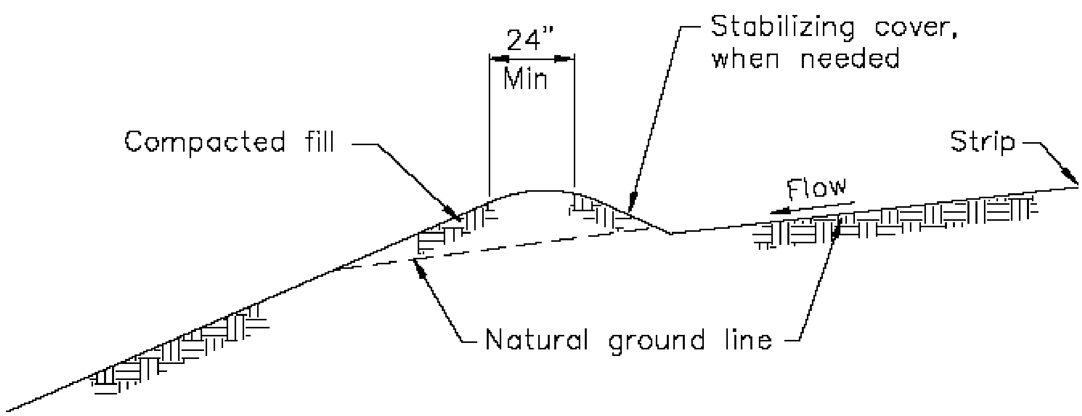
Earth Dikes/Drainage Swales and Lined Ditches



TYPICAL DRAINAGE SWALE
NOT TO SCALE

NOTES:

1. Stabilize inlet, outlets and slopes.
2. Properly compact the subgrade.



TYPICAL EARTH DIKE
NOT TO SCALE

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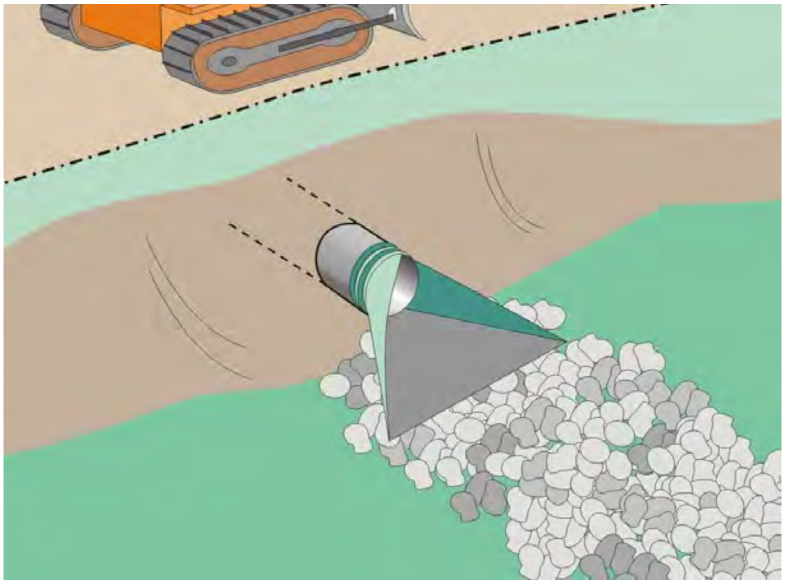
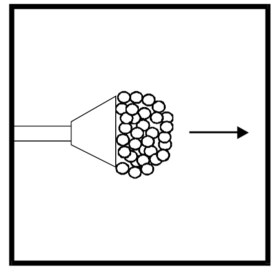
Outlet Protection/Velocity Dissipation Devices

SS-10





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Outlet protection and velocity dissipation devices are placed at pipe outlets to prevent scour and reduce the velocity and/or energy of storm water flows.

Appropriate Applications

- These devices may be used at the following locations:
  - Outlets of pipes, drains, culverts, slope drains, diversion ditches, swales, conduits or channels.
  - Outlets located at the bottom of mild to steep slopes.
  - Points where lined conveyances discharge to unlined conveyances.

Limitations

The use of outlet protection and velocity dissipation devices in streambeds shall be in compliance with the contract Special Provisions and approved by the Engineer.

Standards and Specifications

- There are many types of energy dissipaters, with rock being the one that is represented in the figure on Page 3. Please note that this is only one example and the Engineer may approve other types of devices proposed by the contractor.
- Install riprap, grouted riprap, or concrete apron at selected outlet. Riprap aprons are best suited for temporary use during construction.
- Grouted riprap shall be approved by the Engineer prior to installation.
- Carefully place riprap to avoid damaging the filter fabric.

- For proper operation of apron:
  - Align apron with receiving stream and keep straight throughout its length. If a curve is needed to fit site conditions, place it in upper section of apron.
  - If size of apron riprap is large, protect underlying filter fabric with a gravel blanket.
- Outlets on slopes steeper than 10% shall have additional protection.

Standards and Specifications

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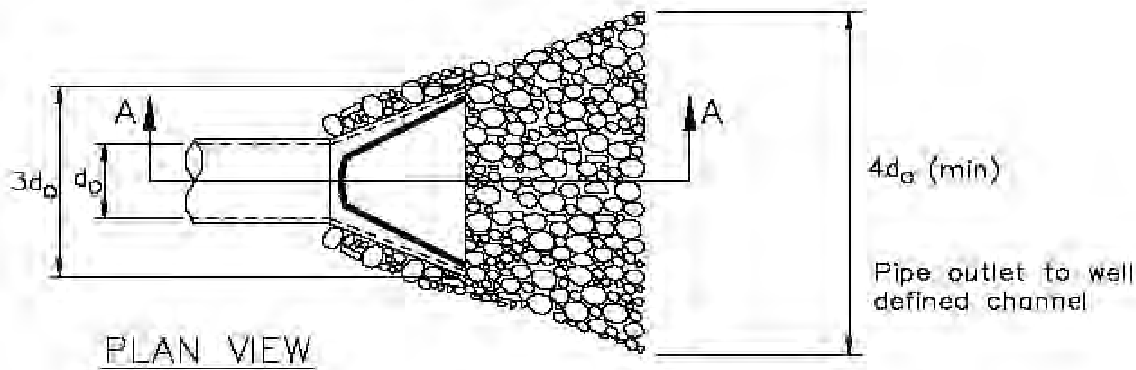
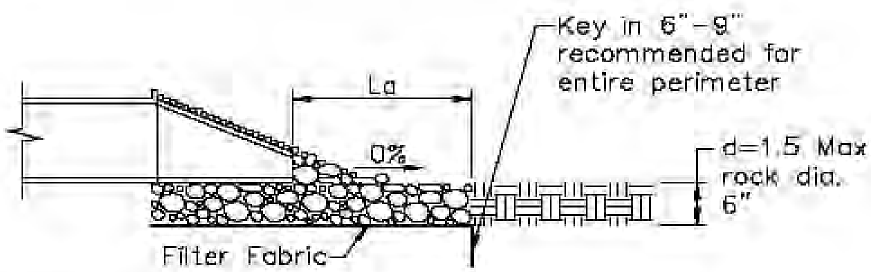
  - If size of apron riprap is large, protect underlying filter fabric with a gravel blanket.
- Outlets on slopes steeper than 10% shall have additional protection.

Maintenance and Inspection

- Inspect all outlet protection and velocity dissipation devices weekly and before and after every rainfall events. During extended rainfall events, inspect outlet protection and velocity dissipation devices at least once every 24 hours.
- Inspect apron for displacement of the riprap and/or damage to the underlying fabric. Repair fabric and replace riprap that has washed away.
- Inspect for scour beneath the riprap and around the outlet. Repair damage to slopes or underlying filter fabric immediately.
- Temporary devices shall be completely removed as soon as the surrounding drainage area has been stabilized, or at the completion of construction.





Pipe Diameter inches	Discharge ft³/s	Apron Length, La ft	Rip Rap D_{50} Diameter Min inches
12	5	10	4
	10	13	6
18	10	10	6
	20	16	8
	30	23	12
	40	26	16
24	30	16	8
	40	26	8
	50	26	12
	60	30	16

For larger or higher flows consult a Registered Civil Engineer
Source: USDA - SCS

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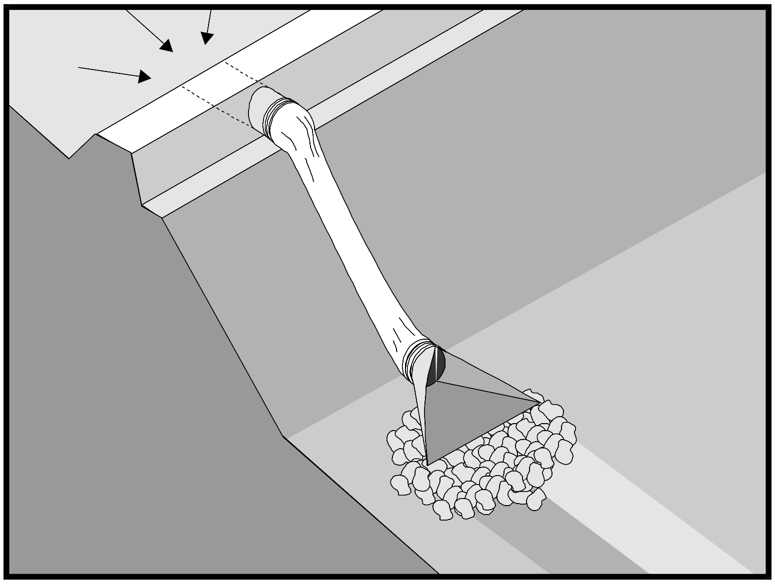
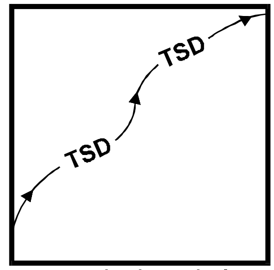
Slope Drains

SS-11





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A slope drain is a pipe used to intercept and direct surface runoff or groundwater into a stabilized watercourse, trapping device or stabilized area. Slope drains are used with lined ditches to intercept and direct surface flow away from slope areas to protect cut or fill slopes.

Appropriate Applications

- Slope drains may be used on construction sites where slopes may be eroded by surface runoff.
- Slope drains shall be implemented in conjunction with other BMPs. Slope drains result in concentrated flow that shall be dissipated at the outlet to prevent erosion.

Limitations

- None identified.

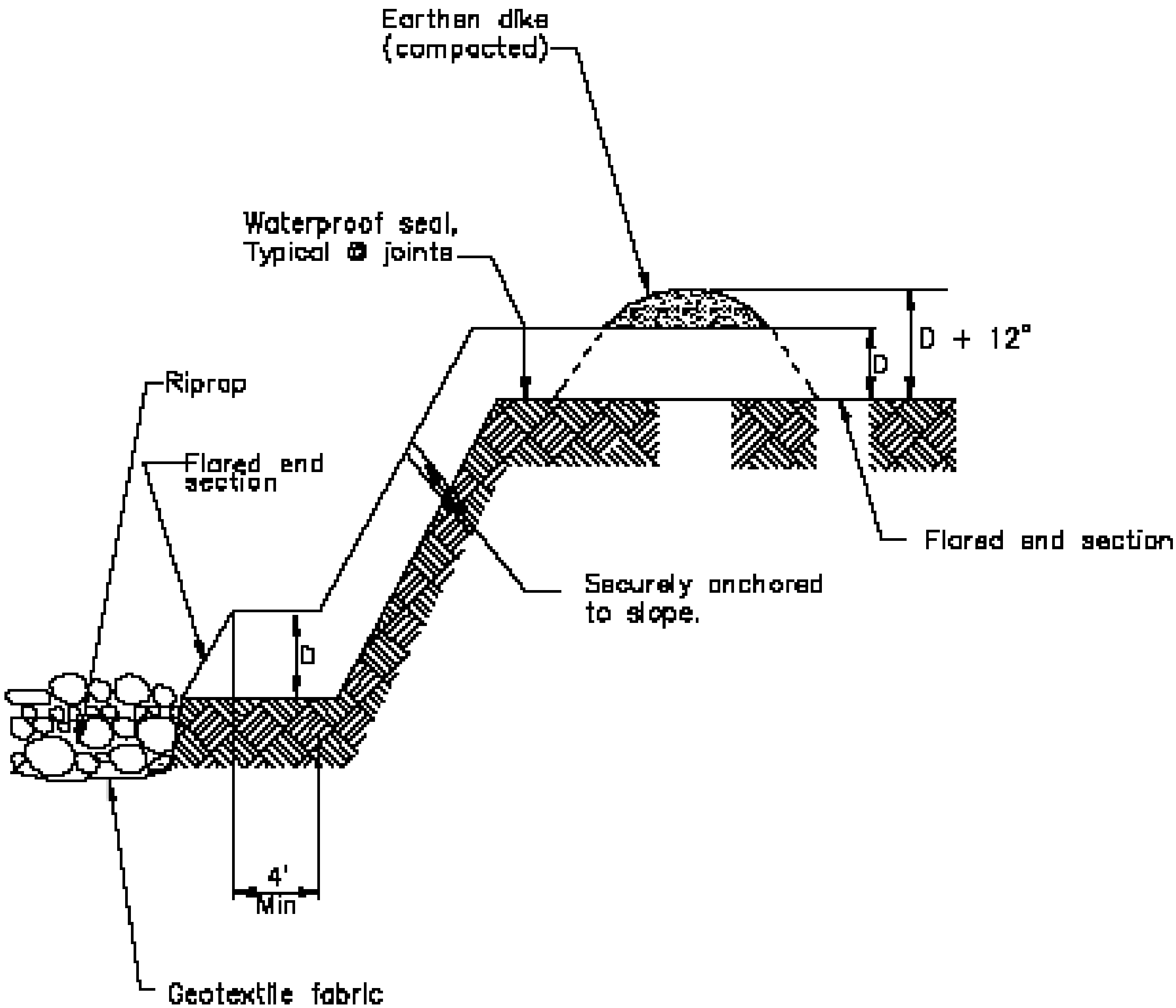
Standards and Specifications

- When using slope drains, limit drainage area to 10 ac per pipe. For larger areas, use a rock-lined channel or a series of pipes.
- Maximum slope should be generally limited to 1:2 (V:H), as energy dissipation below steeper slopes is difficult.
- Direct surface runoff to slope drains with interceptor dikes. See BMP SS-8, “Earth Dikes/Drainage Swales, and Lined Ditches.”
- Slope drains can be placed on or buried underneath the slope surface.
- Recommended materials are PVC, ABS, or comparable pipe.
- When installing slope drains:
  - Install slope drains perpendicular to slope contours.
  - Compact soil around and under entrance, outlet, and along length of pipe.

- Securely anchor and stabilize pipe and appurtenances into soil.
- Check to ensure that pipe connections are water tight.
- Protect area around inlet with filter cloth. Protect outlet with riprap or other energy dissipation device. For high energy discharges, reinforce riprap with concrete or use reinforced concrete device.
- Protect inlet and outlet of slope drains; use standard flared end section at entrance and exit for pipe slope drains 12in. and larger.

Maintenance and Inspection

- Inspect slope drains weekly and before and after every rainfall events. During extended rainfall events, inspect slope drains at least once every 24 hours.
- Inspect outlet for erosion and downstream scour. If eroded, repair damage and install additional energy dissipation measures. If downstream scour is occurring, it may be necessary to reduce flows being discharged into the channel unless other preventative measures are implemented.
- Inspect slope drainage for accumulations of debris and sediment.
- Remove built-up sediment from entrances, outlets, and within drains as required.
- Make sure water is not ponding onto inappropriate areas (e.g., active traffic lanes, material storage areas, etc.).



TYPICAL SLOPE DRAIN

NOT TO SCALE

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SECTION 4

TEMPORARY SEDIMENT CONTROL BMPs

Temporary sediment control BMPs include practices that intercept, slow, or detain the flow of storm water to allow sediment to settle and be contained on the construction site. Temporary sediment control BMPs consist of installing temporary barriers or basins placed below the toe of slopes, down gradient of areas of exposed soil, around stockpiles, and other appropriate locations along the construction site perimeter. Fiber rolls and/or gravel bag berms are required to break up slope lengths. Effective perimeter controls (i.e., silt fence, fiber rolls, gravel bag berms, or sandbag berms) shall be established and maintained. Temporary sediment control practices include the BMPs shown on Table 4-1.

Table 4-1
Temporary Sediment Control BMPs

ID	BMP Name
SC-1	Silt Fence
SC-2	Sediment/Desilting Basin
SC-3	Sediment Trap
SC-4	Check Dam
SC-5	Fiber Rolls
SC-6	Gravel Bag Berm
SC-7	Street Sweeping and Vacuuming
SC-8	Sandbag Barrier
SC-9	Straw Bale Barrier
SC-10	Storm Drain Inlet Protection

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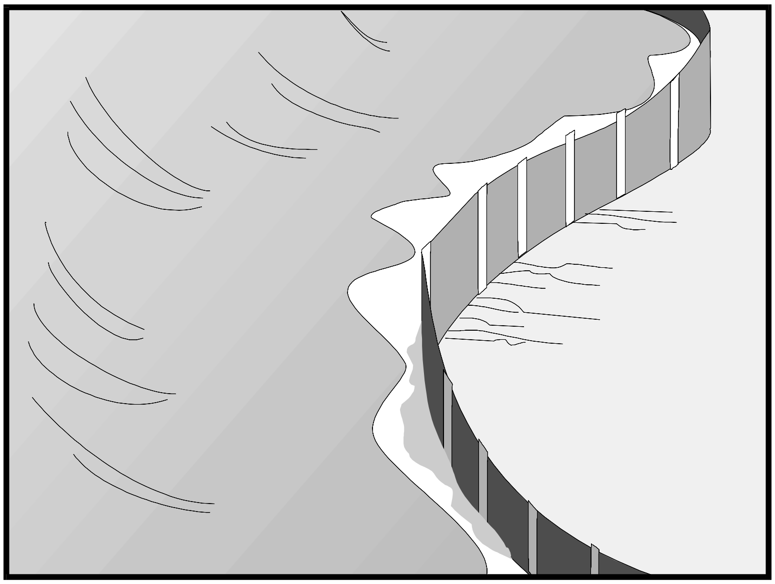
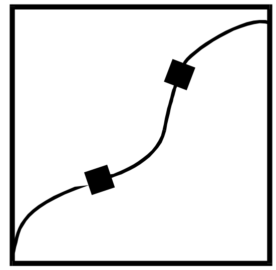
Silt Fence





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A silt fence is a temporary linear sediment barrier of permeable fabric designed to intercept and slow the flow of sediment-laden sheet flow runoff. Silt fences allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

Silt fences are placed:

- Below the toe of exposed and erodible slopes.
- Down-slope of exposed soil areas.
- Around temporary stockpiles.
- Along streams and channels.
- Along the perimeter of a project.

Limitations

- Shall not be used below slopes subject to creep, slumping, or landslides.
- Shall not be used in streams, channels, drain inlets, or anywhere flow is concentrated.
- Shall not be used to divert flow. Silt fences shall not be used in concentrated flow areas.

Standards and Specifications

Design and Layout

- The maximum length of slope draining to any point along the silt fence shall be 200 ft or less.
- The slope of area draining to silt fence shall be less than 1:1 (V:H).
- Shall not use as mid-slope protection on slopes greater than 1:4 (V:H).

- Limit silt fence installation to locations suitable for temporary ponding and deposition of sediment.
- Fabric life span is generally limited. Longer periods may require fabric replacement.
- Lay out shall be in accordance with Pages 5 and 6 of this BMP.
- For slopes steeper than 1:2 (V:H) and that contain a high number of rocks or large dirt clods that tend to dislodge, it may be necessary to install additional protection immediately adjacent to the bottom of the slope, prior to installing silt fence. Additional protection may be a chain link fence or a cable fence.
- For slopes adjacent to water bodies or Environmentally Sensitive Areas (ESAs), or as directed by the engineer, additional temporary soil stabilization BMPs shall be used.

Materials

- Silt fence fabric shall be woven polypropylene with a minimum width of 36 inches and a minimum tensile strength of 100 lb force. The fabric shall conform to the requirements in ASTM designation D4632 and shall have an integral reinforcement layer. The reinforcement layer shall be a polypropylene, or equivalent, net provided by the manufacturer. The permittivity of the fabric shall be between 0.1 sec-1 and 0.15 sec-1 in conformance with the requirements in ASTM designation D4491. Contractor shall submit certificate of compliance with these specifications.
- Wood stakes shall be commercial quality lumber of the size and shape shown on the plans. Each stake shall be free from decay, splits or cracks longer than the thickness of the stake or other defects that would weaken the stakes and cause the stakes to be structurally unsuitable.
- Bar reinforcement may be used in lieu of wood stakes. The bars shall be equal to a number four (4) or greater. End protection shall be provided for any exposed bar reinforcement.
- Staples used to fasten the fence fabric to the stakes shall be not less than 1.75 inches long and shall be fabricated from 15 gauge or heavier wire. The wire used to fasten the tops of the stakes together when joining two sections of fence shall be 9 gauge or heavier wire.

Installation

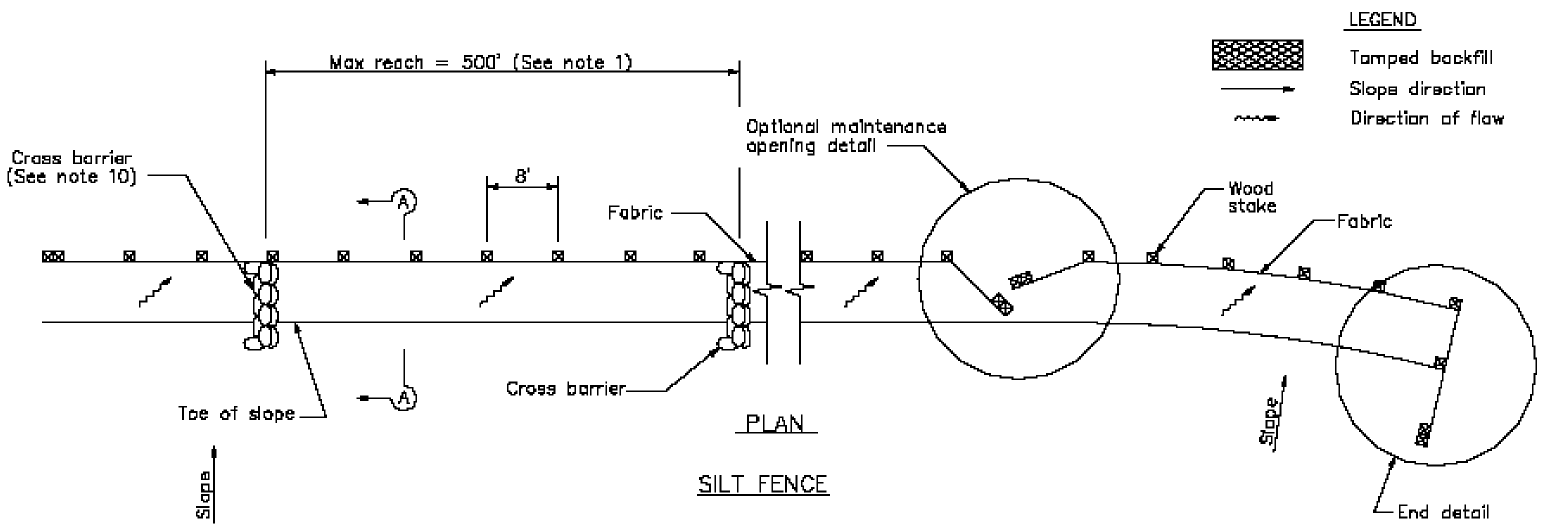
- Silt fences shall be used in conjunction with soil stabilization source controls up slope to provide effective erosion and sediment control.
- Bottom of the silt fence shall be keyed or trenched -in a minimum of 12 inches. Trenches shall not be excavated wider and deeper than necessary for proper installation of the temporary linear sediment barriers.

- Excavation of the trenches shall be performed immediately before installation of the temporary linear sediment barriers.
- Construct silt fences with a set-back of at least 3 feet from the toe of a slope. Where a silt fence is determined to be not practical due to specific site conditions, the silt fence may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practical.
- Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/3 the height of the barrier.
- Cross barriers shall be a minimum of 1/3 and a maximum of 1/2 the height of the linear barrier.

Maintenance and Inspection

- Ensure that perimeter controls are maintained and protected from activities that reduce their effectiveness.
- Repair undercut silt fences. Repair or replace split, torn, slumping, or weathered fabric.
- Inspect all silt fences a minimum of weekly and before and after every rainfall events. During extended rainfall events, inspect inlet protection devices at least once every 24 hours. Perform necessary maintenance, or maintenance required by the Engineer.
- Maintain silt fences to provide an adequate sediment holding capacity. Sediment shall be removed when the sediment accumulation reaches one-third (1/3) of the barrier height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of outside the right-of-way in conformance with all applicable laws and regulations.
- Silt fences that are damaged and become unsuitable for the intended purpose, as determined by the Engineer, shall be removed from the site of work, disposed of outside the project right-of-way in conformance with all applicable laws and regulations, and replaced with new silt fence barriers.
- Remove silt fence when no longer needed or as required by the Engineer. Fill and compact post holes and anchorage trench, remove sediment accumulation, grade fence alignment to blend with adjacent ground and stabilized disturbed soil areas.

Silt Fence

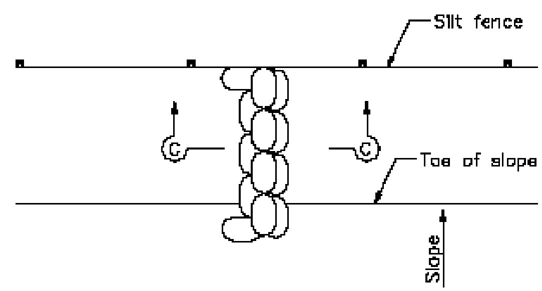


PLAN

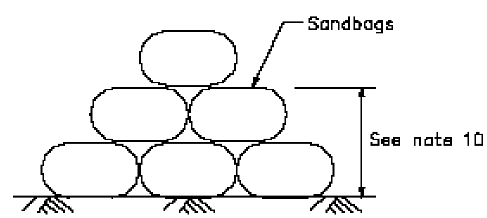
SILT FENCE

NOTES

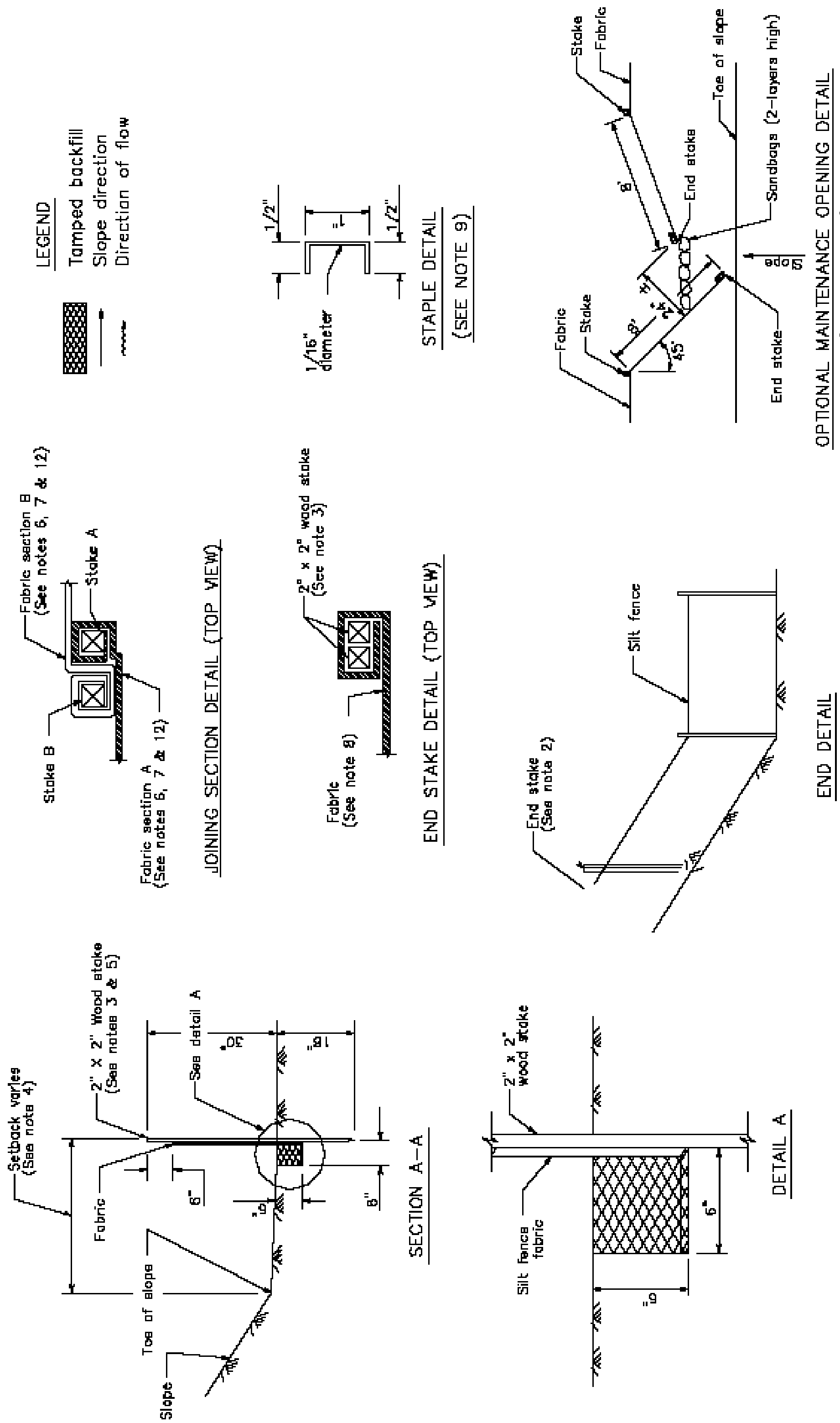
1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/3 the height of the linear barrier, in no case shall the reach length exceed 500'.
2. The last 8'-0" of fence shall be turned up slope.
3. Stake dimensions are nominal.
4. Dimension may vary to fit field condition.
5. Stakes shall be spaced at 8'-0" maximum and shall be positioned on downstream side of fence.
6. Stakes to overlap and fence fabric to fold around each stake one full turn. Secure fabric to stake with 4 staples.
7. Stakes shall be driven tightly together to prevent potential flow-through of sediment at joint. The tops of the stakes shall be secured with wire.
8. For end stake, fence fabric shall be folded around the stakes one full turn and secured with 4 staples.
9. Minimum 4 staples per stake. Dimensions shown are typical.
10. Cross barriers shall be a minimum of 1/3 and a maximum of 1/2 the height of the linear barrier.
11. Maintenance openings shall be constructed in a manner to ensure sediment remains behind silt fence.
12. Joining sections shall not be placed at sump locations.
13. Sandbag rows and layers shall be offset to eliminate gaps.



CROSS BARRIER DETAIL



SECTION C-C


LEGEND
Tamped backfill
Slope direction
Direction of flow
Setback varies (See note 4)
2" X 2" Wood stake (See notes 3 & 5)
See detail A
Fabric
Toe of slope
Slope
30"
18"
6"
8"
6"
SECTION A–A
2" x 2" wood stake
Silt fence fabric
6"
6"
DETAIL A
Fabric section B (See notes 6, 7 & 12)
Stake A
Stake B
Fabric section A (See notes 6, 7 & 12)
JOINING SECTION DETAIL (TOP VIEW)
2" x 2" wood stake (See note 3)
Fabric (See note 8)
END STAKE DETAIL (TOP VIEW)
End stake (See note 2)
Silt fence
END DETAIL
1/2"
1"
1/2"
1/16" diameter
STAPLE DETAIL
(SEE NOTE 9)
Stake
Fabric
Toe of slope
End stake
Sandbags (2–layers high)
8'
8'
4'
45°
Slope
OPTIONAL MAINTENANCE OPENING DETAIL
(SEE NOTE 11)

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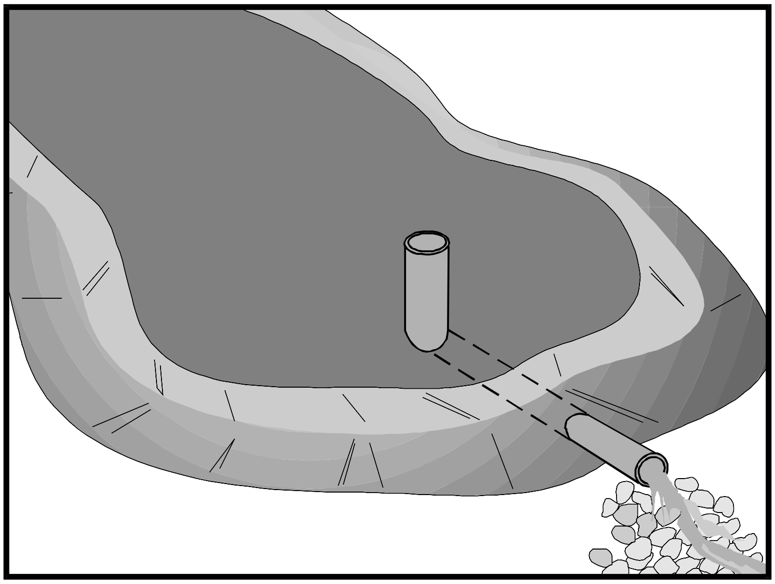
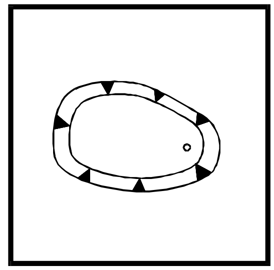
Sediment/Desilting Basin

SC-2





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sediment/desilting basin is a temporary basin formed by excavating and/or constructing an embankment so that sediment-laden runoff is temporarily detained under still conditions, allowing sediment to settle out before the runoff is discharged (refer to Figures 1 and 2).

Appropriate Applications

As required by the Construction General Permit (NPDES No. CAS000002, Order 2009-0009-DWQ), sediment basins shall be designed at a minimum to the method provided in CASQA's Construction BMP Guidance Handbook. This BMP is consistent with the CASQA handbook. This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Engineer.

Sediment/Desilting Basins shall be used:

- Where sediment-laden water may enter the drainage system or watercourses.
- At outlets of disturbed soil areas with areas between 5 ac and 10 ac.

Limitations

- Alternative BMPs must be thoroughly investigated for erosion control before selecting temporary desilting basins.
- Requires large surface areas to permit settling of sediment. Size may be limited by availability of space on the construction site.
- Not appropriate for drainage areas greater than 75 ac.
- For safety reasons, basins shall have protective fencing.
- Not allowed for dewatering or groundwater.

Standards and Specifications

- Limit the contributing area to the sediment/desilting basin to only the runoff from the disturbed soil areas. Use temporary concentrated flow conveyance controls to divert runoff from undisturbed areas away from the sediment/desilting basin.

- Sediment/desilting basin shall be designed by a professional Engineer registered with the State of California. The Design details shall be included in the SWPPP or SWPPP amendment or approved by the Engineer prior to construction.

- The design shall include maintenance requirements, including sediment and vegetation removal, to ensure continuous function of the trap outlet and bypass structures.

Sediment Basin

- Sediment basins shall, at a minimum, be designed as follows:
  - Option 1: Sediment basin(s) shall be designed using the standard equation:

    $$As=1.2Q/Vs \qquad \text{(Eq. 1)}$$

    Where:

    As = Minimum surface area for trapping soil particles of a certain size.

    Vs = Settling velocity of the design particle size chosen(*Vs* = 0.00028 ft/s for a design particle size of 0.01 mm at 68 ºF)

    1.2 = Factor of safety recommended by USEPA to account for the reduction in basin efficiency caused due to turbulence and other non ideal conditions.

    $$Q = C\ I\ A \qquad \text{(Eq. 2)}$$

    Where:

    Q = Discharge rate measured in cubic feet per second

    C = Runoff coefficient (unit less)

    I = Precipitation intensity for the 10-year, 6-hour rain event (in/hr)

    A = Area draining into the sediment basin in acres.

    The design particle size shall be the smallest soil grain size determined by wet sieve analysis, or the fine silt sized (0.01mm [or 0.004 in.]) particle, and the *Vs* used shall be 100 percent of the calculated settling velocity.

The basin length is determined by measuring the distance between the inlet and the outlet. If the outlet structure will be used to control the flow, the length shall be more than twice the dimension as the width. If the topography does not allow for this configuration, baffles shall be used to meet the ratio. If the basin length will be used to control flow, the length shall be designed to capture 100% of the design particle size. The depth shall not be less than 3 ft nor greater than 5 ft for safety reasons and for maximum efficiency (2 ft of sediment storage, 2 ft of capacity). The basin(s) shall be located on the site where it can be maintained on a year-round basis and shall be maintained on a schedule to retain the 2 ft of capacity.

OR

– Option 2: Pursuant to local ordinance for sediment basin design and maintenance, provided that the design efficiency is as protective or more protective of water quality than Option 1.

OR

– Option 3: The use of an equivalent surface area design or equation, provided that the design efficiency is as protective or more protective of water quality than Option 1.

In order to design a sediment basin properly, the site constraints, soil particle size distribution, drainage area, and local hydrology shall be considered.

Typical Hydrologic *Design Methodology*

Evaluate the site constraints and assess the drainage area for the sediment basin. Consider on- and off-site flows as well as changes in drainage areas associated with construction. To minimize additional construction during the course of the project, identify and use the maximum drainage area when calculating the basin dimensions.

The Los Angeles County Department of Public Works, Hydrology Manual, January 2006 (http://dpw.lacounty.gov/wrd/publication/engineering/2006 Hydrology Manual shall be used to obtain the needed rainfall intensity.

Calculate the surface area required for the sediment basin using Equation 1. Discharge is estimated for a 10-year 6-hour event using the rational method procedure. Vs is estimated using Stokes Law (Eq. 3)

$V_s = 2.81\ d^2$ (Eq. 3)

Where:

Vs = Settling velocity in feet per second at 68 ºF.

d = diameter of sediment particle in millimeters (smallest soil grain particle size determined by wet sieve analysis or fine silt (0.01mm [or 00.0004 in.]).

- The basin outlet design requires an iterative trial and error approach that considers the maximum water surface elevation, elevation versus volume relationship, elevation versus discharge relationship, and the estimated inflow hydrograph. To adequately design the basin to settle sediment, the outlet configuration and associated outflow rates shall be estimated. There are numerous methodologies:

- Outlet design typically includes multiple horizontal rows of orifices (3 or more) with at least 2 orifices per row (see figures 1 and 2).
- Select the appropriate orifice diameter and number of perforations per row with the objective if minimizing the number of rows while maximizing the detention time. Each outlet should have more than one orifice
- The diameter of each orifice is typically a maximum of 3-4 inches and a minimum of 0.25 -0.5 inches.
- If a rectangular orifice is used, it is recommended to have a minimum height of 0.5 inches and a maximum height of 6 inches.
- Rows are typically spaced at three times the diameter center to center vertically with a minimum distance of 4 inches on center and a maximum distance of 1 foot on center.
- Each row is calculated separately for outflow rate using the flow through a single orifice and multiplying by the number of orifices in that row. Repeat this step for each row and sum the rows. The total outflow rate is then compared to the detention time within the basin.

  Flow through a single orifice can be estimated using the following equation (Eq. 4):

  $Q = BC' A(2gH)^{0.5}$ (Eq. 4)

  Where:

  Q = Discharge in ft^3/s

  C' = Orifice coefficient (unit less)

  A = area of the orifice (ft^2)

  g = acceleration due to gravity (ft^3/s)

  H = head above the orifice (ft)

  B = anticipated Blockage or clogging factor (unitless), dependent on anticipated sediment and debris load, trash rack configuration, etc., so the value is dependent on professional judgment and/or local requirements (B is never greater than 1 and a value of 0.5 is generally used).

- For the orifice coefficient (C') the value of 0.6 is most often recommended and used, or

  C' = 0.66 for thin materials- where the thickness of the material (used to form the orifice) is equal to or less than the diameter of the orifice, or

  C' = 0.8 when the material is thicker than the orifice diameter.

- If different sizes of orifices are used along the riser then they must be sized so that not more than 50 percent of the design storm event drains in one third of the draw down time. This will allow adequate settling time for events smaller than the design storm event. The entire volume of the basin shall be designed to drain within 72 hours or less if required by local vector control regulations. If the basin fails to empty within 72 hours, the basin shall be pumped dry in accordance with the APP (see NS-2 Dewatering Operations BMPs).

- Floating outlet skimmer: The floating outlet skimmer drains water from the upper portion of the water column in the basin. This prevents clogging from bottom sediments. Figure 4 shows the floating outlet skimmer.

- Hold and release valve: A valve system for releasing water from a detention basin is critical. The valve system may be manual, bladder devices or electronic. The valve shall be closed during the rain event and settling time and then released to drain within 72 hours or less if required by local vector regulations.

Evaluate the Capacity of the Sediment Basin

- Sediment basins cannot be expected to perform as designed if not properly maintained or the sediment yield is larger than expected. Sediment basin design must include maintenance requirements sediment yield and basin storage volume.

- Sediment yield can be estimated using the Modified Universal Soil Loss Equation (MUSLE, Eq. 5) and annual soil loss can be estimated using the Revised Universal Soil Loss Equation (RUSLE, Eq.6).

  $Y = 95 (Q \times q_p)^{0.56} \times K \times LS \times C \times P$ (Eq. 5)

  $A = R \times K \times LS \times C \times P$ (Eq. 6)

  Where:

  A = annual soil loss, tons per acre per year

  R = rainfall erosion index, in 110 ft. tons/acre in /hour

  K = soil erodibility factor, in tons/acre per unit of R

  LS = Slope length and steepness factor (unit less)

  C = vegetative cover factor (unit less)

  P = erosion control practice factor (unit less)

  Y – single storm sediment yield in tons

  Q = runoff volume in acre-feet

  q = peak flow in cfs.

- Determination of the appropriate equation shall consider construction duration and local environmental factors. For example, a year-long project should use RUSLE. Where a project that is less than a year should use the MUSLE. Both equations are used to estimate soil loss and evaluate the sediment storage volume required and maintenance frequency.

- Soil loss estimates are an essential step in the design and maintenance requirements must be understood by the implementers in the field. Providing maintenance methods, frequencies and specifications shall be included on the SWPPP Site map.
- Once the amount of soil entering the basin is estimated, the depth required for sediment storage shall be determined by dividing the estimated sediment loss by the surface area of the basin.

General Requirements

- The basin shall consist of the following 2 zones:
- A sediment storage zone of at least 1 foot deep
- A settling zone at least 2 feet deep
- The basin depth shall be no less than 3 feet deep (not including free board). Free board shall be 1 foot or more as required by local regulations.
- Proper hydraulic design of the outlet is critical to achieving the desired performance of the basin. The water quality outlet should be designed to drain the basin within 24 to 72 hours (also referred to as "drawdown time"). (The 24-hour limit is specified to provide adequate settling time; the 72-hour limit is specified to mitigate vector control concerns.)
- The length to settling depth ratio shall be less than 200.
- SS-10 shall be used to protect the basin inlet and slopes against erosion.
- Design and locate sediment/desilting basins so that they can be maintained. Construct desilting basins prior to construction activities.
- Sediment/desilting basins, regardless of size and storage volume, shall include features to accommodate overflow or bypass flows that exceed the design storm event. The calculated basin volume and proposed location shall be submitted to the Engineer for approval at least 3 days prior to the basin construction.
- Construct an emergency spillway to accommodate flows not carried by the principal spillway.
- Spillway shall consist of an open channel (earthen or vegetated) over undisturbed material (not fill) or constructed of a non-erodible riprap.
- Spillway control section, which is a level portion of the spillway channel at the highest elevation in the channel, shall be a minimum of 20 ft in length.
- A forebay, constructed upstream of the basin may be provided to remove debris and larger particles.

- Basin inlets shall be located to maximize travel distance to the basin outlet.
- If baffles are used, construct them of earthen berms that are stabilized to prevent erosion or other structural materials to divert flows and allow settling throughout the basin. Baffles shall be designed to diver the design flows and allow
- The outflow from the basins shall be provided with outlet protection to prevent erosion and scouring of the embankment and channel. See BMP SS-10, "Outlet Protection/Velocity Dissipation Devices."
- Basin shall be located: (1) by excavating a suitable area or where a low embankment can be constructed across a swale, (2) where post-construction (permanent) detention basins will be constructed, (3) where failure would not cause loss of life or property damage, (4) where the basins can be maintained on a year-round basins to provide access for maintenance, including sediment removal and sediment stockpiling in a protected area, and to maintain the basin to provide the required capacity.
- Areas under embankments, structural works, and sediment/desilting basin must be cleared, stripped of vegetation.
- Structure shall be placed on a firm, smooth foundation with the base securely anchored with concrete or other means to prevent floatation.
- Discharge from the basin shall be accomplished through a water quality outlet. An example is shown in Figure 3. The principal outlet shall consist of a corrugated metal, high density polyethylene (HDPE), or reinforced concrete riser pipe with dewatering holes and an anti-vortex device and trash rack attached to the top of the riser, to prevent floating debris from flowing out of the basin or obstructing the system. This principal structure shall be designed to accommodate the inflow design storm.
- A rock pile or rock-filled gabions can serve as alternatives to the debris screen, although the designer should be aware of the potential for extra maintenance involved should the pore spaces in the rock pile clog.
- The two most common outlet problems that occur are: (1) the capacity of the outlet is too great resulting in only partial filling of the basin and drawdown time less than designed for; and (2) the outlet clogs because it is not adequately protected against trash and debris. To avoid these problems, the following outlet types are recommended for use: (1) a single orifice outlet with or without the protection of a riser pipe, and (2) perforated riser. Design guidance for single orifice and perforated riser outlets are as follows:

Flow Control Using a Single Orifice At The Bottom Of The Basin (Figure 1):

The outlet control orifice should be sized using the following equation:

$$a = \frac{2A(H - Ho)^{0.5}}{3600CT(2g)^{0.5}} = \frac{(7x10^{-5})A(H - Ho)^{0.5}}{CT} \qquad \text{(Eq. 2)}$$

where:

a = area of orifice (ft^2)

A = surface area of the basin at mid elevation (ft^2)

C = orifice coefficient

T = drawdown time of full basin (hrs)

G = gravity (32.2 ft/s^2)

H = elevation when the basin is full (ft)

Ho = final elevation when basin is empty (ft)

With a drawdown time of 40 hours, the equation becomes:

$$a = \frac{(1.75x10^{-6})A(H - Ho)^{0.5}}{C} \qquad \text{(Eq. 3)}$$

Flow Control Using Multiple Orifices (see Figure 2):

$$a_t = \frac{2A(h_{\max})}{CT(2g[h_{\max} - h_{centroid\ of\ orifices}])^{0.5}} \qquad \text{(Eq. 4)}$$

With terms as described above except:

a_t = total area of orifices

h_{max} = maximum height from lowest orifice to the maximum water surface (ft)

$h_{centroid\ of\ orifices}$ = height from the lowest orifice to the centroid of the orifice configuration (ft)

Allocate the orifices evenly on two rows; separate the holes by 3x hole diameter vertically, and by 120 degrees horizontally (refer to Figure 3).

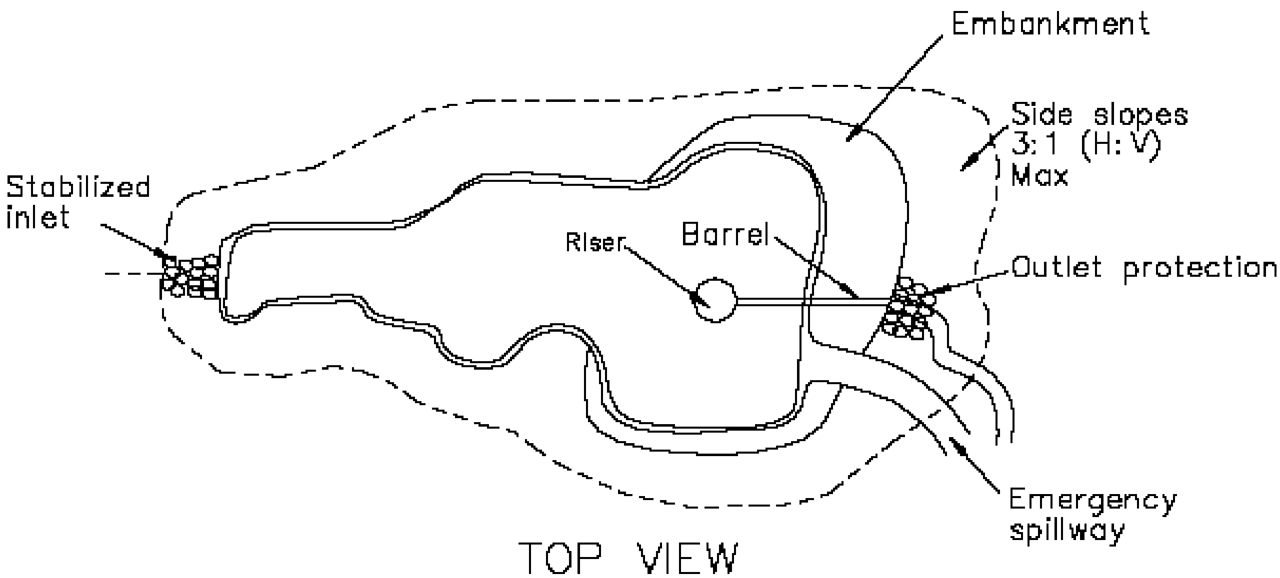
Because basins are not maintained for infiltration, water loss by infiltration should be disregarded when designing the hydraulic capacity of the outlet structure.

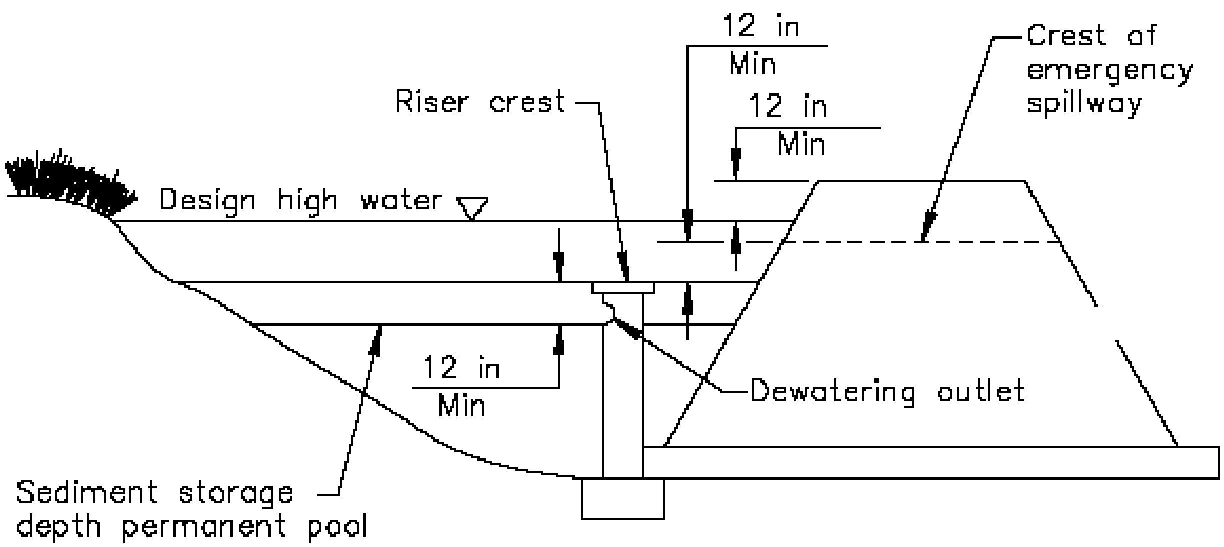
- The Contractor shall verify that the outlet is properly designed to handle the design and peak flows.
- Attach riser pipe (watertight connection) to a horizontal pipe (barrel), which extends through the embankment to toe of fill. Provide anti-seep collars on the barrel.
- Cleanout level shall be clearly marked on the riser pipe

Insignificant quantities of accumulated precipitation may be dewatered to the sediment/desilting basin unless precipitation is forecasted within 24 hours. Refer to NS-2 "Dewatering Operations" and the APP.

Inspection and Maintenance

- Inspect sediment basins weekly and before and after rainfall events. During extended rainfall events, inspect sediment basins at least every 24 hours.
- Examine basin banks for seepage and structural soundness.
- Check inlet and outlet structures and spillway for any damage or obstructions. Repair damage and remove obstructions as needed, or as directed by the Engineer.
- Remove standing water from the basin within 72 hours after accumulation.
- Check inlet and outlet area for erosion and stabilize if required, or if directed by the Engineer.
- Remove accumulated sediment when its volume reaches one-third the volume of the sediment storage. Properly dispose of sediment and debris removed from the basin.
- Check fencing for damage and repair as needed or as directed by the Engineer.





NOTE:
This outlet provides no drainage for permanent pool.

FIGURE 1: TYPICAL TEMPORARY SEDIMENT BASIN

SINGLE ORIFICE DESIGN

NOT TO SCALE

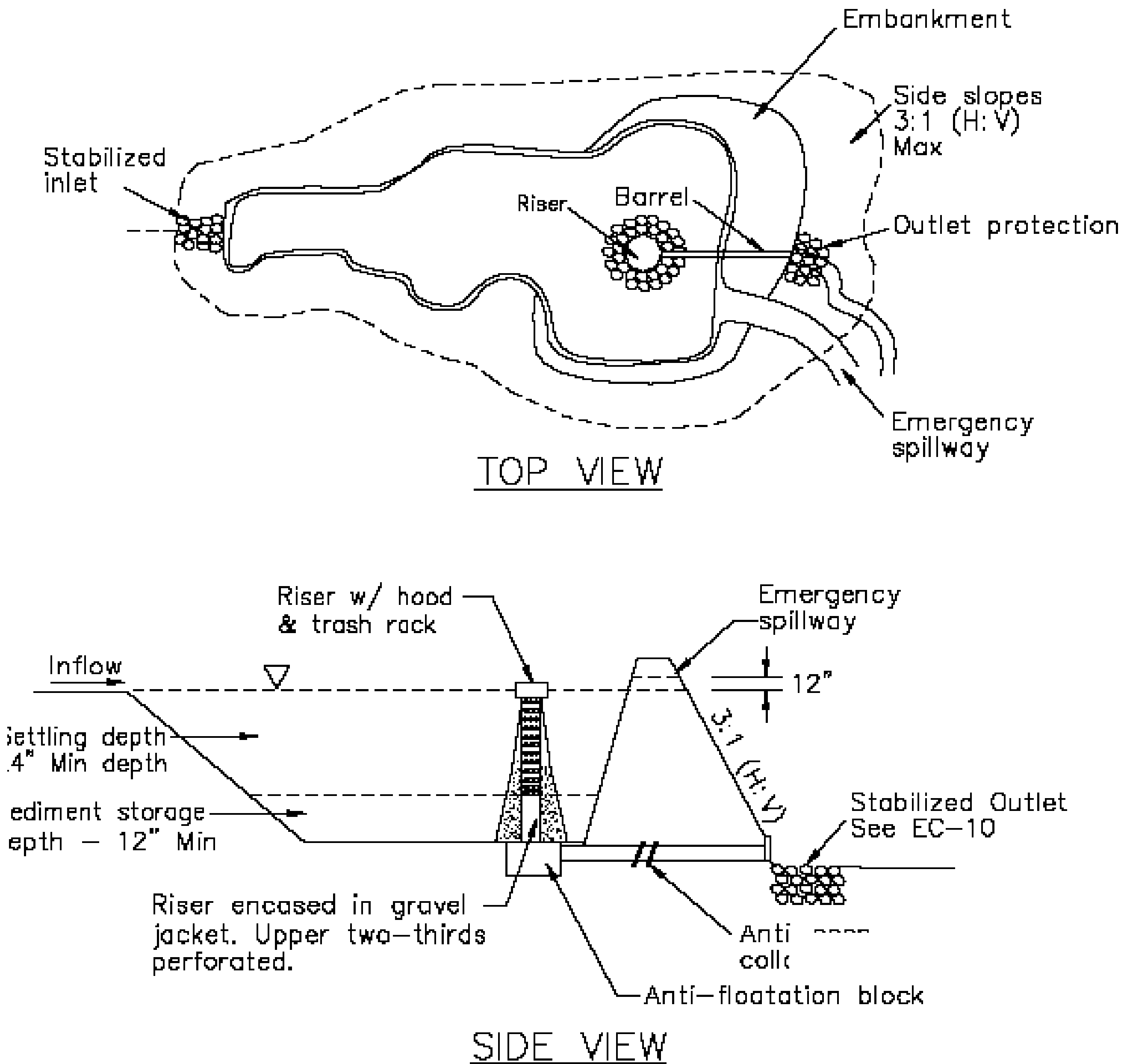


FIGURE 2: TYPICAL TEMPORARY SEDIMENT BASIN

MULTIPLE ORIFICE DESIGN

NOT TO SCALE

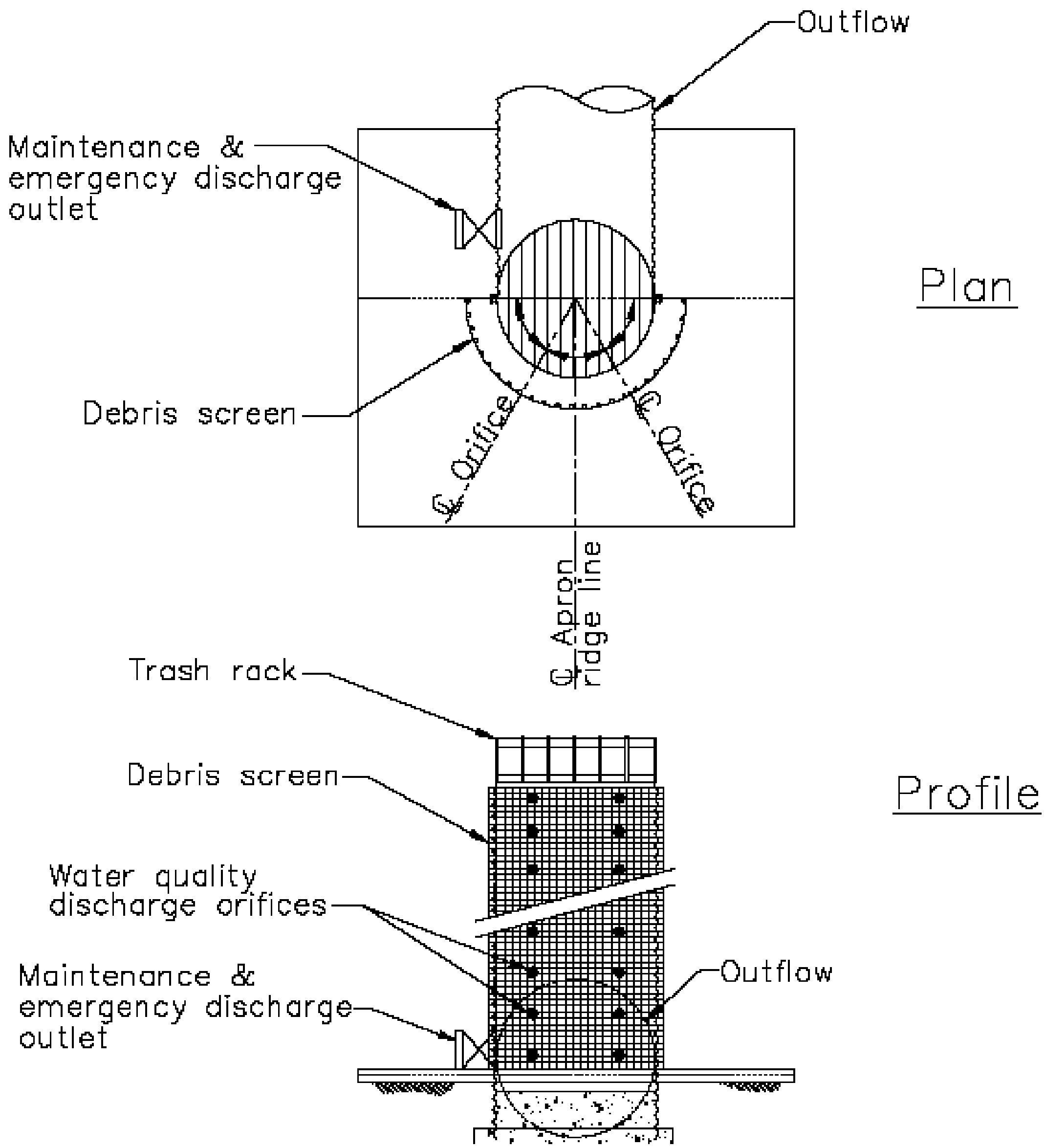


FIGURE 3: MULTIPLE ORIFICE OUTLET RISER

NOT TO SCALE

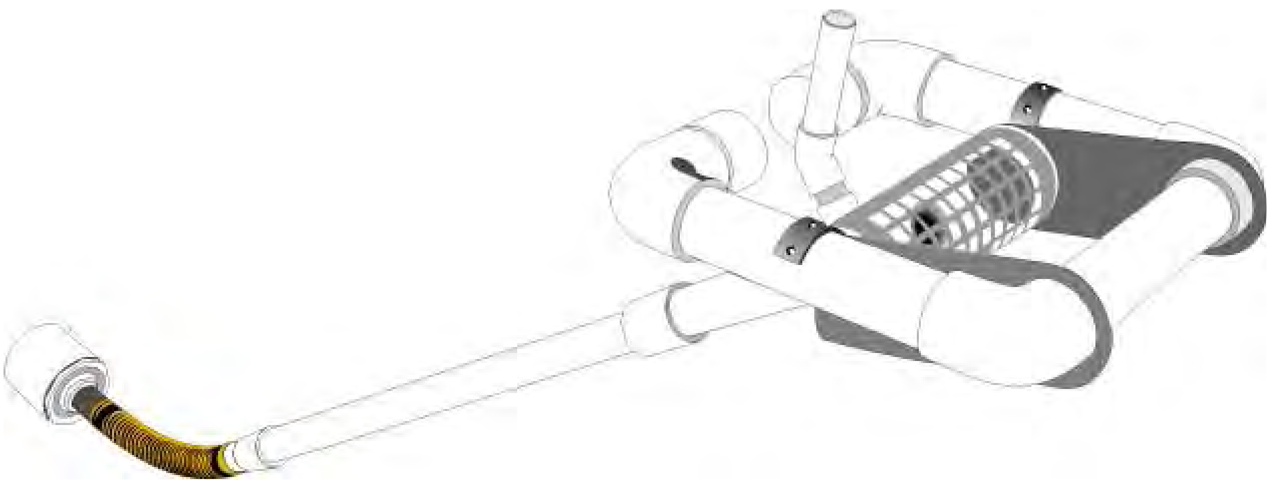


FIGURE 4: FLOATING OUTLET SKIMMER

NOT TO SCALE

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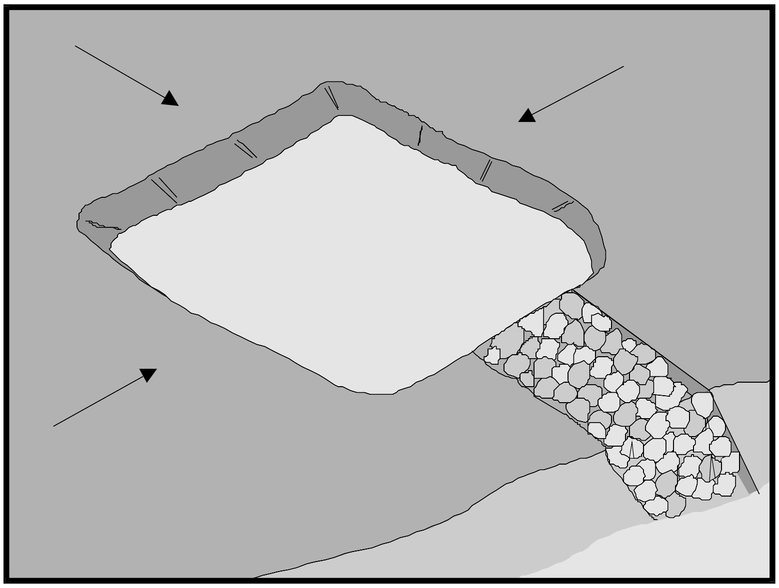
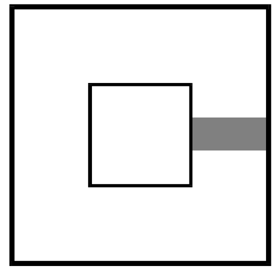
Sediment Trap

SC-3





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sediment trap is a temporary containment area that allows sediment in collected storm water to settle out during infiltration or before the runoff is discharged through a stabilized spillway. Sediment traps are formed by excavating or constructing an earthen or other embankment across a waterway or low drainage area.

Appropriate Applications

- Sediment traps may be used on construction projects where the drainage area is less than 5 ac. Traps should be placed where sediment-laden storm water enters a storm drain or watercourse.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Engineer.
- As a supplemental control, sediment traps provide additional protection for a water body or for reducing sediment before it enters a drainage system.

Limitations

- Requires large surface areas to permit infiltration and settling of sediment.
- Not appropriate for drainage areas greater than 5 ac.
- Only removes large and medium sized particles and requires upstream erosion control.
- Size may be limited by availability of area on construction site.

Standards and Specifications

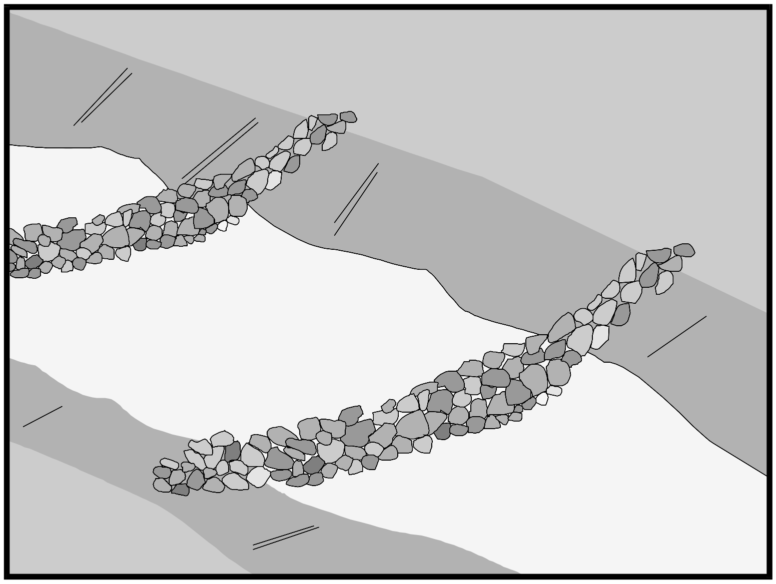
- Trap shall be situated according to the following criteria: (1) by excavating a suitable area or where a low embankment can be constructed across a swale, (2) where failure would not cause loss of life or property damage, and (3) to provide access for maintenance, including sediment removal and sediment stockpiling in a protected area.
- Trap shall be sized to accommodate a settling zone and sediment storage zone with recommended minimum volumes of 67 yd^3/ac and 33 yd^3/ac of contributing drainage area, respectively, based on 0.5 inches of runoff volume over a 24-hr period. Multiple traps and/or additional volume may be required to accommodate site specific rainfall and soil conditions.
- Sediment/desilting basin shall be designed by a professional Engineer registered with the State of California. The design details shall be included in the SWPPP or SWPPP amendment or approved by the Engineer prior to construction.
- The design shall include maintenance requirements, including sediment and vegetation removal, to ensure continuous function of the trap outlet and bypass structures.
- Areas under embankments, structural works, and sediment traps shall be cleared and stripped of vegetation and root material. The pool area shall be cleared.
- Use SS-10 to protect the trap outlets against erosion.
- Fencing shall be provided to prevent unauthorized entry.

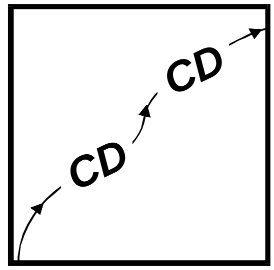
Maintenance and Inspection

- Inspect sediment traps a minimum of weekly, before and after rainfall events. During extended rainfall events, inspect sediment traps at least every 24 hours.
- If captured runoff has not completely infiltrated within 72 hours, the sediment trap must be dewatered per NS-2 requirements.
- Inspect trap banks for embankment seepage and structural soundness. Inspect outlet area for erosion and stabilize as required, or as directed by the Engineer.
- Inspect outlet structure and rock spillway for any damage or obstructions. Repair damage and remove obstructions as needed or as directed by the Engineer.
- Remove accumulated sediment when the volume has reached one-third the original trap volume. Properly dispose of sediment and debris removed from the trap.
- Inspect fencing for damage and repair as needed or as directed by the Engineer.

Check Dams

SC-4





BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Check dams reduce scour and channel erosion by reducing flow velocity and encouraging sediment settlement. A check dam is a small device constructed of rock, gravel bags, sandbags, fiber rolls, or other appropriate product placed across a natural or man-made channel or drainage ditch.

Appropriate Applications

- Check dams may be installed:
  - In small open channels that drain 10 ac or less.
  - In steep channels where storm water runoff velocities exceed 4.9 ft/sec.
  - During the establishment of grass linings in drainage ditches or channels.
  - In temporary ditches where the short length of service does not warrant establishment of erosion-resistant linings.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Engineer.

Limitations

- Not to be used in live streams.
- Not appropriate in channels that drain areas greater than 10 ac.
- Not to be placed in channels that are already grass lined unless erosion is expected, as installation may damage vegetation.
- Require extensive maintenance following high velocity flows.
- Promotes sediment trapping, which can be re-suspended during subsequent storms or removal of the check dam.
- Not to be placed in lined ditches designed for concentrated flow. Sediment must be prevented prior to entering lined or paved drain facilities.
- Not to be constructed from straw bales or silt fence.

Standards and Specifications

- Check dams shall be placed at a distance and height to allow small pools to form behind them. Install the first check dam approximately 16 ft from the outfall device and at regular intervals based on slope gradient and soil type.

- For multiple check dam installation, backwater from downstream check dam shall reach the toe of the upstream dam.

- High flows (typically a 2-year storm or larger) shall safely flow over the check dam without an increase in upstream flooding or damage to the check dam.

- Where grass is used to line ditches, check dams shall be removed when grass has matured sufficiently to protect the ditch or swale.

- Rock shall be placed individually by hand or by mechanical methods (no dumping of rock) to achieve complete ditch or swale coverage.

- Fiber rolls may be used as check dams if approved by the Engineer. Refer to SC-5 "Fiber Rolls."

- Gravel bags may be used as check dams with the following specifications:

Materials

– ***Bag Material:*** Bags shall be either polypropylene, polyethylene or polyamide woven fabric, minimum unit weight (four ounces per square yard), mullen burst strength exceeding 300 psi in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355.

– ***Bag Size:*** Each gravel-filled bag shall have a length of 18 in., width of 12 in., thickness of 3 in., and mass of approximately 33 lb. Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the Engineer for approval prior to deployment.

– ***Fill Material:*** Fill material shall be between 0.4 and 0.8 inch in diameter, and shall be clean and free from clay balls, organic matter, and other deleterious materials. The opening of gravel-filled bags shall be secured such that gravel does not escape. Gravel-filled bags shall be between 28 and 48 lb in mass. Fill material is subject to approval by the Engineer.

Installation

– Install along a level contour.

– Tightly abut bags and stack gravel bags using a pyramid approach. Gravel bags shall not be stacked any higher than 3.2 ft.

– Upper rows of gravel bags shall overlap joints in lower rows.

Maintenance and Inspection

- Inspect all check dams weekly and before and after every rainfall events. During extended rainfall events, inspect check dams at least once every 24 hours.
- Remove sediment when depth reaches one-third of the check dam height.
- Remove accumulated sediment prior to permanent seeding or soil stabilization.
- Remove check dam and accumulated sediment when check dams are no longer needed or when required by the Engineer.
- Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of in conformance with all applicable laws and regulations. If removed sediment is stored on site, it shall be in accordance with WM-3 Stockpile Management.

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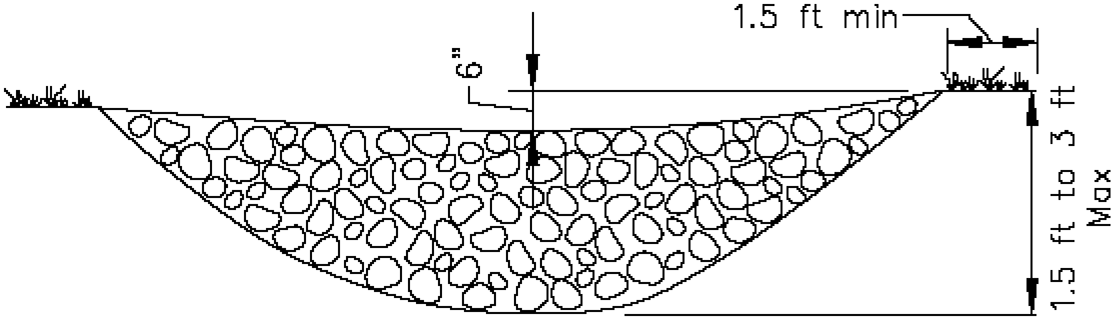
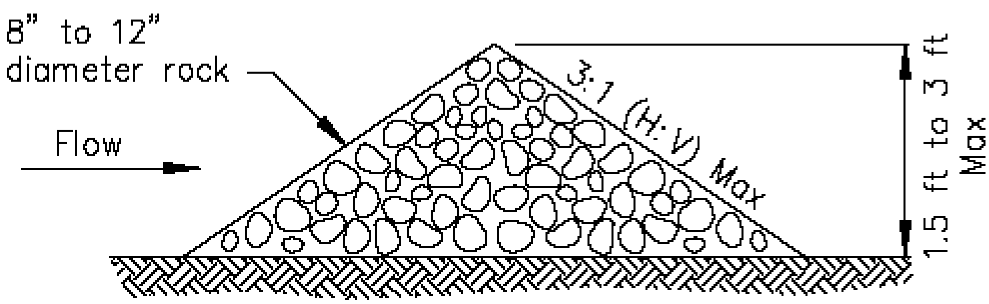
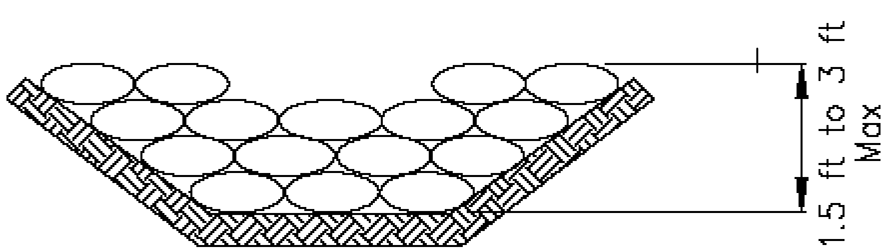


ELEVATION



TYPICAL ROCK CHECK DAM SECTION

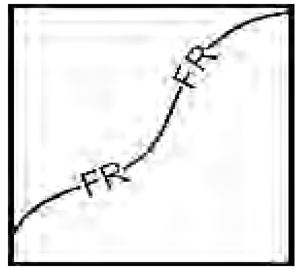
ROCK CHECK DAM
NOT TO SCALE



GRAVEL BAG CHECK DAM ELEVATION
NOT TO SCALE

Fiber Rolls

SC-5



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A fiber roll consists of wood excelsior, rice or wheat straw, or coconut fibers that is rolled or bound into a tight tubular roll and placed on the toe and face of slopes to intercept runoff, reduce its flow velocity, release the runoff as sheet flow and provide removal of sediment from the runoff. Fiber rolls may also be used for run-on diversion, inlet protection and check dams under certain situations.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Contractor or Engineer.
- Along the toe, top, face, and at grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.
- Below the toe of exposed and erodible slopes.
- Fiber rolls may be used as check dams in unlined ditches if approved by the Engineer (refer to SC-4 "Check Dams").
- Fiber rolls may be used for drain inlet protection if they can be properly anchored and if approved by the Engineer (refer to SC-10 "Storm Drain Inlet Protection").
- Fiber rolls may be used for run-on diversion when properly anchored and approved by the Engineer.
- Down-slope of exposed soil areas.
- Around temporary stockpiles.
- Along the perimeter of a project.

Limitations

- Runoff and erosion may occur if the fiber roll is not adequately trenched in.
- Fiber rolls at the toe of slopes greater than 1:5 may require the use of 20" diameter rolls or installations achieving the same protection (i.e., stacked smaller diameter fiber rolls, etc.).
- Difficult to move once saturated.
- Fiber rolls could be transported by high flows if not properly staked and trenched in.
- Fiber rolls have limited sediment capture zone.
- Do not use fiber rolls on slopes subject to creep, slumping, or landslide.

Standards and Specifications

Fiber Roll Materials

- Fiber rolls shall be either:
  - Prefabricated rolls.
  - Rolled tubes of erosion control blanket.

Assembly of Field Rolled Fiber Roll

- Roll length of erosion control blanket into a tube of minimum 8 in. diameter.
- Bind roll at each end and every 4 ft. along length of roll with jute-type twine.

Installation

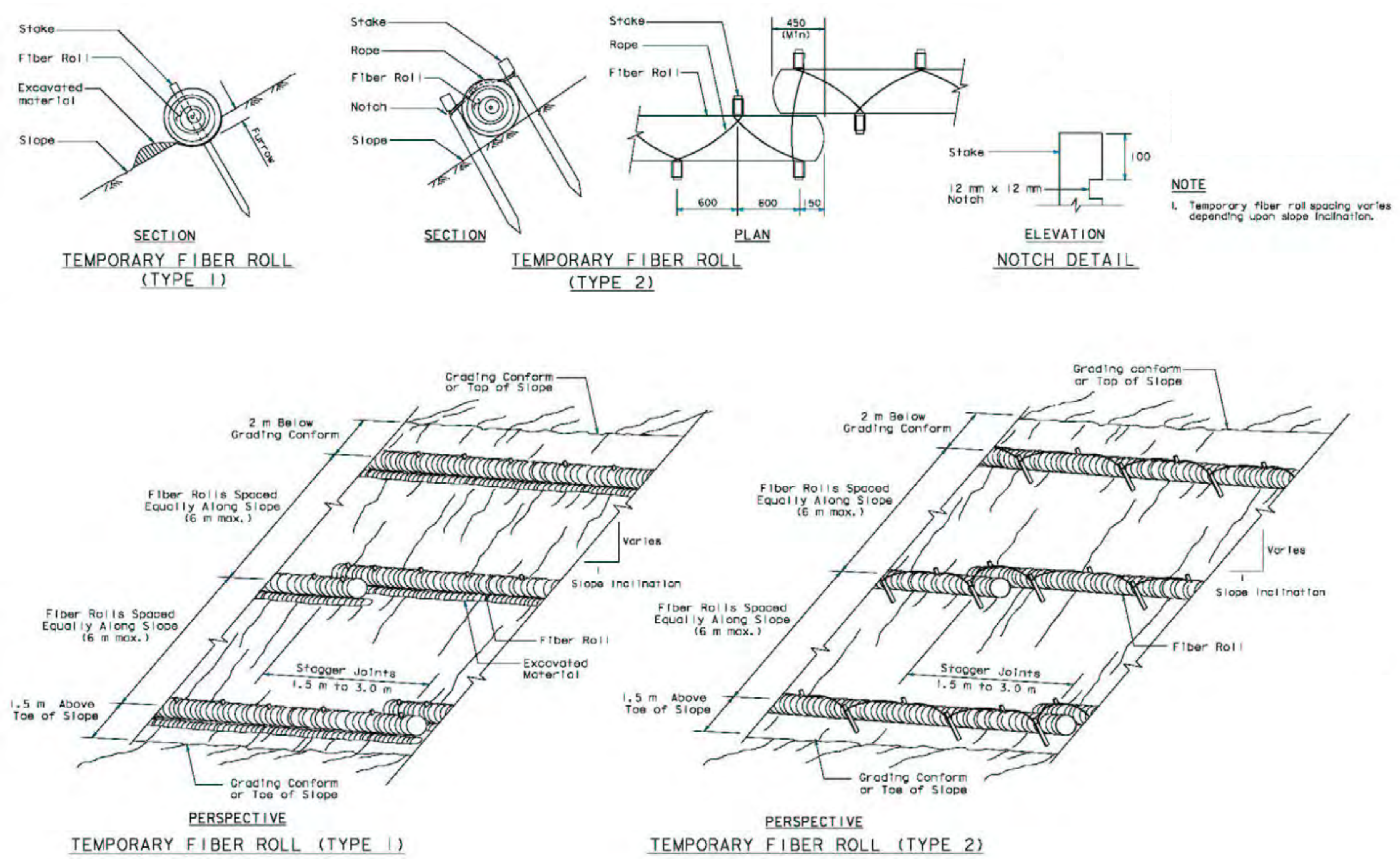
- Slope inclination of 1:4 or flatter: fiber rolls shall be placed on slopes 20 ft. (6m) apart.
- Slope inclination of 1:4 to 1:2: fiber rolls shall be placed on slopes 15 ft. (4.5 m) apart.
- Slope inclination 1:2 or greater: fiber rolls shall be placed on slopes 10 ft. (3 m) apart.
- Stake fiber rolls into a 2 to 4 in. trench.
- Use wood stakes with a nominal classification of 3/4 by 3/4 in, and minimum length of 24 in. Drive stakes at the end of each fiber roll and spaced 2 ft (600 mm) apart if Type 2 installation is used (refer to Page 4). Otherwise, space stakes 4 ft maximum on center if installed as shown on Pages 5 and 6.
- If more than one fiber roll is placed in a row, the rolls shall be overlapped; not abutted.

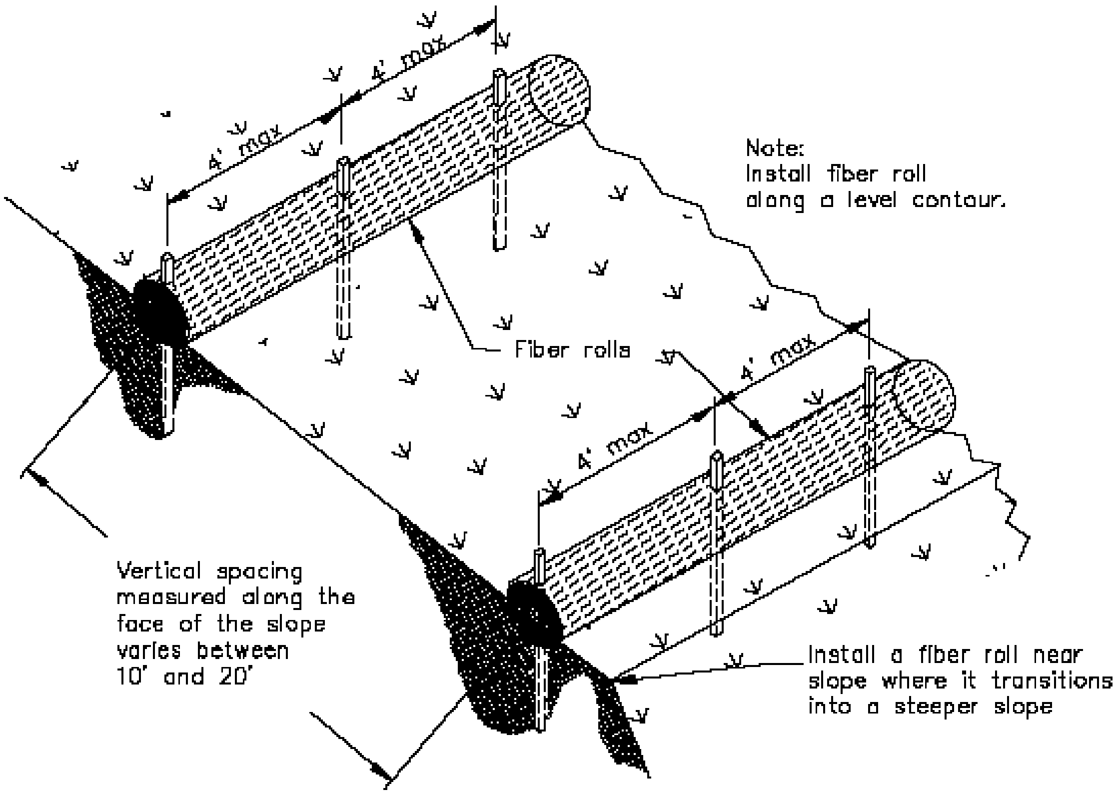
Removal

- Fiber rolls are typically left in place.
- If fiber rolls are removed, collect and dispose of sediment accumulation, and fill and compact holes, trenches, depressions or any other ground disturbance to blend with adjacent ground.

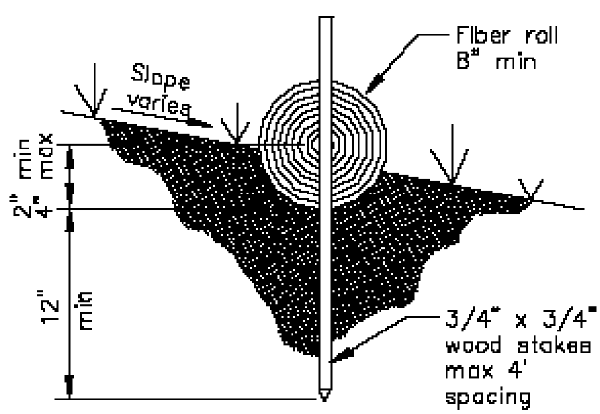
Maintenance and Inspection

- Ensure that all perimeter controls are maintained and protected from activities that reduce their effectiveness.
- Repair or replace split, torn, unraveling, or slumping fiber rolls.
- Inspect all fiber rolls weekly and before and after every rainfall events. During extended rainfall events, inspect fiber rolls at least once every 24 hours.
- Perform maintenance as needed or as required by the Engineer.
- Maintain fiber rolls to provide an adequate sediment holding capacity. Sediment shall be removed when the sediment accumulation reaches three quarters (3/4) of the barrier height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of outside the highway right-of-way in conformance with all applicable laws and regulations. If removed sediment is stored on site, it shall be in conformance with WM-3 Stockpile Management.

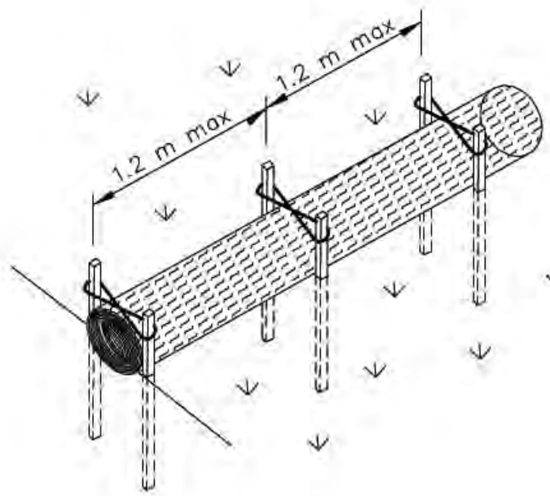

Stake
Fiber Roll
Excavated material
Slope
Furrow
SECTION
TEMPORARY FIBER ROLL (TYPE 1)
Stake
Rope
Fiber Roll
Notch
Slope
SECTION
450 (Min)
600
600
150
PLAN
TEMPORARY FIBER ROLL (TYPE 2)
Stake
12 mm x 12 mm Notch
100
ELEVATION
NOTCH DETAIL
NOTE
1. Temporary fiber roll spacing varies depending upon slope inclination.
Grading Conform or Top of Slope
2 m Below Grading Conform
Fiber Rolls Spaced Equally Along Slope (6 m max.)
Varies
Slope Inclination
Fiber Rolls Spaced Equally Along Slope (6 m max.)
Fiber Roll
Excavated Material
Stagger Joints 1.5 m to 3.0 m
1.5 m Above Toe of Slope
Grading Conform or Toe of Slope
PERSPECTIVE
TEMPORARY FIBER ROLL (TYPE 1)
Grading conform or Top of Slope
2 m Below Grading Conform
Fiber Rolls Spaced Equally Along Slope (6 m max.)
Varies
Slope Inclination
Fiber Rolls Spaced Equally Along Slope (6 m max.)
Fiber Roll
Stagger Joints 1.5 m to 3.0 m
1.5 m Above Toe of Slope
Grading Conform or Toe of Slope
PERSPECTIVE
TEMPORARY FIBER ROLL (TYPE 2)

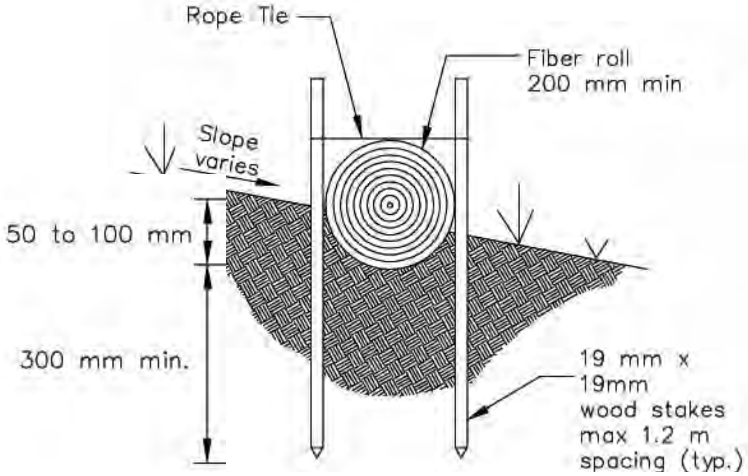


TYPICAL FIBER ROLL INSTALLATION
N.T.S.



ENTRENCHMENT DETAIL
N.T.S.



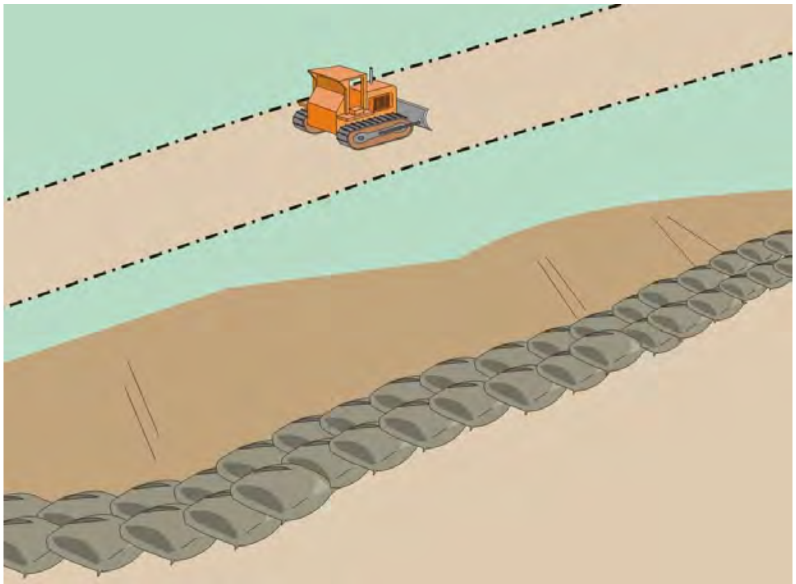


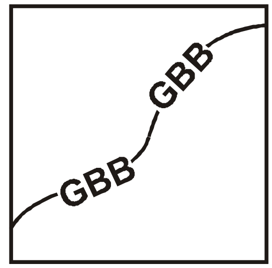
OPTIONAL ENTRENCHMENT DETAIL

N.T.S.

Gravel Bag Berm

SC-6





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A gravel bag berm consists of one or more rows of gravel bags that are installed end to end to form a barrier across a slope to intercept runoff, reduce its flow velocity, release the runoff as sheet flow and provide some sediment removal. Gravel bags can be used where flows are moderately concentrated, such as ditches, swales, and storm drain inlets (see BMP SC-10, Storm Drain Inlet Protection), and to divert and/or detain flows.

Appropriate Applications

- BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the Contractor or Engineer.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- At grade breaks of exposed and erodible slopes to shorten slope length and spread runoff as sheet flow.
  - Slope inclination of 1:4 or flatter: fiber rolls shall be placed on slopes 20 ft. (6m) apart.
  - Slope inclination of 1:4 to 1:2: fiber rolls shall be placed on slopes 15 ft. (4.5 m) apart.
  - Slope inclination 1:2 or greater: fiber rolls shall be placed on slopes 10 ft. (3 m) apart.
- Around stockpiles.
- Across channels to serve as a barrier for utility trenches or provide a temporary channel crossing for construction equipment, to reduce stream impacts.
- Parallel to a roadway to keep sediment off paved areas.

- At the top of slopes to divert runoff away from disturbed slopes.
- Along the perimeter of a site.
- To divert or direct flow or create a temporary sediment basin.
- During construction activities in stream beds when the contributing drainage area is less than 5 ac.
- When site conditions or construction sequencing require adjustments or relocation of the barrier to meet changing field conditions and needs during construction.
- Gravel bag berms may be used as check dams in accordance with SC-4.

Limitations

- Degraded gravel bags may rupture, spilling contents.
- Installation can be labor intensive.
- Limited durability for long term projects.
- When used to detain concentrated flows, maintenance requirements increase.

Standards and Specifications

Materials

- Bag Material: Bags shall be woven polypropylene, polyethylene or polyamide fabric, minimum unit weight four ounces per square yard, mullen burst strength exceeding 300 psi in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355.
- Bag Size: Each gravel-filled bag shall have a length of 18 in., width of 12 in., thickness of 3 in., and mass of approximately 33 lb. Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the Engineer for approval prior to deployment.
- Fill Material: Gravel shall be between 0.4 and 0.8 inch in diameter, and shall be clean and free from clay balls, organic matter, and other deleterious materials. The opening of gravel-filled bags shall be secured such that gravel does not escape. Gravel-filled bags shall be between 28 and 48 lb in mass. Fill material is subject to approval by the Engineer.

Installation

- When used as a linear control for sediment removal:
  - Install along a level contour.
  - Turn ends of gravel bag row up slope to prevent flow around the ends.
  - Generally, gravel bag barriers shall be used in conjunction with temporary soil stabilization controls up slope to provide effective erosion and sediment control.

- When used for concentrated flows:
  - Stack gravel bags to required height using a pyramid approach.
  - Upper rows of gravel bags shall overlap joints in lower rows.
- Construct gravel bag barriers with a set-back of at least 3 ft from the toe of a slope to maximize sediment storage capacity. Where it is determined to be not practicable due to specific site conditions, the gravel bag barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practicable.
- Contractor shall certify compliance with these specifications when installing gravel bag berms.

Maintenance and Inspection

- Ensure that all perimeter controls are maintained and protected from activities that reduce their effectiveness.
- Inspect all gravel bag berms weekly and before and after every rainfall events. During extended rainfall events, inspect gravel bag berms at least once every 24 hours.
- Reshape or replace gravel bags as needed, or as directed by the Engineer.
- Repair washouts or other damages as needed, or as directed by the Engineer.
- Inspect gravel bag berms for sediment accumulation and remove sediment when accumulation reaches one-third of the berm height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of outside the highway right-of-way in conformance with all applicable laws and regulations. If removed sediment is stored on site, it shall be stored in performance with WM-3 Stockpile Management.
- Remove gravel bag berms when no longer needed. Remove accumulated sediment and clean, re-grade, and stabilize the area.

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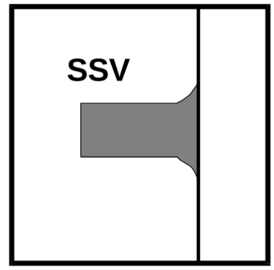
Street Sweeping and Vacuuming

SC-7



Standard Symbol

BMP Objectives
- ● Soil Stabilization
- ● Sediment Control
- ● Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Practices to remove tracked sediment to prevent the sediment from entering a storm drain or watercourse.

Appropriate Applications

These practices are implemented anywhere sediment is tracked from the project site onto public or private paved roads, typically at points of ingress/egress.

Limitations

Sweeping and vacuuming may not be effective when soil is wet or muddy.

Standards and Specifications

- ■ Streets will be cleaned in such a manner as to prevent unauthorized non-storm water discharges from reaching surface water or MS4 drainage systems.
- ■ Manually sweep or shovel may be used or a sweeper/vacuum truck. The swept sediment and debris shall be vacuumed or contained and swept off site.
- ■ Kick brooms or sweeper attachments shall not be used.
- ■ Visible sediment tracking shall be swept and/or vacuumed daily.
- ■ If not mixed with debris or trash, consider incorporating the removed sediment back into the project.

Maintenance and Inspection

- ■ Inspect ingress/egress access points daily and sweep tracked sediment as needed, or as required by the Engineer.
- ■ Be careful not to sweep up any unknown substance or any object that may be potentially hazardous.
- ■ Adjust brooms frequently; maximize efficiency of sweeping operations.
- ■ After sweeping is finished, properly dispose of sweeper wastes at an approved dumpsite per WM-5 and WM-6 for proper disposal procedures.

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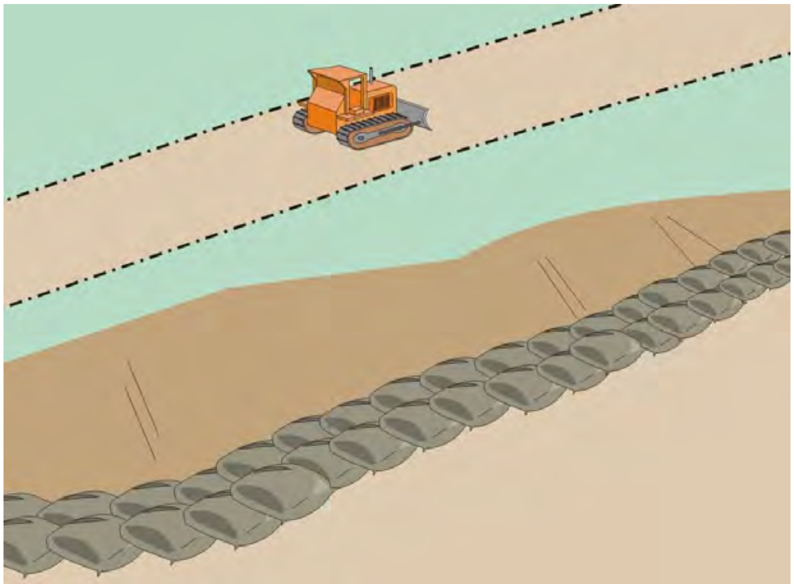
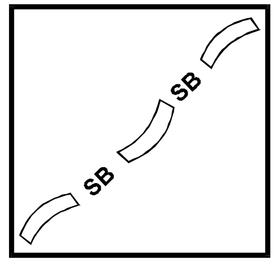
Sandbag Barrier

SC-8





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A sandbag barrier is a temporary linear sediment barrier consisting of stacked sandbags, designed to intercept and slow the flow of sediment-laden sheet flow runoff. Sandbag barriers allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis in addition to other BMPs when determined necessary and feasible by the Contractor or Engineer.
- Along the perimeter of a site.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- Down slope of exposed soil areas.
- Around stockpiles.
- Across channels to serve as a barrier for utility trenches or provide a temporary channel crossing for construction equipment, to reduce stream impacts.
- Parallel to a roadway to keep sediment off paved areas.
- At the top of slopes to divert roadway runoff away from disturbed slopes.
- To divert or direct flow or create a temporary sediment/desilting basin.
- During construction activities in stream beds when the contributing drainage area is less than 5 ac.

- With plastic cover along the perimeter of vehicle and equipment fueling and maintenance areas or chemical storage areas.
- To capture and detain non-storm water flows until proper cleaning operations occur.
- When site conditions or construction sequencing require adjustments or relocation of the barrier to meet changing field conditions and needs during construction.
- To temporarily close or continue broken, damaged or incomplete curbs.

Limitations

- Limit the drainage area upstream of the barrier to 5 ac.
- Degraded sandbags may rupture spilling sand.
- Installation can be labor intensive.
- Limited durability for long-term projects.
- When used to detain concentrated flows, maintenance requirements increase.

Standards and Specifications

Materials

- Sandbag Material: Sandbag shall be woven polypropylene, polyethylene or polyamide fabric, minimum unit weight four ounces per square yard, mullen burst strength exceeding 300 psi in conformance with the requirements in ASTM designation D3786, and ultraviolet stability exceeding 70% in conformance with the requirements in ASTM designation D4355. Use of burlap is not acceptable.
- Sandbag Size: Each sand-filled bag shall have a length of 18 in., width of 12 in., thickness of 3 in., and mass of approximately 33 lb. Bag dimensions are nominal, and may vary based on locally available materials. Alternative bag sizes shall be submitted to the Engineer for approval prior to deployment.
- Fill Material: All sandbag fill material shall be non-cohesive, Class 1 or Class 2 permeable material free from clay and deleterious material. Fill material is subject to approval by the Engineer.

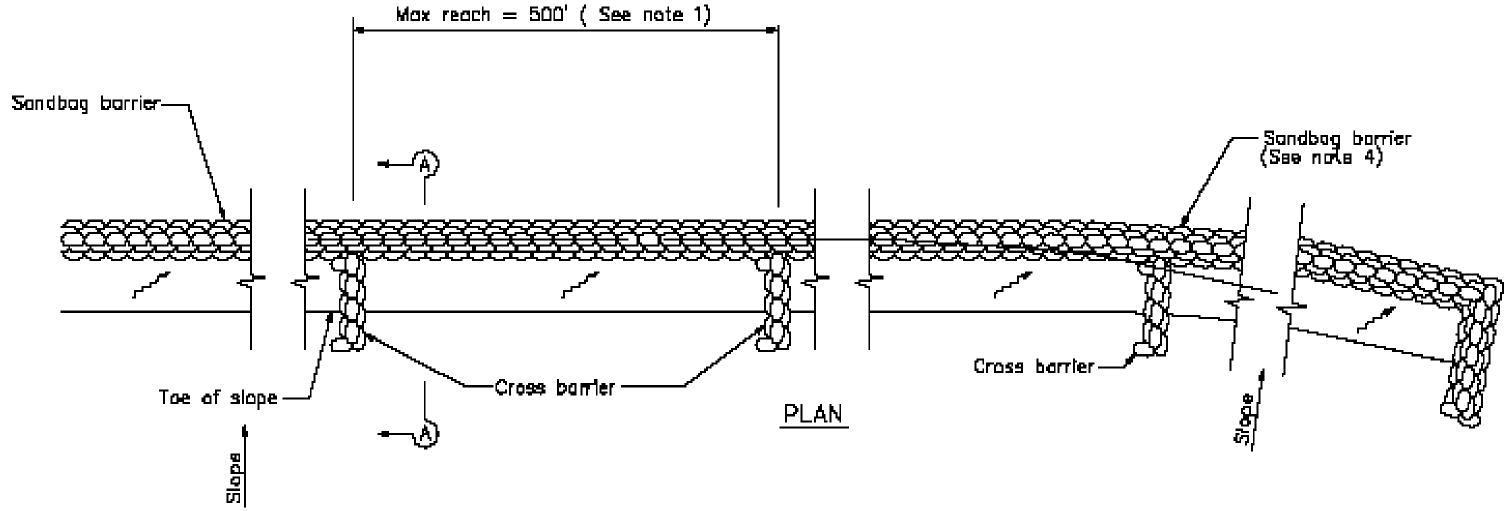
Installation

- When used as a linear sediment control:
  - Install along a level contour.
  - Turn ends of sandbag row up slope to prevent flow around the ends.
  - Generally, sandbag barriers shall be used in conjunction with temporary soil stabilization controls up slope to provide effective erosion and sediment control.
  - Install as shown in Pages 4 and 5 of this BMP.

- Construct sandbag barriers with a set-back of at least 3 ft from the toe of a slope. Where a setback is determined to be not practical due to specific site conditions, the sandbag barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practicable.

Maintenance and Inspection

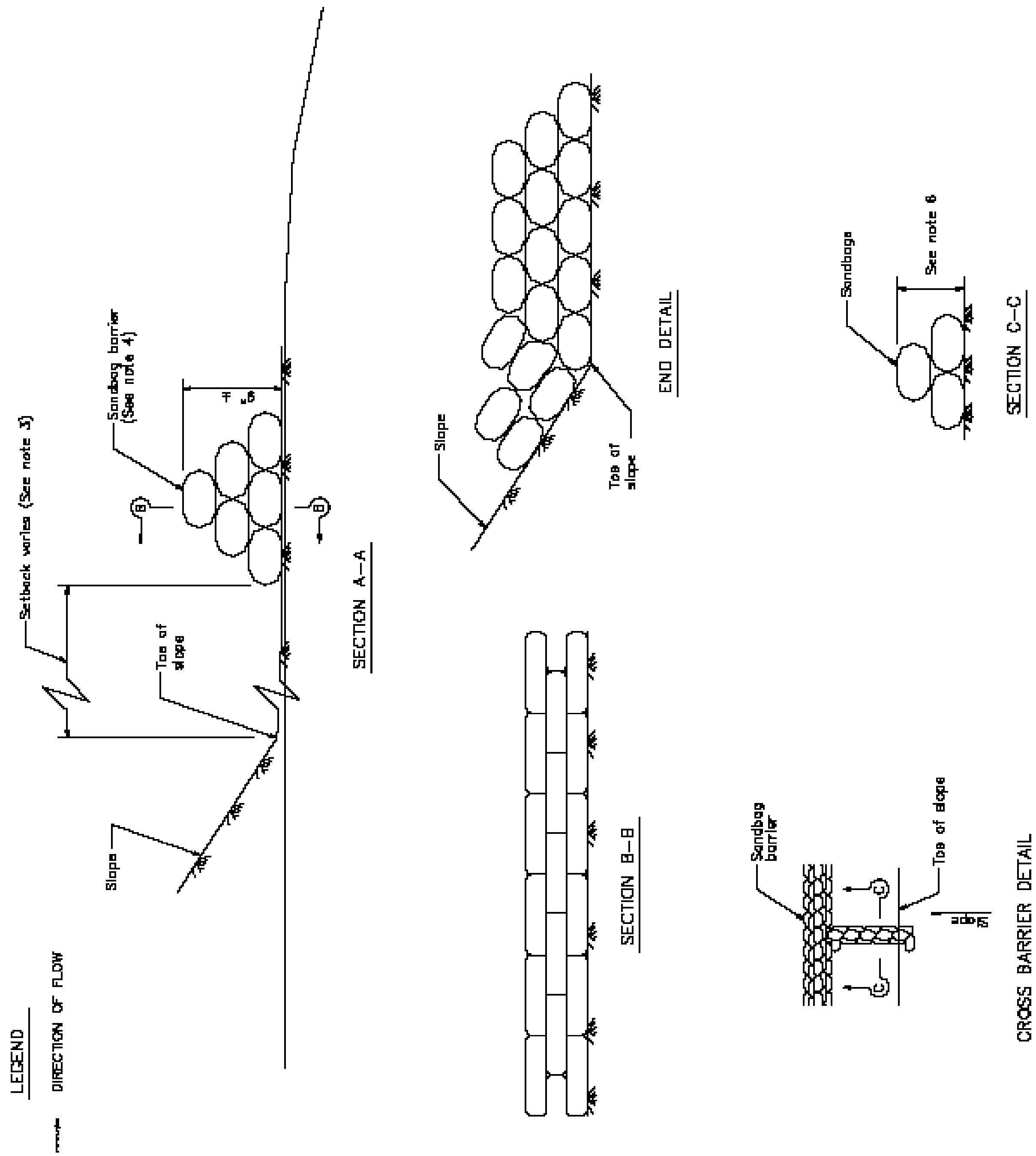
- Ensure that all perimeter controls are maintained and protected from activities that reduce their effectiveness.
- Inspect all sandbag barriers weekly and before and after every rainfall events. During extended rainfall events, inspect sandbag barriers at least once every 24 hours.
- Reshape or replace sandbags as needed, or as directed by the Engineer.
- Repair washouts or other damages as needed, or as directed by the Engineer.
- Inspect sandbag barriers for sediment accumulations and remove sediments when accumulation reaches one-third the barrier height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of off the construction site in conformance with all applicable laws and regulations. If accumulated sediment is stored on site, it shall be in accordance with WM-3 Stockpile Management.
- Remove sandbags when no longer needed. Remove sediment accumulation, and clean, re-grade, and stabilized the area.



SANDBAG BARRIER

NOTES

1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/2 the height of the linear barrier. In no case shall the reach length exceed 500'.
2. Place sandbags tightly.
3. Dimension may vary to fit field condition.
4. Sandbag barrier shall be a minimum of 3 bags high.
5. The end of the barrier shall be turned up slope.
6. Cross barriers shall be a min of 1/2 and a max of 2/3 the height of the linear barrier.
7. Sandbag rows and layers shall be staggered to eliminate gaps.


Setback varies (See note 3)
Sandbag barrier (See note 4)
Toe of slope
Slope
SECTION A-A
LEGEND
DIRECTION OF FLOW
Slope
Toe of slope
END DETAIL
SECTION B-B
Sandbags
See note 6
SECTION C-C
Sandbag barrier
Toe of slope
CROSS BARRIER DETAIL

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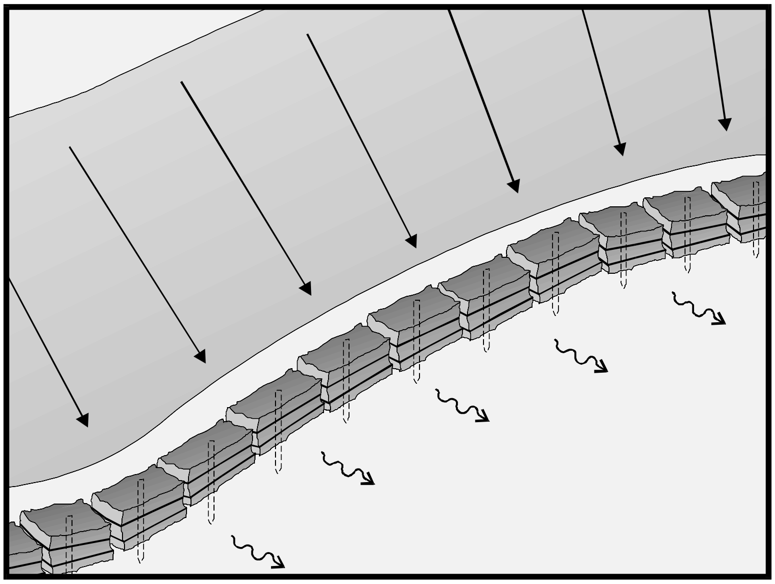
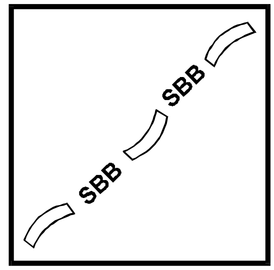
Straw Bale Barrier





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A straw bale barrier is a temporary linear sediment barrier consisting of straw bales, designed to intercept and slow sediment-laden sheet flow runoff. Straw bale barriers allow sediment to settle from runoff before water leaves the construction site.

Appropriate Applications

- This BMP may be implemented on a project-by-project basis in addition to other BMPs when determined necessary and feasible by the Contractor or Engineer.
- Along the perimeter of a site.
- Along streams and channels.
- Below the toe of exposed and erodible slopes.
- Down slope of exposed soil areas.
- Around stockpiles.
- Across minor swales or ditches with small catchments.
- Around above grade type temporary concrete washouts (See BMP WM-8, "Concrete Waste Management").
- Parallel to a roadway to keep sediment off paved areas.

Limitations

- Installation can be labor intensive.
- Straw bale barriers are maintenance intensive.
- Degraded straw bales may fall apart when removed or left in place for extended periods.
- Shall not be used on paved surfaces.
- Shall not to be used for drain inlet protection or in areas of concentrated flow.
- May introduce undesirable non-native plants to the area or be an attractive food source for some animals (see Permits in Section 7-5 of the contract Special Provisions).

Standards and Specifications

Materials

- **Straw Bale Size**: Each straw bale shall be a minimum of 14 in. wide, 18 in. in height, 36 in. in length and shall have a minimum mass of 51 lb. The straw bale shall be composed entirely of vegetative matter, except for the binding material.
- **Bale Bindings**: Bales shall be bound by either steel wire, nylon or polypropylene string placed horizontally. Jute and cotton binding shall not be used. Baling wire shall be a minimum diameter of 14 gauge. Nylon or polypropylene string shall be approximately 12 gauge in diameter with a breaking strength of 80 lbs. force.
- **Stakes**: Wood stakes shall be commercial quality lumber of the size and shape shown on the plans. Each stake shall be free from decay, splits or cracks longer than the thickness of the stake, or other defects that would weaken the stakes and cause the stakes to be structurally unsuitable. Steel bar reinforcement shall be equal to a number four designation or greater. End protection shall be provided for any exposed bar reinforcement.

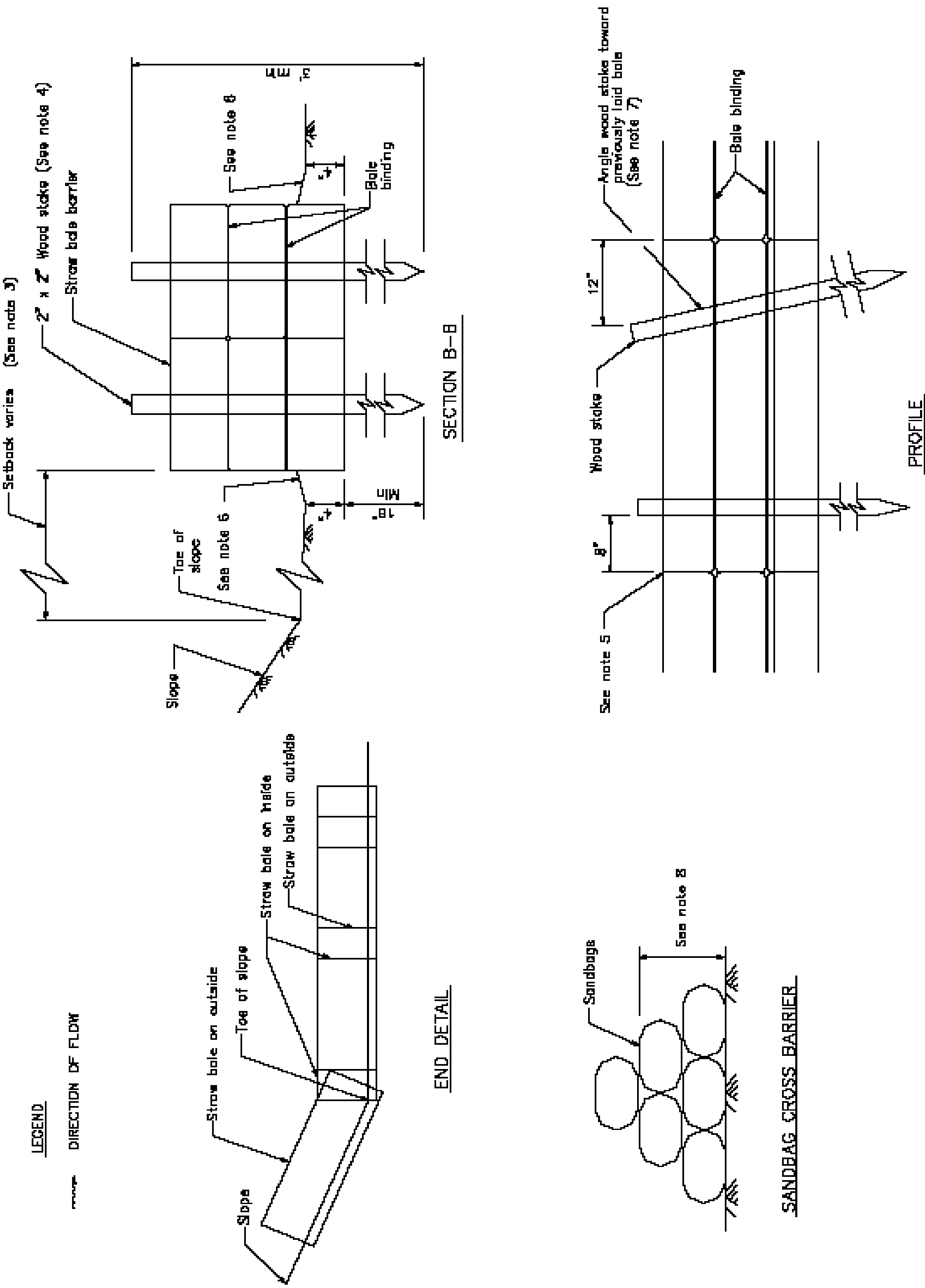
Installation

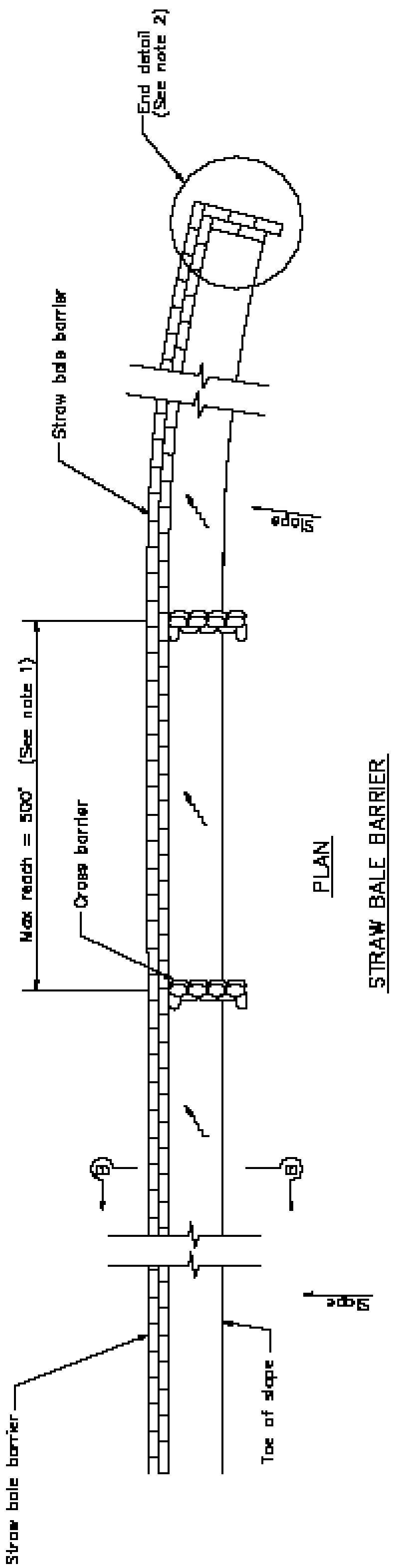
- Limit the drainage area upstream of the barrier to 0.25 ac/100ft of barrier.
- Limit the slope length draining to the straw bale barrier to 100 ft.
- Slopes of 2:100 (V:H) (2%) or flatter are preferred. If the slope exceeds 1:10 (V:H) (10%), the length of slope upstream of the barrier must be less than 50 ft.
- Install straw bale barriers along a level contour, with the last straw bale turned up slope.

- Straw bales must be installed in a trench and tightly abut adjacent bales.
- Install straw bale barriers with a set-back of at least 3 ft from the toe of a slope. Where it is determined to be not practical due to specific site conditions, the straw bale barrier may be constructed at the toe of the slope, but shall be constructed as far from the toe of the slope as practical.
- Install straw bale barriers per pages 4 and 5 of this BMP for installation detail.

Maintenance and Inspection

- Ensure that all perimeter controls are maintained and protected from activities that reduce their effectiveness.
- Inspect all straw bale barriers weekly and before and after every rainfall events. During extended rainfall events, inspect straw bale barriers at least once every 24 hours.
- Inspect straw bale barriers for sediment accumulations and remove sediment when depth reaches one-third the barrier height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of outside the right-of-way in conformance with all applicable laws and regulations.
- Replace or repair damage bales as needed or as directed by the Engineer.
- Repair washouts or other damages as needed or as directed by the Engineer.
- Remove straw bales when no longer needed. Remove sediment accumulation, and clean, re-grade, and stabilized the area.


Setback varies (See note 3)
2" x 2" Wood stake (See note 4)
Straw bale barrier
See note 6
Bale binding
3 m
Toe of slope
See note 6
18" Min
Slope
SECTION B-B
Angle wood stake toward previously laid bale (See note 7)
Bale binding
12"
Wood stake
8"
See note 5
PROFILE
LEGEND
DIRECTION OF FLOW
Straw bale on outside
Toe of slope
Straw bale on inside
Straw bale on outside
Slope
END DETAIL
Sandbags
See note 8
SANDBAG CROSS BARRIER



PLAN

STRAW BALE BARRIER

NOTES

1. Construct the length of each reach so that the change in base elevation along the reach does not exceed 1/2 the height of the linear barrier. In no case shall the reach length exceed 500'.
2. The end of barrier shall be turned up slope.
3. Dimension may vary to fit field condition.
4. Stake dimensions are nominal.
5. Place straw bales tightly together.
6. Tamp embedment spoils against sides of installed bales.
7. Drive angled wood stake before vertical stake to ensure tight abutment to adjacent bale.
8. Sandbag cross barriers should be a min of 1/2 and a max of 2/3 the height of the linear barrier.
9. Sandbag rows and layers should be offset to eliminate gaps.

LEGEND

DIRECTION OF FLOW

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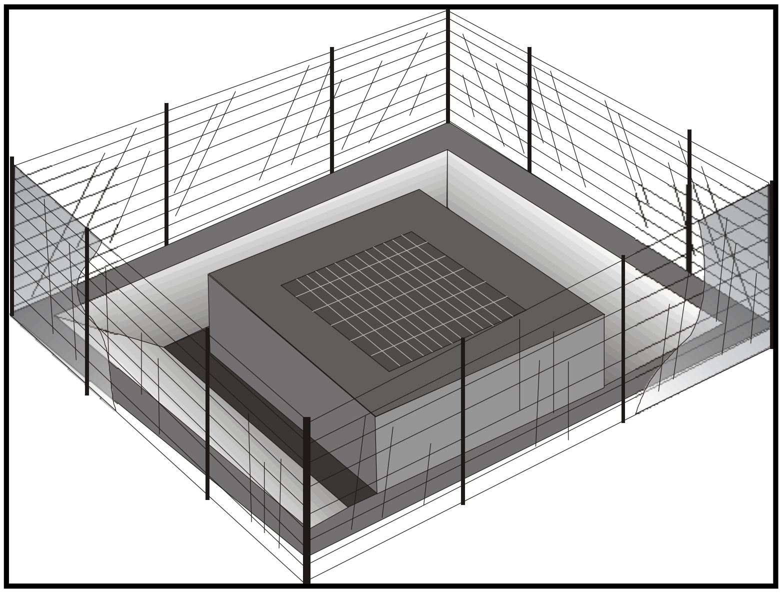
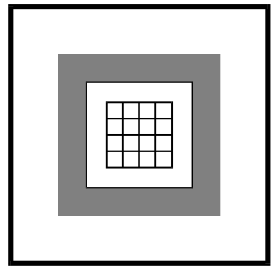
Storm Drain Inlet Protection

SC-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Storm drain inlet protection includes devices used at storm drain inlets that are subject to runoff from construction activities to detain and/or filter sediment-laden runoff to allow sediment to settle and/or to filter sediment prior to discharge into storm drainage systems or watercourses.

Appropriate Applications

- Where ponding will not encroach into roadway traffic.
- Where sediment laden surface runoff may enter an inlet.
- Where disturbed drainage areas have not yet been permanently stabilized.
- Required to be implemented on a year around basis.

Limitations

- Not a stand-alone BMP. Storm Drain Inlet Protection shall always be implemented with other erosion and sediment controls upgradient.
- Requires an adequate area for water to pond without encroaching upon traveled way and shall not be an obstacle to oncoming traffic.
- Other methods of temporary protection are required to prevent non-storm water discharges from entering the storm drain system.
- Sediment removal may be difficult in high flow conditions or if runoff is heavily sediment laden. If high flow conditions are expected, use other on-site sediment trapping techniques (e.g. check dams) in conjunction with inlet protection.
- For drainage areas larger than 1 ac, runoff shall be routed to a sediment trapping device designed for larger flows. See BMPs SC-2, “Sediment/Desilting Basin,” and SC-3 “Sediment Trap.”
- Filter fabric fence inlet protection is appropriate in open areas that are subject to sheet flow and for flows not exceeding 0.5 cfs.

- Gravel bag barriers for inlet protection are applicable when sheet flows or concentrated flows exceed 0.5 cfs, and it is necessary to allow for overtopping to prevent flooding.
- Fiber rolls and foam barriers are not appropriate for locations where they cannot be properly anchored to the surface.
- Excavated drop inlet sediment traps are appropriate where relatively heavy flows are expected and overflow capability is needed.

Standards and Specifications

Identify existing and/or planned storm drain inlets that have the potential to receive sediment-laden surface runoff. Determine which method to use.

Methods and Installation

- ***DI Protection Type 1 - Filter Fabric Fence -*** The filter fabric fence (Type 1) protection is illustrated on Page 5. It is similar to constructing a silt fence. See BMP SC-1, "Silt Fence." Do not place filter fabric underneath the inlet grate since the collected sediment may fall into the drain inlet when the fabric is removed or replaced.
- ***DI Protection Type 2 - Excavated Drop Inlet Sediment Trap -*** The excavated drop inlet sediment trap (Type 2) is illustrated in Page 6. It is similar to constructing a temporary silt fence, See BMP SC-1, "Silt Fence." Size excavated trap to provide a minimum storage capacity calculated at the rate of 67 yd^3/ac of drainage area.
- ***DI Protection Type 3 – Gravel bag -*** The gravel bag barrier (Type 3) is illustrated in Page 7. Flow from a severe storm shall not flow over the curb. In areas of high clay and silts, use filter fabric and gravel as additional filter media. Construct gravel bags in accordance with BMP SC-6, "Gravel Bag Berm." Gravel bags shall be used due to their high permeability.
- ***DI Protection Type 4 – Block and Gravel Filter – The block and gravel filter*** (Type 4) is placed around the inlet as illustrated in Page 8. Block and gravel filters are suitable for curb inlets commonly used in residential, commercial, and industrial construction. Engineer approval is required.
- ***DI Protection Type 5 – Foam Barriers and Fiber Rolls –*** Foam barrier or fiber roll (Type 5) is placed around the inlet and keyed and anchored to the surface. Foam barriers and fiber rolls are intended for use as inlet protection where the area around the inlet is unpaved and the foam barrier or fiber roll can be secured to the surface. Engineer approval is required.

Maintenance and Inspection

General

- Inspect all inlet protection devices weekly and before and after every rainfall events. During extended rainfall events, inspect inlet protection devices at least once every 24 hours.

- Ensure that all storm drain inlets are maintained and protected from activities that reduce their effectiveness.
- Remove all inlet protection devices within thirty days after the site is stabilized, or when the inlet protection is no longer needed.
  - Bring the disturbed area to final grade and smooth and compact it. Appropriately stabilize all bare areas around the inlet.
  - Clean and re-grade area around the inlet and clean the inside of the storm drain inlet as it must be free of sediment and debris.

Requirements by Method

- ***Type 1 - Filter Fabric Fence***

This method shall be used for drain inlets requiring protection in areas where finished grade is established and erosion control seeding has been applied or is pending.

  - Make sure the stakes are securely driven in the ground and are structurally sound (i.e., not bent, cracked, or splintered, and are reasonably perpendicular to the ground). Replace damaged stakes.
  - Replace or clean the fabric when the fabric becomes clogged with sediment. Make sure the fabric does not have any holes or tears. Repair or replace fabric as needed or as directed by the Engineer.
  - At a minimum, remove the sediment behind the fabric fence when accumulation reaches one-third the height of the fence or barrier height. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of outside the right-of-way in conformance with all applicable laws and regulations.

- ***Type 2 – Excavated Drop Inlet Sediment Trap***

This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas are subject to grading.

  - Remove sediment from basin when the volume of the basin has been reduced by one-third.

- ***Type 3 - Gravel Bag Barrier***

This method may be used for drain inlets surrounded by AC or paved surfaces.

  - Inspect bags for holes, gashes, and snags.
  - Check gravel bags for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier. Removed sediment shall be incorporated in the project at locations designated by the Engineer or disposed of in conformance with applicable laws and regulations.

■ ***Type 4 -Block and Gravel Filter***

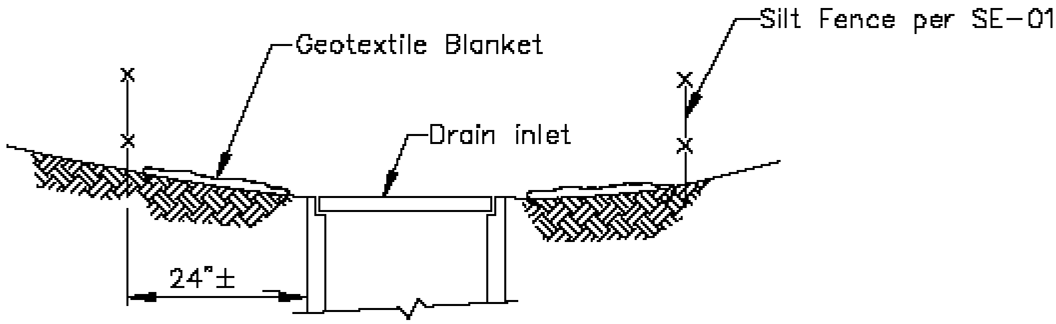
The block and gravel filter (Type 4) is shown in the figures. Block and gravel filters are suitable for curb inlets commonly used in residential, commercial, and industrial construction.

- Place hardware cloth or comparable wire mesh with 0.5 in. openings over the drop inlet so that the wire extends a minimum of 1 ft beyond each side of the inlet structure. If more than one strip is necessary, overlap the strips. Place filter fabric over the wire mesh.
- Place concrete blocks lengthwise on their sides in a single row around the perimeter of the inlet, so that the open ends face outward, not upward. The ends of adjacent blocks should abut. The height of the barrier can be varied, depending on design needs, by stacking combinations of blocks that are 4 in., 8 in., and 12 in. wide. The row of blocks should be at least 12 in. but no greater than 24 in. high.
- Place wire mesh over the outside vertical face (open end) of the concrete blocks to prevent stone from being washed through the blocks. Use hardware cloth or comparable wire mesh with 0.5 in. opening.
- Pile washed stone against the wire mesh to the top of the blocks. Use 0.75 to 3 in.

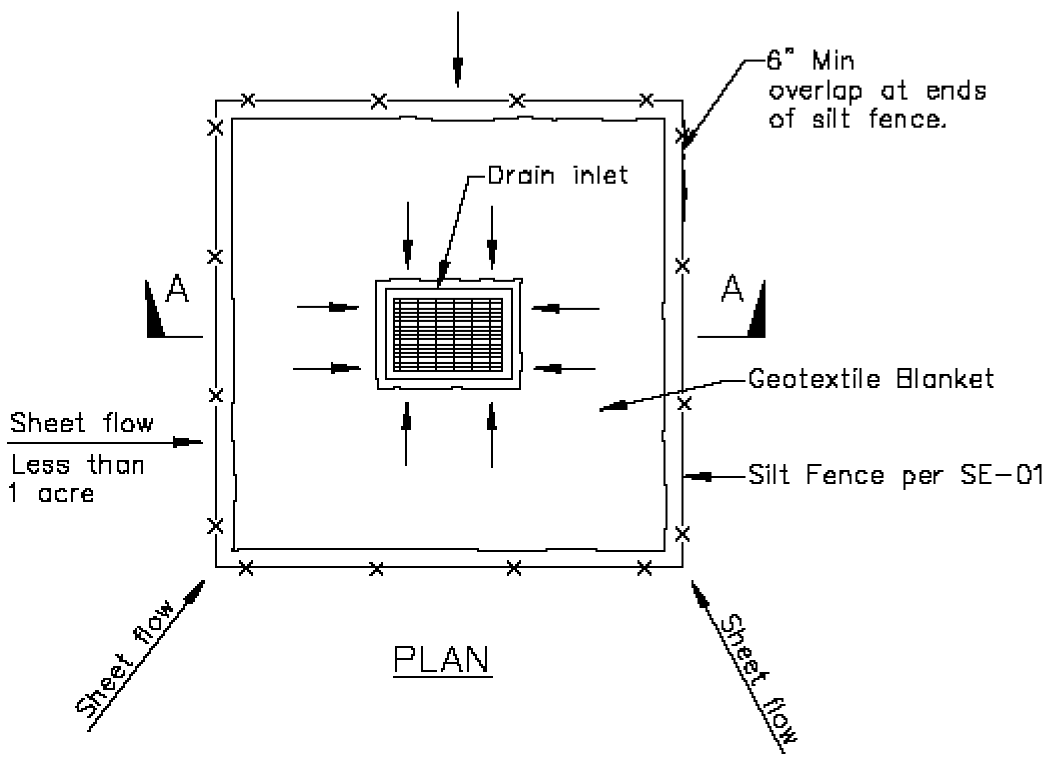
■ ***Type 5 Foam Barriers and Fiber Rolls***

This method may be used for drain inlets requiring protection in areas that have been cleared and grubbed, and where exposed soil areas subject to grading. Engineer approval is required.

- Check foam barrier or fiber roll for proper arrangement and displacement. Remove the sediment behind the barrier when it reaches one-third the height of the barrier. Removed sediment shall be incorporated in the construction site at locations designated by the Engineer or disposed of in conformance with all applicable laws and regulations.



SECTION A–A



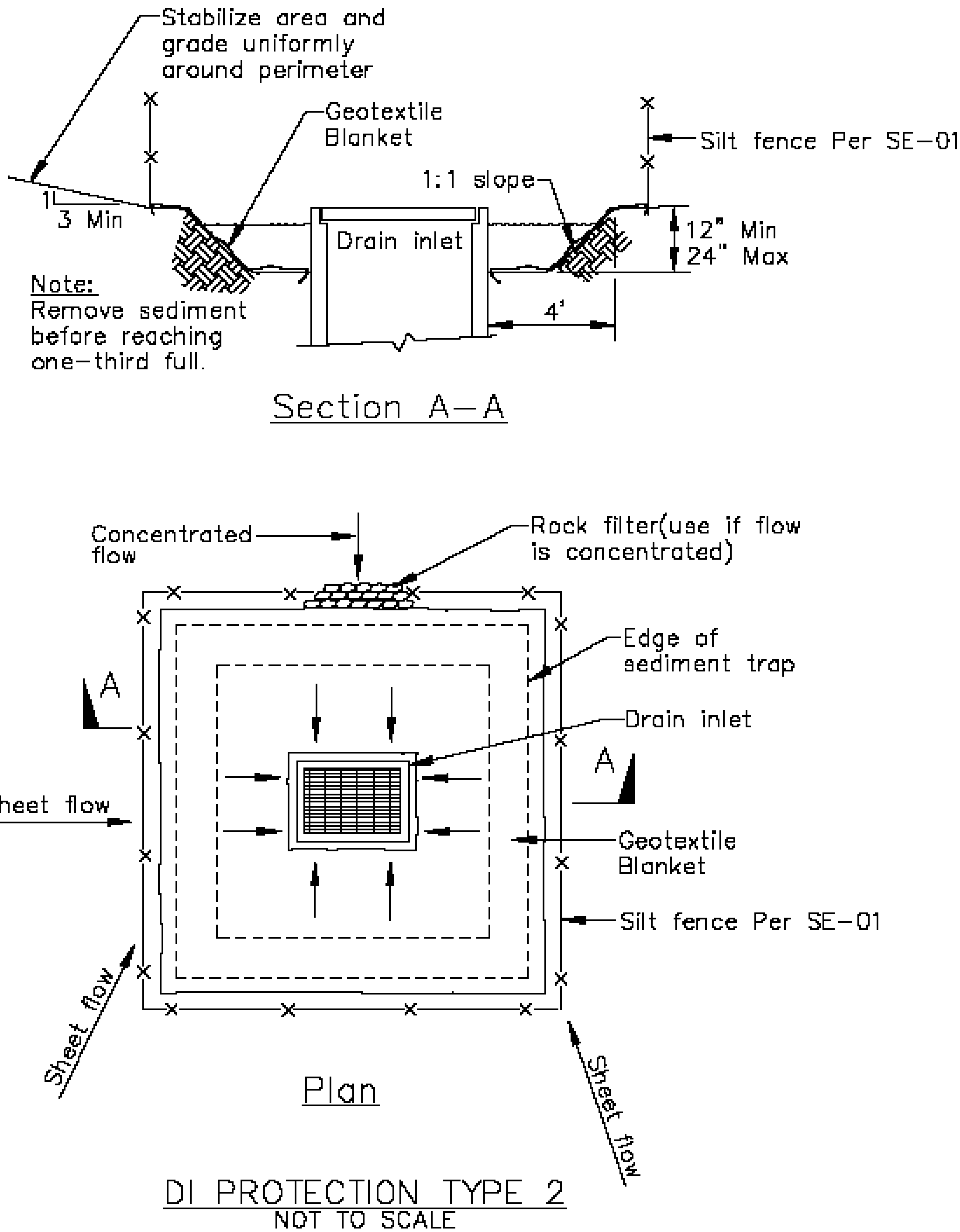
PLAN

DI PROTECTION TYPE 1
NOT TO SCALE

NOTES:

1. For use in areas where grading has been completed and final soil stabilization and seeding are pending.
2. Not applicable in paved areas.
3. Not applicable with concentrated flows.

Storm Drain Inlet Protection

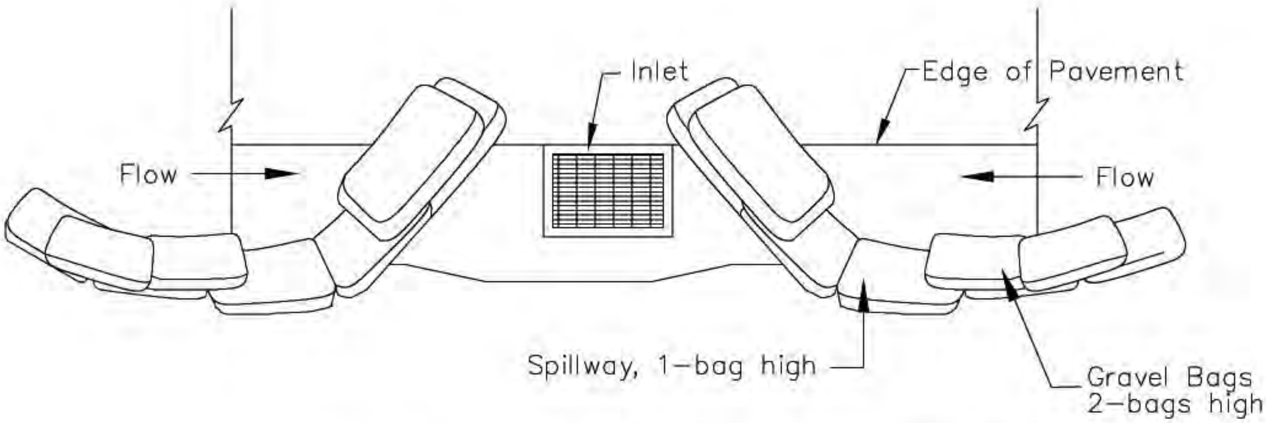


DI PROTECTION TYPE 2

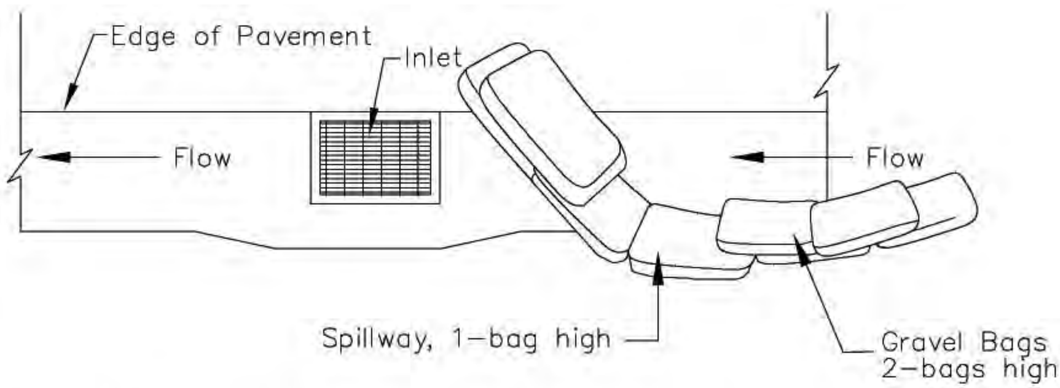
NOT TO SCALE

Notes

1. For use in cleared and grubbed and in graded areas.
2. Shape basin so that longest inflow area faces longest length of trap.
3. For concentrated flows, shape basin in 2:1 ratio with length oriented towards direction of flow.



TYPICAL PROTECTION FOR INLET WITH OPPOSING FLOW DIRECTIONS



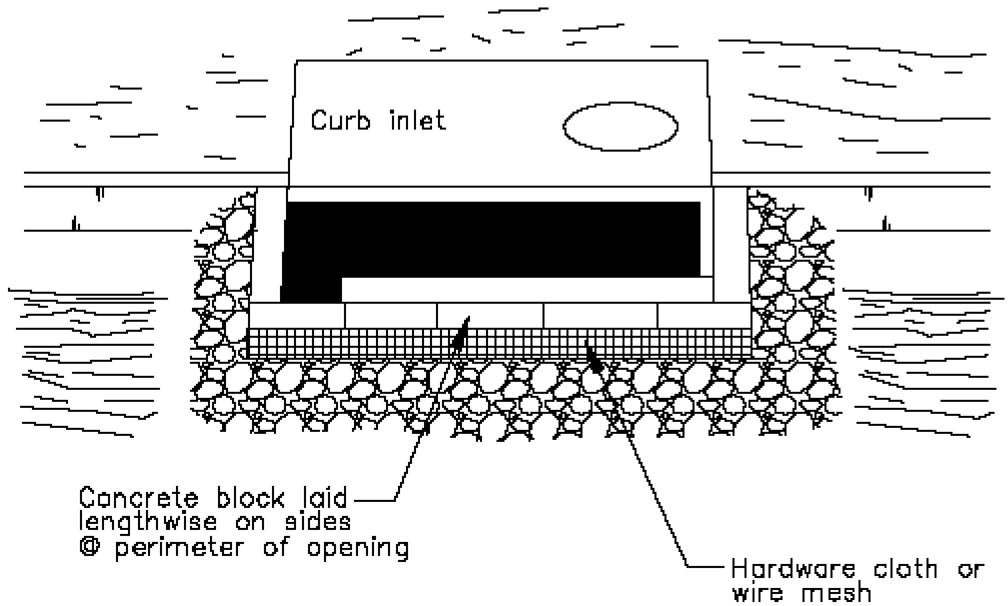
TYPICAL PROTECTION FOR INLET WITH SINGLE FLOW DIRECTION

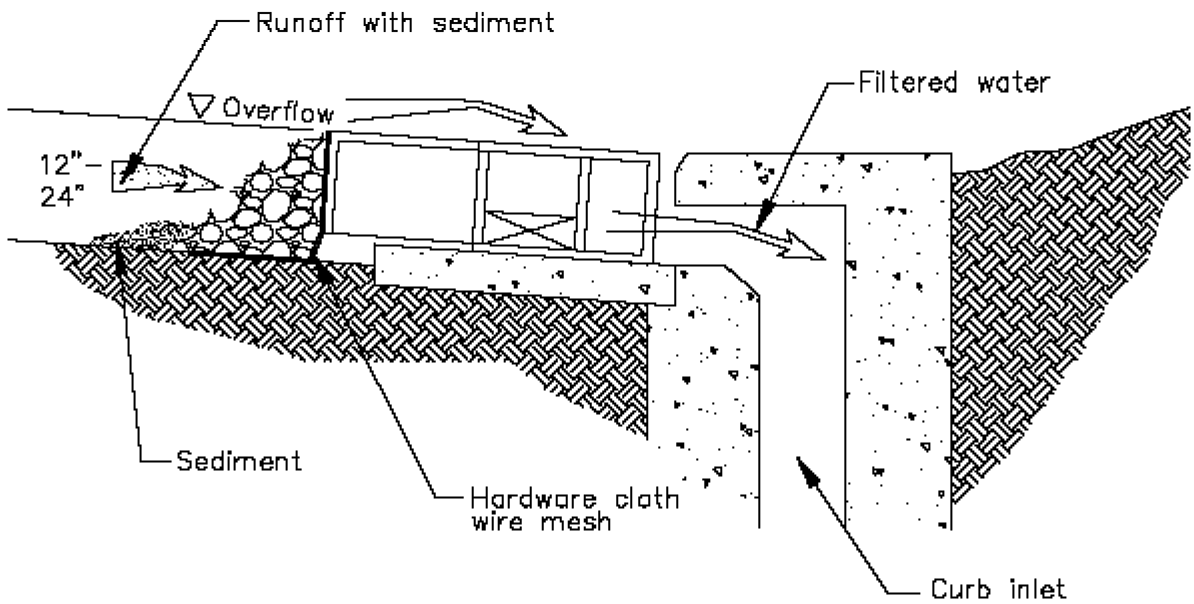
NOTES:

1. Intended for short-term use.
2. Use to inhibit non-storm water flow.
3. Allow for proper maintenance and cleanup.
4. Bags must be removed after adjacent operation is completed
5. Not applicable in areas with high silts and clays without filter fabric.

DI PROTECTION - TYPE 3

Not to scale





DI PROTECTION – TYPE 4

NOT TO SCALE

SECTION 5

WIND EROSION CONTROL BMPS

Wind erosion control consists of applying water or dust palliatives, covering or other control method approved by the Engineer to prevent or alleviate wind erosion, dust nuisance and prevent sediment from leaving the construction site. It is recognized that soil stabilization BMPs are also effective as wind erosion control (i.e., hydromulch, hydroseeding, soil binders, straw mulch, geotextiles, plastic covers, wind erosion control blankets/mats, wood mulch). Implementation of effective wind erosion controls is required. Wind erosion control BMPs are shown on Table5-1.

Table 5-1 Wind Erosion Control BMPs	
ID	**BMP Name**
WE-1	Wind Erosion Control

RB-AR33361

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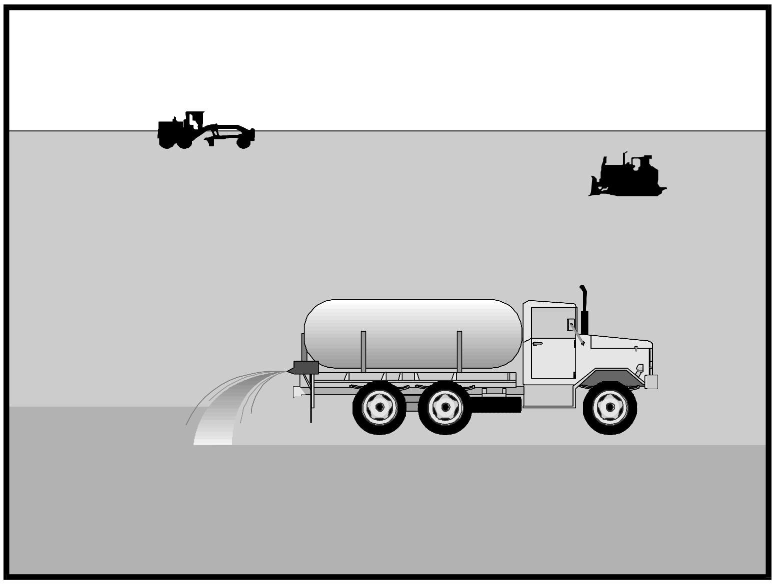
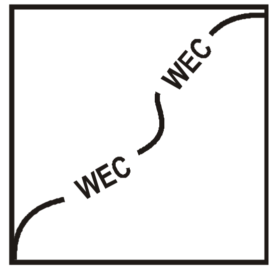
Wind Erosion Control

WE-1





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Wind erosion control consists of applying water and/or other dust palliatives as necessary to prevent or alleviate erosion by the forces of wind. Covering of all stockpiles is required year round.

Appropriate Applications

This practice is implemented on all exposed soils subject to wind erosion.

Standards and Specifications

- Effective wind erosion control shall be implemented.
- Implement good housekeeping measures on the construction site to control the air deposition of site materials and from site operations. Such particulates can include, but are not limited to, sediment, nutrients, trash, metals, bacteria, oil and grease and organics.
- Water shall be applied by means of pressure-type distributors or pipelines equipped with a spray system or hoses and nozzles that will ensure even distribution.
- All distribution equipment shall be equipped with a positive means of shutoff.
- Unless water is applied by means of pipelines, at least one mobile unit shall be available at all times to apply water or dust palliative to the project.
- If reclaimed water is used, the sources and discharge must meet California Department of Health Services water reclamation criteria and the Regional Water Quality Control Board requirements. Non-potable water shall not be conveyed in tanks or drain pipes that will be used to convey potable water and there shall be no connection between potable and non-potable supplies. Non-potable tanks, pipes and other conveyances shall be marked "NON-POTABLE WATER - DO NOT DRINK."
- Soil stabilization BMPs are also effective as wind erosion control (SS-3, SS-4, SS-5, SS-6, SS-7, and SS-8).

Maintenance and Inspection

- Inspect wind erosion control measures daily and document weekly.
- Check areas that have been protected to ensure coverage and effectiveness of Wind erosion controls. If wind erosion or dust are observed, Contractor shall immediately reapply or implement additional wind erosion control BMPs.

SECTION 6

TRACKING CONTROL BMPS

Tracking control consists of preventing or reducing vehicle and equipment tracking of sediment and other debris onto paved surfaces and preventing sediment from entering the storm drain system or watercourses. Sediment control for Street Sweeping and Vacuuming is also recognized as a tracking control BMP. However, street sweeping and vacuuming is not allowed as a stand-alone BMP for tracking control. Tracking control BMPs are shown on Table 6-1.

Table 6-1
Tracking Control BMPs

ID	BMP Name
TC-1	Stabilized Construction Entrance/Exit
TC-2	Stabilized Construction Roadway
TC-3	Entrance/Outlet Tire Wash

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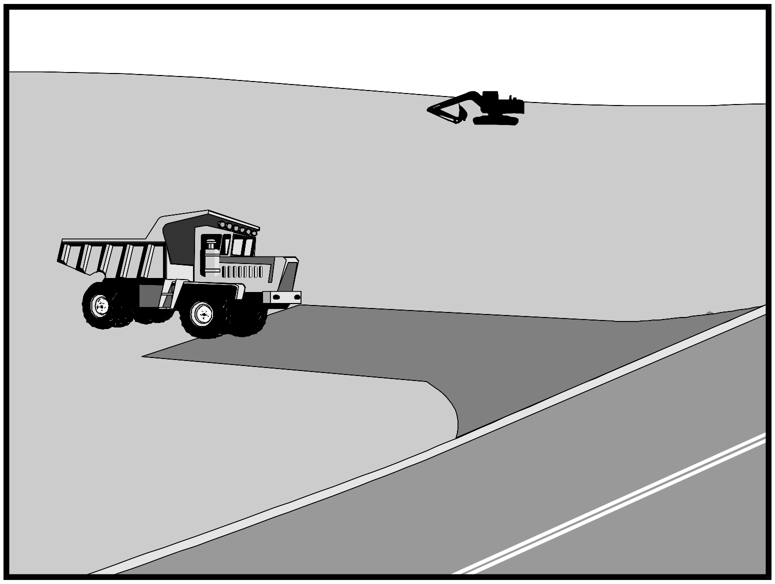
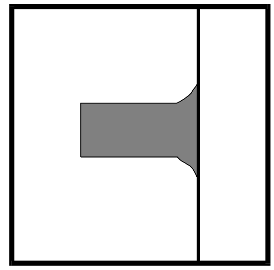
RB-AR33366

Stabilized Construction Entrance/Exit TC-1





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ● Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A stabilized construction access is defined by a point of entrance/exit to a construction site that is stabilized to reduce the tracking of mud and dirt onto all paved surfaces and paved private and public roads by construction vehicles.

Appropriate Applications

- Use at all construction sites:
  - Where dirt or mud can be tracked onto paved surfaces or paved private or public roads.
  - Adjacent to water bodies.
  - Where poor soils are encountered.
  - Where dust is a problem during dry weather conditions.
- This BMP shall be implemented on all construction sites.

Limitations

- None identified

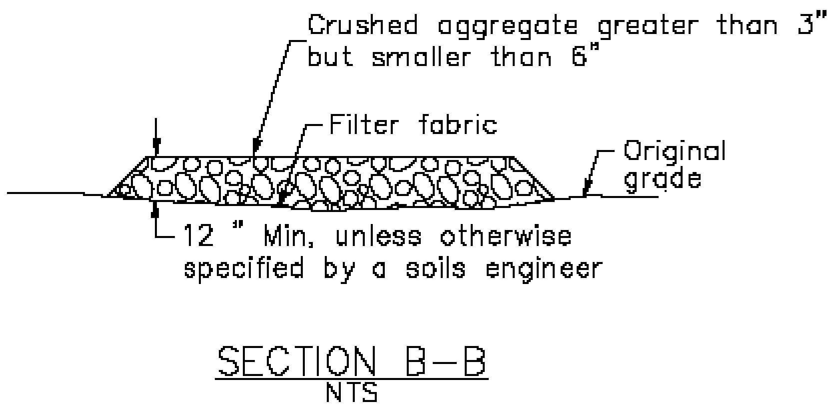
Standards and Specifications

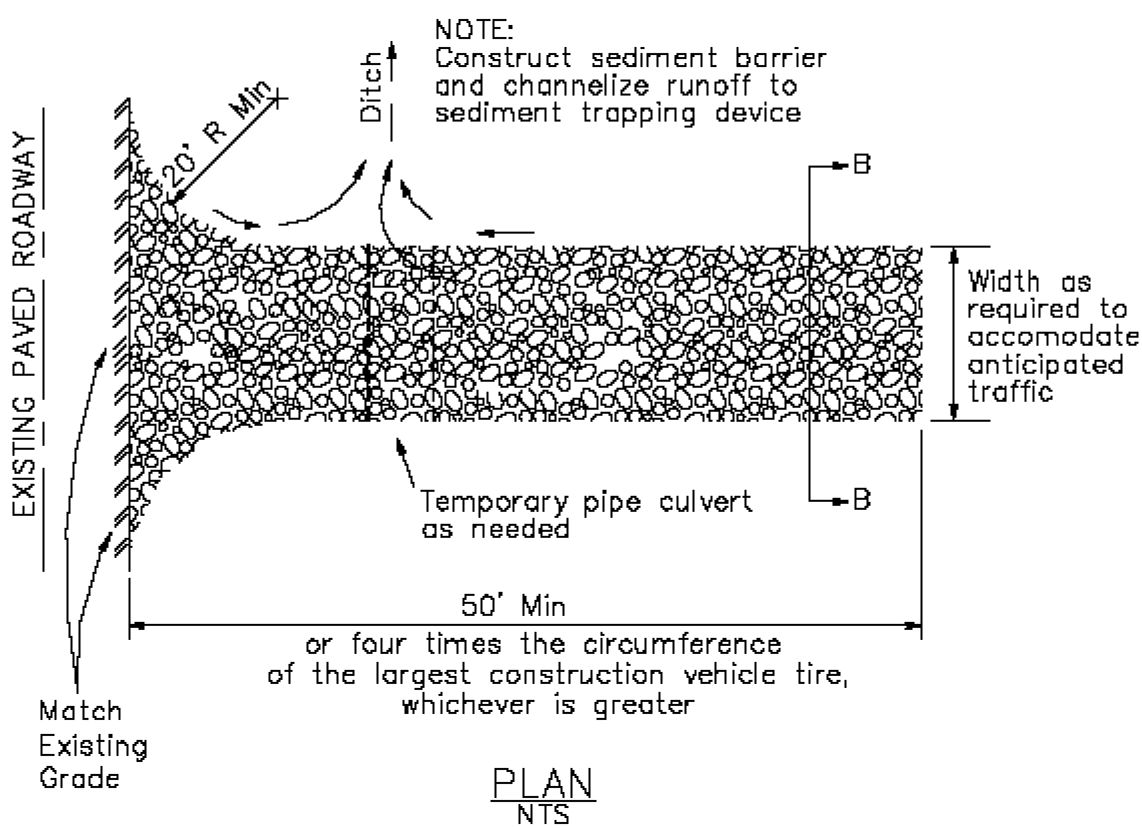
- Stabilize all construction entrances and exits to the construction site.
- Ensure that construction activity traffic to and from the project is limited to entrances and exits that employ effective controls to prevent offsite tracking of sediment.
- Prevent the off-site tracking of loose construction and landscape materials.
- Limit speed of vehicles to control dust.
- Properly grade each construction entrance/exit to prevent runoff from leaving the construction site.
- Route runoff from stabilized entrances/exits through a sediment-trapping device before discharge.

- Design stabilized entrance/exit to support the heaviest vehicles and equipment that will use it.
- Select construction access stabilization (aggregate, asphaltic concrete, concrete) based on longevity, required performance, and site conditions. The use of asphalt concrete (AC) grindings for stabilized construction access/roadway is not allowed.
- Use of constructed/manufactured steel plates with ribs for entrance/exit access is allowed with written approval from the Engineer.
- Place crushed aggregate over geotextile fabric to at least 12 in. depth, or place aggregate to a depth recommended by the Engineer. Crushed aggregate greater than 3 inches and smaller than 6 inches shall be used.
- Designate combination or single purpose entrances and exits to the construction site.
- Implement BMP SC-7, "Street Sweeping and Vacuuming" as needed and as required.
- Require all employees, subcontractors, and suppliers to utilize the stabilized construction access.

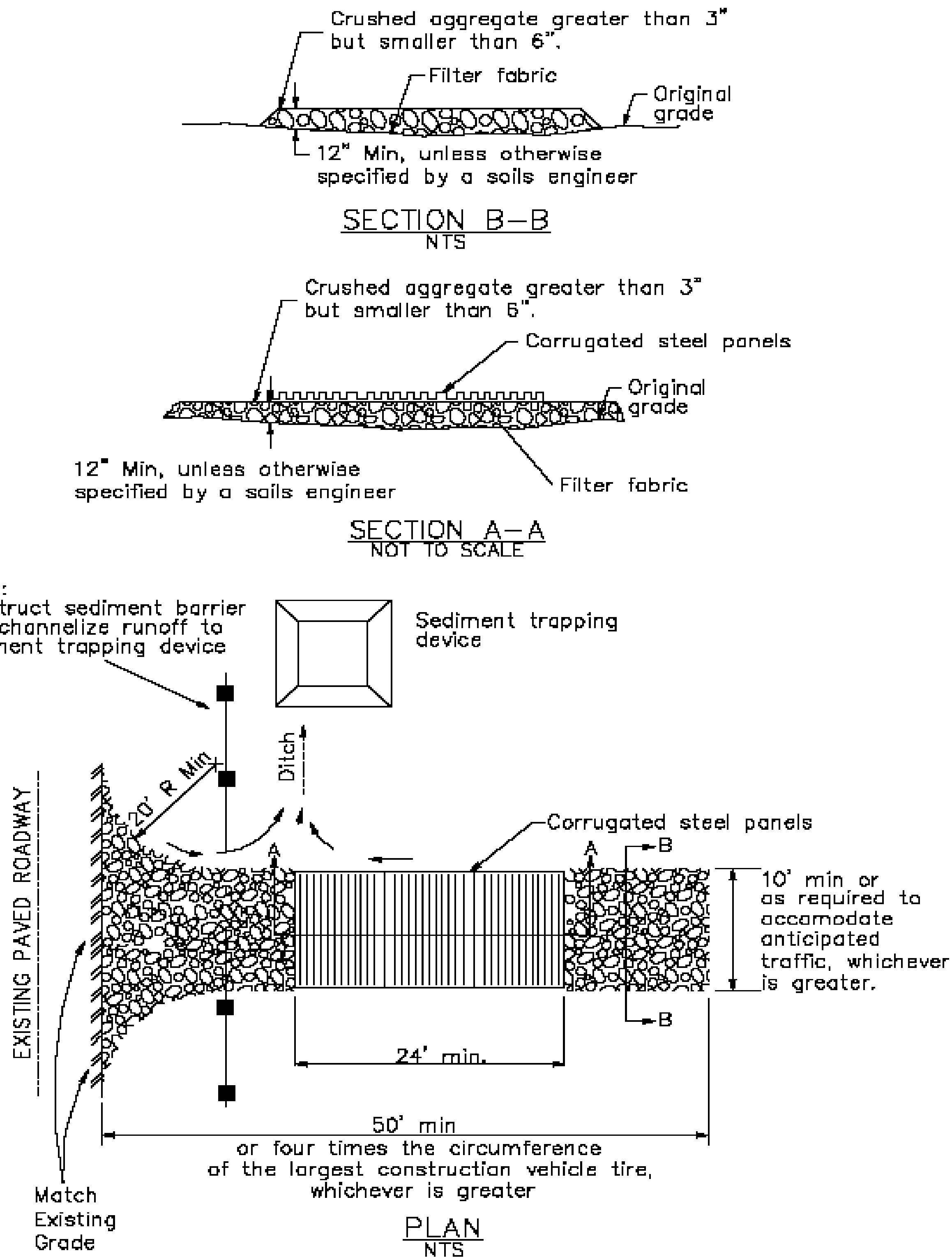
Maintenance and Inspection

- Ensure that all pollutant controls at entrances and exits are maintained and protected from activities that reduce their effectiveness.
- Inspect all entrances, exits, access roads daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect all entrances, exits, access roads at least once every 24 hours.
- Remove any sediment or other construction activity related materials that are deposited on the roads (by sweeping and vacuuming).
- Remove aggregate, separate and dispose of sediment if construction entrance/exit is clogged with sediment or as directed by the Engineer.





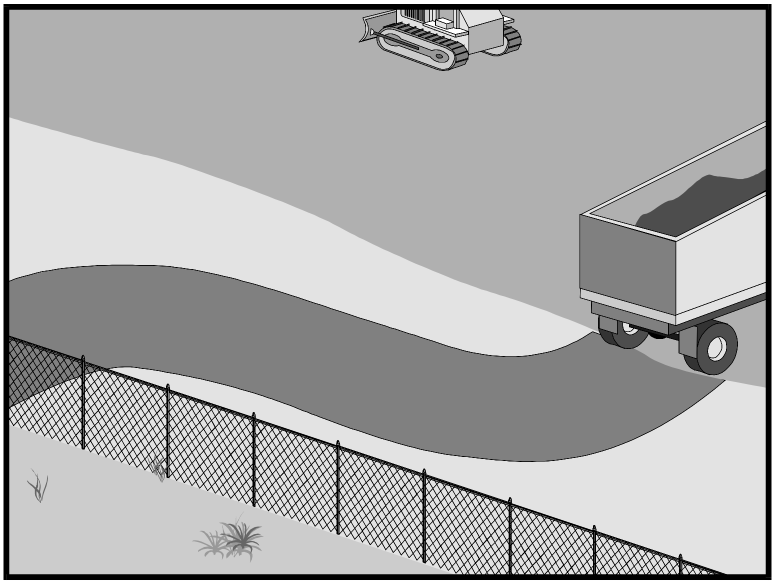
Stabilized Construction Entrance/Exit (Type 1)

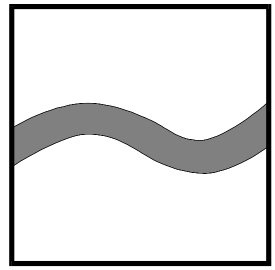


Stabilized Construction Entrance/Exit (Type 2)

Stabilized Construction Roadway

TC-2





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ● Tracking Control
- ● Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A stabilized construction roadway is a temporary access road. It is designed for the control of dust and erosion created by vehicular tracking.

Appropriate Applications

- Construction roadways and short-term detour roads:
  - Where tracking is a problem.
  - Where dust is a problem.
  - Adjacent to water bodies.
  - Where poor soils are encountered.
  - Where there are steep grades and additional traction is needed.

Limitations

None identified.

Standards and Specifications

- Properly grade roadway to prevent runoff from leaving the construction site.
- Install NS-4 Temporary Stream Crossing as directed by the Engineer.
- Design stabilized access to support the heaviest vehicles and equipment that will use it.
- Stabilize roadway using aggregate, asphalt concrete, or concrete based on longevity, required performance, and site conditions. The use of cold mix asphalt or asphalt concrete (AC) grindings for stabilized construction roadway is not allowed.
- If aggregate is selected, place crushed aggregate over geotextile fabric to at least 12 in. depth, or place aggregate to a depth recommended by the Engineer. Crushed aggregate greater than 3 inches and smaller than 6 inches shall be used.

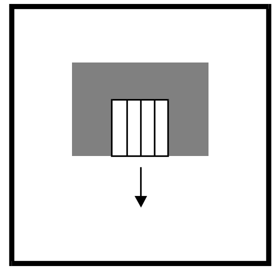
- Properly grade roadway to prevent runoff from leaving the construction site.
- Limit speed of vehicles to control dust or as directed by the Engineer.
- Coordinate materials with those used for stabilized construction entrance/exit points.

Maintenance and Inspection

- Inspect stabilized construction roadways weekly and before and after every rainfall events. During extended rainfall events, inspect stabilized construction roadways at least once every 24 hours.
- Keep all temporary roadway ditches clear.
- When no longer required, remove stabilized construction roadway and re-grade and repair slopes.

Entrance/Outlet Tire Wash

TC-3



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ● Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A tire wash is an area located at stabilized construction access points to remove sediment tires and undercarriages, and to prevent sediment from being transported onto paved roadways.

Appropriate Applications

- Tire washes may be used on construction sites where dirt and mud tracking onto paved roads by construction vehicles may occur.
- This BMP may be implemented on a project-by-project basis with other BMPs when determined necessary and feasible by the contract special provisions or Engineer.

Limitations

- Requires a supply of wash water.
- The waste water shall not be disposed of onsite.

Standards and Specifications

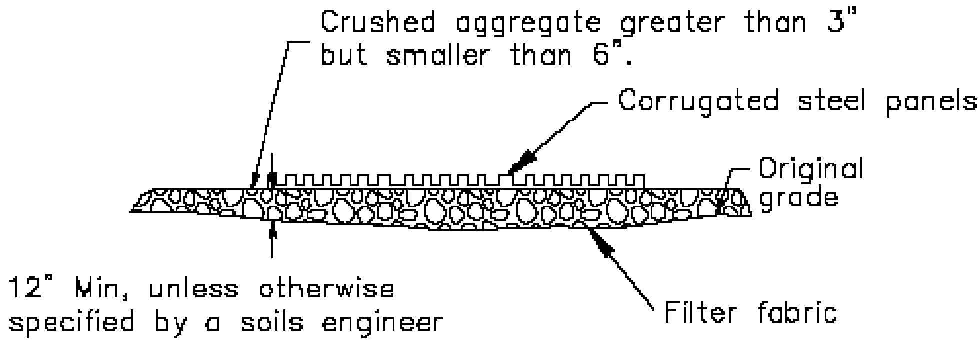
- Incorporate with a stabilized construction entrance/exit. See BMP TC-1, “Stabilized Construction Entrance/Exit” and BMP SC-7, “Street Sweeping and Vacuuming”
- Pre-constructed tire wash systems are available for purchase or lease.
- Construct on level ground when possible, on a pad of coarse aggregate, greater than 3 inches and smaller than 6 inches. A geotextile fabric shall be placed below the aggregate.
- The tire wash shall be designed and constructed/manufactured for anticipated traffic loads.
- The tire wash shall be activated automatically upon vehicle’s approach.

- Tire Wash shall remove all dirt/mud and debris from the tires and tire-grooves, wheel wells and undercarriages of the vehicles.
- The water recycling system shall be capable of processing the water to sufficiently remove mud/silt and debris for re-use. The water shall be replaced as needed or as directed by the engineer.
- The tire wash shall perform so that no visible mud/silt or debris, dried or wet, is observed on the paved road after the tire wash.
- The tire was shall perform so that no visible mud/silt and debris is observed on the truck tires or the undercarriage of the trucks after the tire wash
- Require all employees, subcontractors, and others that leave the site to use the wash facility.
- Implement BMP SC-7, "Street Sweeping and Vacuuming".

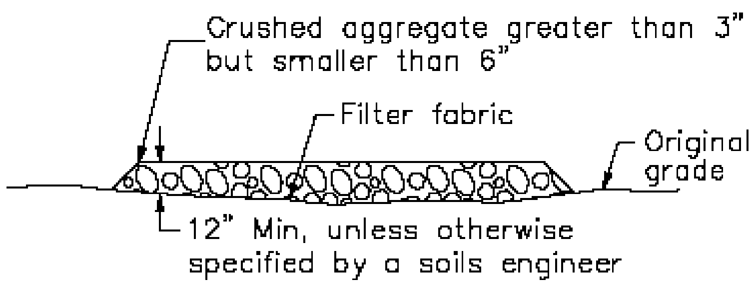
Maintenance and Inspection

- Inspect tire wash weekly and before and after every rainfall events. During extended rainfall events, inspect tire wash at least once every 24 hours.
- Ensure that all pollutant controls at entrances and exits (e.g. tire wash off locations) are maintained and protected from activities that reduce their effectiveness.
- Remove accumulated sediment in wash rack and/or sediment trap to maintain system performance.

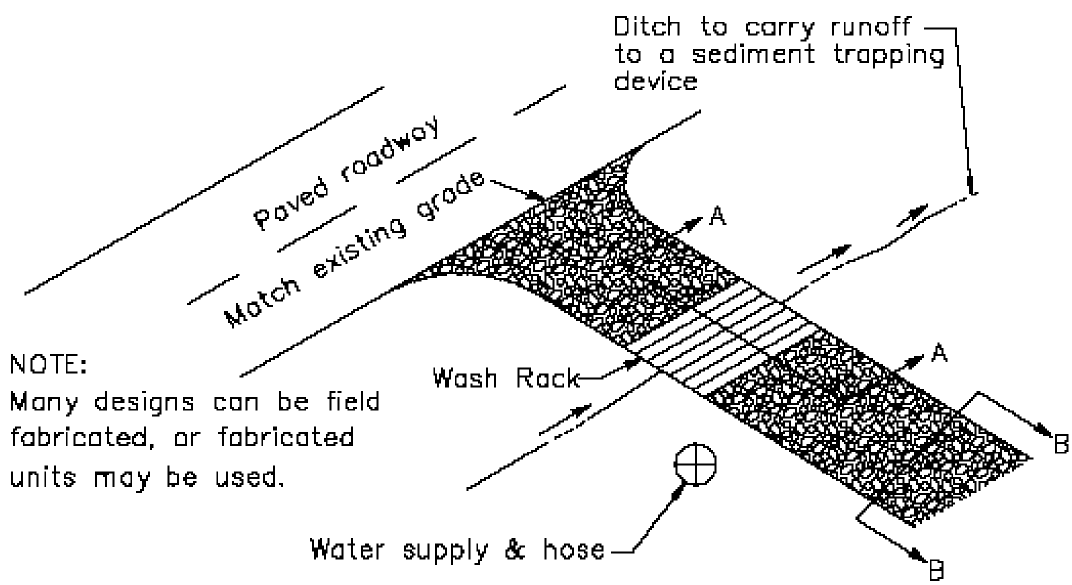
Entrance/Outlet Tire Wash



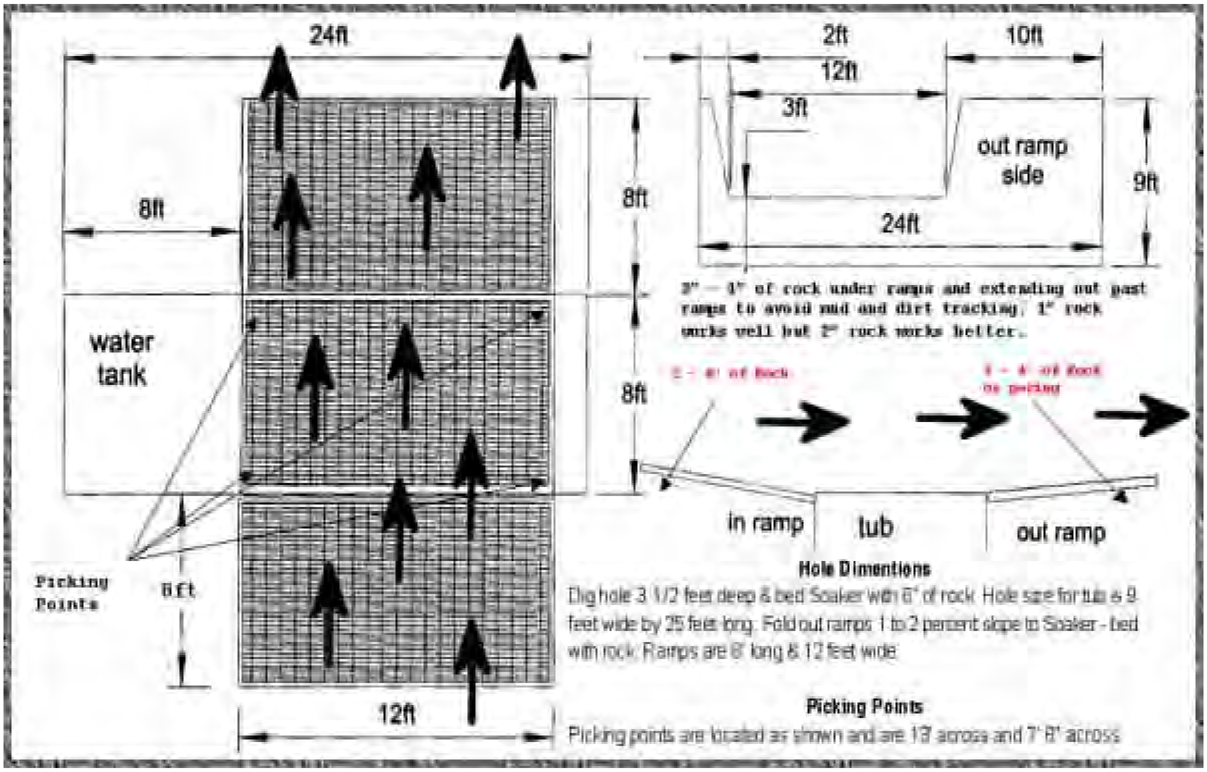
SECTION A–A
NOT TO SCALE



SECTION B–B
NTS



TYPICAL TIRE WASH
NOT TO SCALE



Example Self-Contained Tire Washing System

SECTION 7

NON-STORM WATER MANAGEMENT BMPS

The discharge of materials other than storm water and authorized non-storm water discharges are prohibited. Non-storm water management BMPs are source control BMPs that prevent pollution by limiting or preventing potential pollutants at the source, eliminating onsite and off-site discharge and discharge the ground. These non-storm water management BMPs are also referred to as “good housekeeping practices” which involve day-to-day operations of the construction site and contractor’s yard in order to maintain a clean, orderly, and safe construction site. Non-storm water management BMPs are shown on Table 7-1.

Table 7-1
Non-Storm Water Management BMPs

ID	BMP Name
NS-1	Water Conservation Practices
NS-2	Dewatering Operations (see Section 7.1 and 7.2)
NS-3	Paving and Grinding Operations
NS-4	Temporary Stream Crossing
NS-5	Clear Water Diversion
NS-6	Illicit Connection/Illegal Discharge Detection and Reporting
NS-7	Potable Water/Irrigation
NS-8	Vehicle and Equipment Cleaning
NS-9	Vehicle and Equipment Fueling
NS-10	Vehicle and Equipment Maintenance
NS-11	Pile Driving Operations
NS-12	Concrete Curing
NS-13	Material and Equipment Use Over Water
NS-14	Concrete Finishing
NS-15	Structure Demolition/Removal Over or Adjacent to Waters
NS-16	Temporary Batch Plant

7.1 Construction Dewatering

All construction groundwater dewatering shall be in full compliance with the Monitoring and Reporting Program and Waste Discharge Requirements (WDR) of the NPDES permit included in the contract Special Provisions, if applicable. All Contractor operations shall be in full compliance with all applicable laws and regulations that govern water quality.

If groundwater is encountered on the construction site and the contract Special Provisions do **not** include provisions for construction dewatering **and** an NPDES permit from the RWQCB, the Contractor shall immediately notify the Engineer for direction. No groundwater shall be discharged to the sanitary sewer system, street/gutter, ground or any other location, whether contaminated, treated, or not, until approved by the Engineer. A construction dewatering plan in accordance with contract Special Provisions and NPDES Permit issued by the RWQCB, must be submitted to the Engineer for approval, prior to any dewatering discharge.

7.2 Accumulated Precipitation

Accumulated precipitation can be water from rain or snow melt. Accumulated precipitation on the construction site shall be managed in order to minimize the discharge of pollutants (mainly sediment) from entering the storm drain system.

The Contractor shall submit an Accumulated Precipitation Procedure (APP) detailing methods and procedures for management and discharge of accumulated precipitation on the construction site (contract Special Provisions 7-8.6). The APP shall include a description of: treatment technologies/BMPs, equipment, and discharge locations. The APP shall describe other pertinent information including: areas expected to accumulate precipitation, BMPs to protect accumulated precipitation from becoming sediment laden, inspection of accumulated precipitation prior to discharge, notification to the Engineer before any discharge of precipitation, options for not discharging precipitation, inspection, maintenance and repair procedures, and APP amendments.

If a SWPPP is required for the project per the contract Special Provisions (7-8.6.3), the APP shall be included in Attachment K of the SWPPP. If a SWPPP is not required per the contract Special Provisions, the Contractor shall prepare an APP and submit it to the Engineer separately in accordance with contract Special Provision Section 7-8.6.2.

The Contractor shall follow the procedures identified in NS-2 Dewatering Operations BMPs for the treatment of accumulated precipitation. The controls identified in BMP NS-2 Dewatering Operations are for sediment only. If the accumulated precipitation is determined or suspected to have come into contact with any pollutants other than sediment, the Contactor shall not discharge or immediately terminate discharge, and notify the Engineer for direction.

Accumulated precipitation that has been mixed with groundwater shall be managed as groundwater (see Section 7.1 Construction Dewatering). Accumulated precipitation, that has been mixed with non-storm water, shall be managed the same as the non-storm water in accordance with WM-10 Liquid Waste Management BMPs.

See the following example for a SWPPP project. After the example, see the required text for preparation of an APP for all projects.

EXAMPLE: (for SWPPP Project)

Accumulated Precipitation Procedure (APP)

Project Name: ______________________________

Project ID/ID Number: ______________________________

☒SWPPP required for this project ☐SWPPP not required for this project

This project may accumulate precipitation due to low lying areas, planned excavations or other construction-related water trapping equipment or materials. No accumulated water will be discharged without implementing this accumulated precipitation procedure (APP).

Areas Expected to Trap Precipitation

The planned excavation areas for this project include the roadway areas, parking lots, alleys, sidewalks and roadway medians where the existing asphalt concrete will be removed and where the shoulder will be excavated for roadway widening. The project plans and water pollution control drawings (WPCDs) in the SWPPP show the areas that will be excavated. No other areas are expected to accumulate significant precipitation on the project when it rains. If other areas are observed to accumulate precipitation, they will be added by amending this APP.

BMPs Selected to Protect Accumulated Precipitation

To keep accumulated rainwater in the excavated areas from becoming laden with sediment, the excavated areas will be protected with erosion and sediment control BMPs as described in Section 500.4.1 and 500.4.2 of the SWPPP. A sand bag barrier will be placed along the edge of the shoulder where the shoulder meets the existing vegetation that will be preserved during construction. The excavated areas will be provided with compacted base in accordance with the contract plans and specifications as much as possible 24 hours before a 50% or more chance of rain. Plastic sheeting will be kept on hand to further protect areas where compacted base cannot be placed prior to a rain event. At no time will more than an acre of exposed soil be allowed when there is a 50% chance of rain. If it begins raining, the remaining exposed soil will be covered with plastic to prevent erosion. The potential flows along the length of the roadway will be checked using check dams. The combination of compacted base, plastic sheeting, check dams and sandbag barriers should provide and effective erosion and sediment control prior to rainwater entering the storm drain system. Drain inlets will also be protected during construction using the storm drain inlet BMPs described in Section 500.4.2 of the SWPPP. In addition, during the roadway paving and removal of existing materials, drain inlets will be covered when rain is not expected using filter fabric and sand bags as described in Section 500.4.6 of the SWPPP, BMP NS-3 and as shown in WPCD 14 of the SWPPP (drain inlet cover detail). Note: SC-10 drain inlet protection is not adequate for non-storm water discharges such as paving.

Option(s) for not Discharging Accumulated Precipitation

If less than 3,000 gallons of water is accumulated (standard size of water truck tank), the water may be pumped into the water truck on site and used for dust control in accordance with BMP WE-1 as described in Section 500.4.4 of the SWPPP. The accumulated precipitation may be pumped to a tank if it is determined to be feasible by the contractor. The stored water will be used for dust control or will be disposed of properly offsite.

Inspection Prior to Discharge

After a precipitation event, water that is trapped in the excavation may need to be discharged to continue construction. The water will be inspected to determine whether it has come into contact with any other pollutants (e.g., spilled fuel) prior to discharge. If other pollutants are suspected, the water will be handled in accordance with BMP WM-10 liquid waste management for disposal off site.

Discharge BMPs and Location(s)

If sediment is the only potential pollutant, the water will be discharged through a gravity bag filter (See attached typical construction drawing and specifications). The accumulated rainwater will be pumped through a non-woven geotextile fabric that collects sand, silt and fines as described in BMP NS-2. The pump will be selected to match the flow capacity of the gravity bag filter in accordance with the manufacturer's specifications. The sediment particle size, the available pore sizes of the filter material and the expected flow rates will be considered when selecting the proper pump and filter bag. The bag may need to be cleaned frequently if there is clogging. The bag material (pore size) or pump may need to be changed to address clogs, bursts or other problems. The manufacturer's specifications are attached to this APP. The actual size of the gravity bag filter, and pump will be determined after the rain event and will coincide with the amount of water trapped.

The gravity bag filter will be located on a paved area as shown on WPCD 4 of the SWPPP, where the additional water will not result in erosion. The flow path from the gravity bag filter to the storm drain inlet will be inspected and cleaned as necessary to prevent transfer of pollutants to the storm drain system. The gravity bag filter will be placed on a bed of clean gravel 0.4 to 0.8 inch in diameter that will extend outside the bag at least 6 inches on all sides.

Notification

The Engineer will be informed prior to each discharge of accumulated precipitation even though this procedure is followed.

Sampling and Analysis

The discharge of accumulated precipitation will be sampled and analyzed in accordance with the sampling and analysis plan in the SWPPP Section 600.2.

EXAMPLE

Inspection, Maintenance and Repair
The gravity bag filter will be monitored hourly during discharge events. The flow, bag condition, bag capacity and secondary gravel barrier will be inspected for adequate function. If the discharge treatment system is not functioning adequately, the discharge will be stopped immediately. The gravity bag filter will be maintained and repaired as necessary for adequate function. If necessary the treatment method will be modified and a revised APP will be submitted to the Engineer for Approval prior to discharge.

Joe Control

September 26, 2007

Contractor's QSP or BMP Manager Signature

Date

Joe Control/ QSP

(800) 123-4567

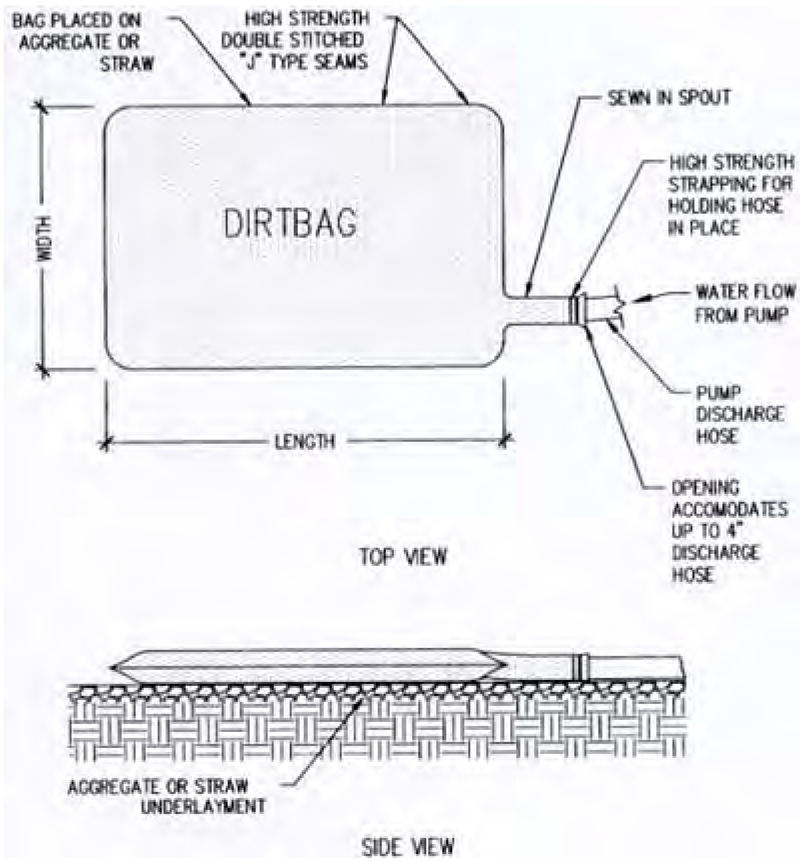
Contractor's QSP or BMP Manager Name and Title

Telephone Number

EXAMPLE

DIRTBAG®

Typical Construction:



Dirtbag® Specification:
Control of Sediment In Pumped Water

1.0 **Description**

1.1 This work shall consist of furnishing, placing and removing Dirtbag® pumped sediment control device as directed by the design enginer or as shown on the contract drawings. Dirtbag® pumped-silt control system is marketed by The BMP Store.

2.0 **Materials**

2.1 Dirtbag®

2.1.1 Dirtbag® shall be manufactured using a polypropylene nonwoven geotextile from SI Geosolutions, then sewn into a bag with a double needle matching using a high strength thread.

2.1.2 Each standard Dirtbag® has a fill spout large enough to accommodate a 4" discharge hose. Straps are attached to secure the hose and prevent pumped water from escaping without being filtered.

2.1.3 Dirtbag® seams shall have an average wide width strength per ASTM D-4884 as follows:

EXAMPLE

Dirtbag® Style	Test Method	Test Method
Dirtbag® 53	ASTM D-4884	60 lbs./in
Dirtbag® 55	ASTM D-4884	100 lbs./in

Property	Test Method	Units	Test Results Style 53	Style 55
Weight	ASTM D-3776	oz/yd	8	10
Grab Tensile	ASTM D-4632	lbs.	205	250
Puncture	ASTM D-4833	lbs.	110	150
Flow Rate	ASTM D-4491	gal/min/ft²	110	85
Permittivity	ASTM D-4491	sec.⁻¹	1.5	1.2
Mullen Burst	ASTM D-3786	lbs. in²	350	460
UV Resistant	ASTM D-4355	%	70	70
AOS % Retained	ASTM D-4751	US Sieve	80	100

All properties are Minimum Average Roll Value (MARV) except the weight of the fabric which is given for information only. Depending on soil conditions and filtration requirements, additional geotextile options are available. Please call our engineering staff for solutions.

3.0 **Construction Sequence**

3.1.1 To install Dirtbag® on a slope so incoming water flows downhill through Dirtbag® without creating more erosion. Strap the neck of Dirtbag® tightly to the discharge hose. To increase the efficiency of filtration, place the bag on an aggregate or haybale bed to maximize water flow through the surface area of the bag.

3.1.2 Dirtbag® is full when it no longer can efficiently filter sediment or allow water to pass at a reasonable rate. Flow rates will vary depending on the size of Dirtbag®, the type and amount of sediment discharged into Dirtbag®, the type of ground, rock or other substance under the bag and the degree of the slope on which the bag lies. Under most circumstances Dirtbag® will accommodate flow rates of 1100 gallons per minute. Use of excessive flow rates or overfilling Dirtbag® with sediment will cause the bag to rupture or failure of the hose attachment straps.

3.1.3 Dispose Dirtbag® as directed by the site engineer. If allowed, Dirtbag® may be cut open and the contents seeded after removing visible fabric. Dirtbag® is strong enough to be lifted with optional straps if it must be hauled away. Off-site disposal may be facilitated by placing Dirtbag® in the back of a dump truck or flatbed prior to use and allowing the water to drain from the bag while in place, thereby eliminating the need to lift Dirtbag®.

4.0 **Basis of Payment**

4.1 The payment for any Dirtbag® used during construction is to be included in the bid of overall erosion and sediment control plan unless a unit price is requested.

REQUIRED TEXT: To be completed by Contractor for all projects if APP is required.

Accumulated Precipitation Procedure (APP)

Project Name: ____

Project ID/ID Number: ____

[Check appropriate box below based on contract Special Provisions Section 7-8.6.]

☐SWPPP required for this project ☐SWPPP not required for this project

This project may accumulate precipitation due to: **[Insert brief description of how precipitation may be trapped on site such as in low lying areas, planned excavations or other means where it may be necessary to discharge water to the storm drain system or water body.]**. No accumulated water will be discharged without implementing this accumulated precipitation procedure (APP).

Areas Expected to Trap Precipitation
[Describe in detail the areas that are expected to trap rain water on the construction site.]

BMPs Selected to Protect Accumulated Precipitation
[Describe BMPs that are selected for the project that will minimize sediment in accumulated precipitation, if any.]

Option(s) for not Discharging Accumulated Precipitation
[Describe options for not discharging accumulated precipitation offsite such as storing the water on site, infiltration, using the water for dust control or other method approved by the Engineer.]

Inspection Prior to Discharge
After a precipitation event, water that is trapped in the excavation may need to be discharged to continue construction. The water will be inspected to determine whether it has come into contact with any other pollutants (e.g., spilled fuel) prior to discharge. If other pollutants are suspected, the water will be handled in accordance with BMP WM-10 liquid waste management for disposal off site.

Discharge BMPs and Location(s)
If sediment is the only potential pollutant, the water will be **[Describe how NS-2 Dewatering Operations BMPs will be implemented including a description of the selected BMPs and equipment for minimizing sediment in the discharge. Describe the location of the BMPs and equipment to be used.] [Describe location(s) of the discharge such as to the gutter, drain inlet,**

water body, etc. Include BMPs for erosion control and velocity dissipation at the discharge point where erosion could occur.]

Notification

The Engineer will be informed prior to each discharge of accumulated precipitation even though this procedure is followed.

Sampling and Analysis

The discharge of accumulated precipitation will be sampled and analyzed in accordance with the sampling and analysis plan in the SWPPP Section 600.2. **[If the construction project does not require a SWPPP, delete this sampling and analysis section.]**

Inspection, Maintenance and Repair

The accumulated precipitation discharge and associated BMPs and equipment will be monitored hourly during discharge events. The flow, BMP conditions and potential for sediment in the flow path will be inspected. In the event the BMPs, equipment or flow path are not functioning adequately, the discharge will be stopped until the treatment system is maintained or repaired to function adequately. This may require a revision to this APP which will need to be approved by the Engineer.

__________________________________ __________________________

Contractor's QSP or BMP Manager Signature — Date

__________________________________ __________________________

Contractor's QSP or BMP Manager Name and Title — Telephone Number

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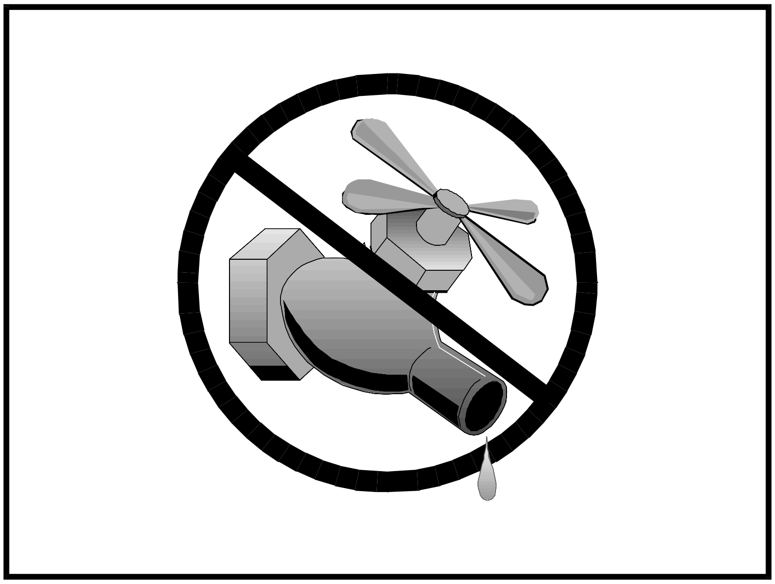
Water Conservation Practices

NS-1



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Water conservation practices are activities that use water during the construction of a project in a manner that avoids discharge to the ground or discharge causing erosion and/or the transport of pollutants off site.

Appropriate Applications

- Water conservation practices are implemented on all construction sites and wherever water is used.
- Applies to all construction projects.

Limitations

- None identified.

Standards and Specifications

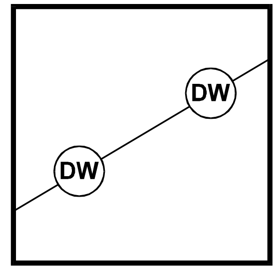
- Keep water equipment in good working condition.
- Stabilize water truck filling area.
- Repair water leaks immediately.
- Do not allow water to flow offsite or into storm drain system.
- Vehicles and equipment washing on the construction site is discouraged.
- Avoid using water to clean construction areas. Do not use water to clean pavement. Paved areas shall be swept and vacuumed.
- Direct construction water runoff to areas where it can infiltrate into the ground.
- Apply water for wind erosion control in accordance with WE-1 BMPs.
- Report discharges to Engineer immediately.

Maintenance and Inspection

- Inspect water conservation practices weekly and before and after every rainfall events. During extended rainfall events, inspect water conservation practices at least once every 24 hours.
- Repair water equipment as needed or as directed by the Engineer.

Dewatering Operations

NS-2



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Dewatering Operations are practices that manage the discharge of pollutants when non-storm water and accumulated precipitation (storm water) must be removed from a work location so that construction work may be accomplished.

Appropriate Applications

- These practices are implemented for discharges of non-storm water and storm water (accumulated rain water) from construction sites. Non-storm water includes, but is not limited to, dewatering of piles, water from cofferdams, water diversions, and water used during construction activities that must be removed from a work area.

- Practices identified in this section are also appropriate for implementation when managing the removal of accumulated precipitation (storm water) from a construction site.

- Storm water mixed with non-storm water shall be managed as non-storm water.

Limitations

- All construction groundwater dewatering shall be in full compliance with the contract special provisions and Monitoring and Reporting Program and Waste Discharge Requirements (WDR) of the NPDES permit included in the contract Special Provisions. All Contractor operations shall be in full compliance with all applicable laws and regulations that govern water quality.

- If groundwater is encountered on the construction site and the contract Special Provisions do **not** include provisions for construction dewatering, the Contractor shall immediately notify the Engineer for direction. No groundwater shall be discharged to the sanitary sewer system, street/gutter, or any other location, whether contaminated, treated, or not, without prior approval by the Engineer.

Dewatering Operations

Standards and Specifications

- Dewatering for accumulated precipitation (storm water) shall follow this BMP in accordance with the approved Accumulated Precipitation Procedure (APP) and use treatment measures specified herein (See example in Section 7.2).
- The Contractor shall submit an APP as part of the SWPPP detailing methods and procedures for management and discharge of accumulated precipitation on the construction site, including treatment technologies/BMPs, equipment, discharge locations, and all other pertinent information. If a SWPPP is not required per the contract Special Provisions, the Contractor shall prepare an APP and submit it to the Engineer separately.
- Sediment control and other appropriate BMPs. Implement SS-10 "Outlet Protection/Velocity Dissipation Devices" to prevent erosion at the discharge point.
- Discharges must comply with regional and watershed-specific discharge requirements.
- The controls discussed in this BMP address sediment only. If the presence of other pollutants is identified in the contract Special Provisions, the Contractor shall implement dewatering pollution controls as required by the contract Special Provisions.
- If other pollutants are identified or suspected in the water to be removed by dewatering, and are not identified in the contract Special Provisions, the contractor shall not discharge the water and immediately notify the Engineer.
- Reuse water on-site (such as dust control, compaction, etc) if approved by the Engineer.
- Treatment system shall be fenced to prevent unauthorized entry
- Additional permits or permissions from other agencies may be required for dewatering cofferdams or diversions.

Maintenance and Inspection

- Inspect dewatering operations daily and document weekly and before and after every rainfall events. During extended rainfall events, inspect paving and grinding operations at least once every 24 hours.
- Inspect all BMPs implemented to comply with permit requirements frequently and repair or replace BMPs to ensure they function as designed.
- Conduct water quality monitoring pursuant to the permit requirements of the contract Special Provisions. Documentation must be included in the SWPPP.
- Accumulated sediment that is commingled with other pollutants must be disposed of in accordance with all applicable laws and regulations and as approved by the Engineer.

Sediment Treatment

A variety of methods can be used to treat water during dewatering operations from the construction site. Several devices are presented in this section that provide options to achieve sediment removal. The size of particles present in the sediment and Permit or receiving water limitations on sediment are key considerations for selecting sediment treatment option(s); in some cases, the use of multiple devices may be appropriate. If a selected method or device does not adequately remove sediment, a different or additional method shall be implemented.

Category 1: Constructed Settling Technologies

The devices discussed in this category are to be used exclusively for dewatering operations only.

Sediment/Desilting Basin (SC-2)

A sediment/desilting basin is a temporary basin with a controlled release structure that is formed by excavation and/or construction of an embankment to detain sediment-laden runoff and allow sediment to settle out before discharging.

Appropriate Applications:

- Effective for the removal of trash, gravel, sand, and silt and some metals that settle out with the sediment.

Maintenance:

- Maintenance is required for safety fencing, vegetation, embankment, inlet and outfall structures, as well as other features.
- Removal of sediment is required when the storage volume is reduced by one-third.

Sediment Trap (SC-3)

A sediment trap is a temporary basin formed by excavation and/or construction of an earthen embankment across a waterway or low drainage area to detain sediment-laden runoff and allow sediment to settle out before discharging.

Appropriate Applications:

- Effective for the removal of large and medium sized particles (sand and gravel) and some metals that settle out with the sediment.

Maintenance:

- Maintenance is required for vegetation, embankment, inlet and outfall structures, as well as other features.
- Removal of sediment is required when the storage volume is reduced by one-third.

Category 2: Mobile Settling Technologies

The devices discussed in this category are typical of tanks that can be used for sediment treatment of dewatering operations. A variety of vendors are available who supply these tanks.

Weir Tank

A weir tank separates water and waste by using weirs. The configuration of the weirs (over and under weirs) maximizes the residence time in the tank and determines the waste to be removed from the water, such as oil, grease, and sediments.

Appropriate Applications:

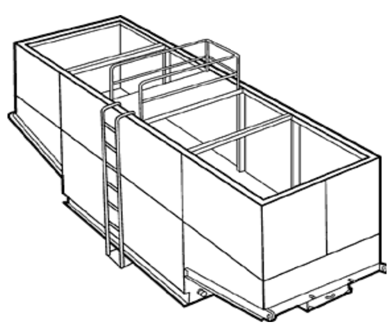
- The tank removes trash, some settleable solids (gravel, sand, and silt), some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in series or as pre-treatment for other methods.

Implementation:

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors shall be consulted to appropriately size tank.

Maintenance:

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be by licensed waste disposal company in accordance with WM-6.



Weir Tank

Dewatering Tank

A dewatering tank removes debris and sediment. Flow enters the tank through the top, passes through a fabric filter, and is discharged through the bottom of the tank. The filter separates the solids from the liquids.

Appropriate Applications:

- The tank removes trash, gravel, sand, and silt, some visible oil and grease, and some metals (removed with sediment). To achieve high levels of flow, multiple tanks can be used in parallel. If additional treatment is desired, the tanks can be placed in series or as pre-treatment for other methods.

Implementation:

- Tanks are delivered to the site by the vendor, who can provide assistance with set-up and operation.
- Tank size will depend on flow volume, constituents of concern, and residency period required. Vendors shall be consulted to appropriately size tank.

Maintenance:

- Periodic cleaning is required based on visual inspection or reduced flow.
- Oil and grease disposal must be by licensed waste disposal company in accordance with WM-6..

Dewatering Tanks

Category 3: Basic Filtration Technologies

Gravity Bag Filter

A gravity bag filter, also referred to as a dewatering bag, is a square or rectangular bag made of non-woven geotextile fabric that collects sand, silt, and fines.

Appropriate Applications:

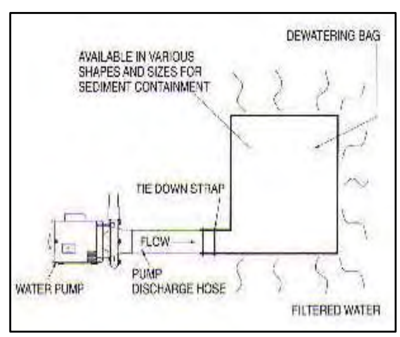
- Effective for the removal of sediments (gravel, sand, and silt). Some metals are removed with the sediment.

Implementation:

- Water is pumped into one side of the bag and seeps through the bottom and sides of the bag.
- A secondary barrier, such as a rock filter bed or gravel bag barrier, is placed beneath and beyond the edges of the bag to capture sediments that escape the bag.

Maintenance:

- Inspection of the flow conditions, bag condition, bag capacity, and the secondary barrier is required.
- Replace the bag when it no longer filters sediment or passes water at a reasonable rate.
- The bag is disposed off-site, or on-site as directed by the Engineer.



Gravity Bag Filter

Category 4: Advanced Filtration Technologies

Sand Media Particulate Filter

Water is treated by passing it through canisters filled with sand media. Generally, sand filters provide a final level of treatment. They are often used as a secondary or higher level of treatment after a significant amount of sediment and other pollutants have been removed.

Appropriate Applications:

- Effective for the removal of trash, gravel, sand, and silt and some metals, as well as the reduction of biochemical oxygen demand (BOD) and turbidity.
- Sand filters can be used for standalone treatment or in conjunction with bag and cartridge filtration if further treatment is required.
- Sand filters can also be used to provide additional treatment to water treated via settling or basic filtration.

Implementation:

- The filters require delivery to the site and initial set up. The vendor can provide assistance with installation and operation.

Maintenance:

- The filters require monthly service to monitor and maintain the sand media.

Sand Media Particulate Filters

Pressurized Bag Filter

A pressurized bag filter is a unit composed of single filter bags made from polyester felt material. The water filters through the unit and is discharged through a header, allowing for the discharge of flow in series to an additional treatment unit. Vendors provide pressurized bag filters in a variety of configurations. Some units include a combination of bag filters and cartridge filters for enhanced contaminant removal.

Appropriate Applications:

- Effective for the removal of sediment (sand and silt) and some metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Oil absorbent bags are available for hydrocarbon removal.
- Filters can be used to provide secondary treatment to water treated via settling or basic filtration.

Implementation:

- The filters require delivery to the site and initial set up. The vendor can provide assistance with installation and operation.

Maintenance:

- The filter bags require replacement when the pressure differential exceeds the manufacturer's recommendation.

Pressurized Bag Filter

Cartridge Filter

Cartridge filters provide a high degree of pollutant removal by utilizing a number of individual cartridges as part of a larger filtering unit. They are often used as a secondary or higher (polishing) level of treatment after a significant amount of sediment and other pollutants are removed. Units come with various cartridge configurations (for use in series with pressurized bag filters) or with a larger single cartridge filtration unit (with multiple filters within).

Appropriate Applications:

- Effective for the removal of sediment (sand, silt, and some clays) and metals, as well as the reduction of BOD, turbidity, and hydrocarbons. Hydrocarbons can effectively be removed with special resin cartridges.
- Filters can be used to provide secondary treatment to water treated via settling or basic filtration.

Implementation:

- The filters require delivery to the site and initial set up. The vendor can provide assistance.

Maintenance:

- The cartridges require replacement when the pressure differential exceeds the manufacturer's recommendation.

Cartridge Filter

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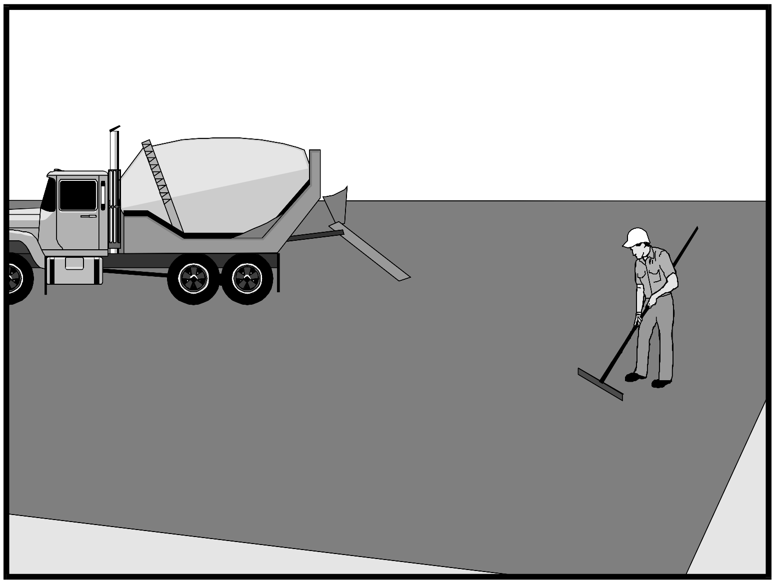
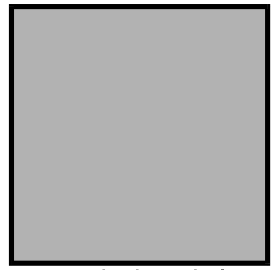
Paving and Grinding Operations

NS-3





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices for conducting paving, concrete slurry, cement or masonry, saw cutting, and grinding operations to minimize the transport of pollutants to the storm drain system or receiving water body.

Appropriate Applications

These procedures are implemented where paving, surfacing, resurfacing, grinding, slurry, cement, mortar or sawcutting, may pollute storm water runoff or discharge to the storm drain system or watercourses.

Limitations

- ■ Finer solids are not effectively removed by sediment control BMPs (SC-1 through SC-10) settling or filtration systems. SC-10 is not adequate for drain inlet protection from paving/concrete pollutants.

Standards and Specifications

- ■ Substances used to coat asphalt transport trucks, asphalt trucks, and asphalt spreading equipment shall not contain soap and shall be non-foaming and non-toxic.
- ■ Place plastic materials under asphaltic concrete (AC) paving equipment while not in use, to catch and/or contain drips and leaks. See also BMP WM-4, “Spill Prevention and Control.”
- ■ When paving involves AC, the following steps shall be implemented to prevent the discharge of uncompacted or loose AC, tack coats, equipment cleaners, or other paving materials:
- – Minimize sand and gravel from new asphalt from getting into storm drains, streets, and creeks by sweeping.
- – Old, broken, or spilled asphalt shall be removed from the project site and recycled or disposed of as approved by the Engineer.
- – AC grindings, pieces, or chunks shall not be used in embankments or shoulder backing unless approved by the Engineer.

- Collect and remove all broken asphalt and recycle off-site or dispose of offsite in accordance with all applicable laws and regulations.
- During chip seal application and sweeping operations, petroleum or petroleum covered aggregate shall not be discharged to the ground surface, enter any storm drain or water courses. Filter fabrics or plastic must be used to cover inlets to prevent any discharge of sediment or water until installation is complete.
- Use only non-toxic substances to coat asphalt transport trucks and asphalt spreading equipment.

■ Drainage inlet structures and manholes shall be covered with plastic during application of seal coat, tack coat, slurry seal, and/or fog seal, or any other paving/concrete, cement, slurry or mortar related pollutant to prevent any discharge to the storm drain system.

■ Seal coat, tack coat, slurry seal, or fog seal shall not be applied if rainfall is predicted to occur during the application or curing period.

■ Paving equipment parked onsite shall be parked over plastic to prevent discharge to the ground surface.

■ No washing of asphalt equipment shall be conducted on-site. When cleaning dry, hardened asphalt from equipment, manage hardened asphalt debris as described in BMP WM-5, "Solid Waste Management." Any cleaning onsite shall follow BMP NS-8, "Vehicle and Equipment Cleaning."

■ Do not wash sweepings from exposed aggregate concrete into a storm drain system. Collect and return to stockpile (WM-3), or dispose of properly.

Sawcutting

■ Do not conduct sawcutting during rain or when there is a 50% percent chance of measurable precipitation (0.01 inches or more).

■ Use minimum sawcutting blade speed to reduce required amount of water needed.

■ Vacuum up sawcutting waste as it is generated. Do not wait to complete sawcutting operation.

■ After vacuuming, the fine slurry shall be swept up after it dries.

■ Do not allow sawcutting waste slurry to get to storm drain inlet. SC-10 Storm Drain Inlet Protection and other sediment BMPs are not adequate to prevent discharge. Drain inlets shall be protected by impervious materials such as plastic. The impervious drain inlet protection shall be removed after the sawcutting operation is completed and all waste is cleaned up. The waste slurry must be completely contained in a concrete washout (WM-8) and/or shall be disposed of offsite without discharging to permeable or impermeable surfaces.

Pavement Grinding or Removal

- Residue from PCC grinding operations shall be picked up by means of a vacuum attachment to the grinding machine, shall not be allowed to flow across the pavement, and shall not be left on the surface of the pavement. See also BMP WM-8, "Concrete Waste Management;" and BMP WM-10, "Liquid Waste Management."
- Collect pavement digout material by mechanical or manual methods. This material may be recycled if approved by the Engineer for use as shoulder backing or base material at locations approved by the Engineer.
- If digout material cannot be recycled, transport the material to a storage site approved by the Engineer or offsite in accordance with all applicable laws and regulations. Digout activities shall not be conducted in the rain.
- When approved by the Engineer, stockpile material removed from roadways away from drain inlets, drainage ditches, and watercourses and stored consistent with BMP WM-3, "Stockpile Management."
- Disposal or use of AC grindings shall be approved by the Engineer. See also BMP WM-8, "Concrete Waste Management."
- No "kick-brooms" shall be used.

Thermoplastic Striping

- All thermoplastic striper and pre-heater equipment shutoff valves shall be inspected to ensure that they are working properly to prevent leaking thermoplastic from entering drain inlets, the storm water drainage system, or watercourses.
- The pre-heater shall be filled carefully to prevent splashing or spilling of hot thermoplastic. Leave six inches of space at the top of the pre-heater container when filling thermoplastic to allow room for material to move when the vehicle is deadheaded.
- Contractor shall not pre-heat, transfer, or load thermoplastic near drain inlets or watercourses.
- Clean truck beds daily of loose debris and melted thermoplastic. When possible recycle thermoplastic material. Thermoplastic waste shall be disposed of in accordance with all applicable laws and regulations.

Raised/Recessed Pavement Marker Application and Removal

- Do not transfer or load bituminous material near drain inlets, the storm water drainage system or watercourses.

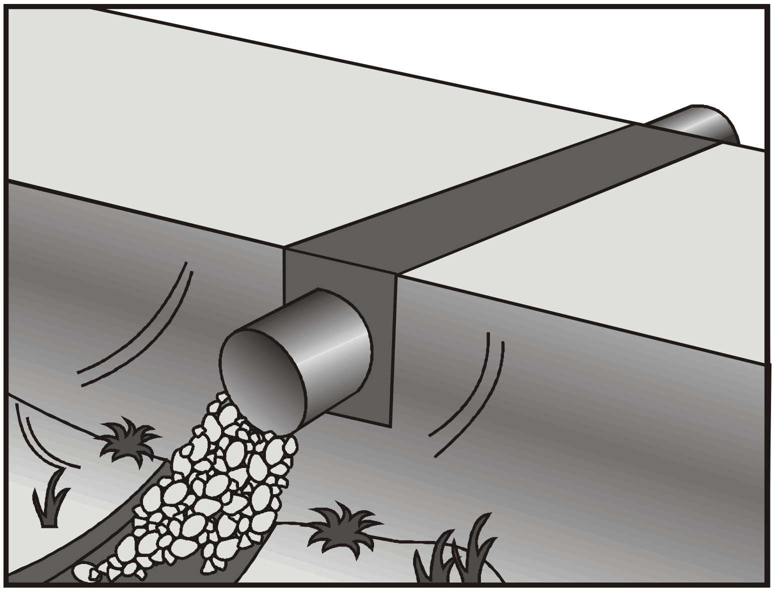
- Melting tanks shall be loaded with care and not filled to beyond six inches from the top to leave room for splashing when vehicle is deadheaded.
- When servicing or filling melting tanks, ensure all pressure is released before removing lids to avoid spills.
- On large scale construction sites, use mechanical or manual methods to collect excess bituminous material from the roadway after removal of markers.
- Waste shall be disposed of in accordance with all applicable laws and regulations.

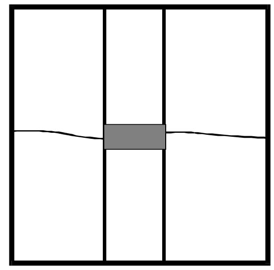
Maintenance and Inspection

- Inspect paving and grinding operations weekly and before and after every rainfall events. During extended rainfall events, inspect paving and grinding operations at least once every 24 hours.
- Inspect sawcutting operation and ensure that all waste slurry is vacuumed up. Any residual shall be swept or scraped up if necessary to remove it.
- Ensure that employees and subcontractors are implementing appropriate measures during paving operations.

Temporary Stream Crossing

NS-4





Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

A temporary stream crossing is a structure placed across a waterways, drainage swales or ditches that allows vehicles to cross the waterway during construction, minimizing, reducing, or managing erosion and downstream sedimentation caused by the vehicles.

Appropriate Applications

Temporary stream crossings are installed at sites:

- Where construction equipment or vehicles need to cross a waterways drainage swales or ditches.

Limitations

- Fully comply with the specific permit requirements or mitigation measures identified in the contract Special Provisions and all regulatory permits, such as Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit, California Department of Fish and Game Streambed Alteration Agreement, and US Forest Service Permits. Comply with all water quality monitoring and numerical-based water quality standards identified in the contract Special Provisions and all regulatory permits.
- Appropriate erosion and sediment control BMPs shall be installed during construction and removal of stream crossing.
- May become a constriction in the waterway, which can obstruct flood flow and cause flow backups or washouts. If improperly designed, flow backups can increase the pollutant load through washouts and scouring.
- Dry Ford shall only be used in the non-rainy season and when no flows are present. The use of the Ford is contingent on a 5-day clear weather forecast.
- CCS should not be used in excessively high or fast flows. Use of natural or other gravel in the stream for construction of Cellular Confinement System (CCS) crossing will be contingent upon approval by fisheries agencies.

■ Upon completion of construction activities, all stream crossing shall be removed and the area stabilized and restored to pre-construction conditions or as directed by the Engineer.

Standards and Specifications

General Considerations

■ No stream crossing is allowed without prior approval by the Engineer and compliance with the contract Special Provisions, applicable permits, laws and regulations.

■ Select site where erosion potential is low.

The following types of temporary stream crossings shall be considered:

■ Culverts - Used on perennial and intermittent streams.

■ Dry Fords - Appropriate during the dry season only. Used on dry washes, streams, and channels.

■ Cellular Confinement System (CCS) crossing structures consist of clean, washed gravel and cellular confinement system blocks. Used on dry washes and ephemeral streams, and low flow perennial streams.

■ Bridges - Appropriate for streams with high flow velocities, steep gradients and/or where temporary restrictions in the channel are not allowed.

Design and installation requires knowledge of stream flows and soil strength. Stream crossing shall be designed by a professional Engineer registered with the State of California. The Design details shall be included in the SWPPP or SWPPP amendment or approved by the Engineer prior to construction. Both hydraulic and construction loading requirements shall be considered with the following:

■ Comply with all applicable requirements for culvert and bridge crossings, particularly if the temporary stream crossing will remain through the rainy season.

■ Provide stability in the crossing and adjacent areas to withstand the design flow. The design flow and safety factor shall be selected based on careful evaluation of the risks due to over flowing, flow backups, or washout.

■ Shall not use oil or other potentially hazardous materials for surface treatment.

■ A Spill Prevention and Clean-up Plan shall be developed and included in the SWPPP, or submitted to the Engineer for approval prior to construction, for all potential spills from the crossing as a result of construction traffic or activities.

Construction Requirements:

- Stabilize construction roadways, adjacent work area and streambed against erosion.
- Construct during the non-rainy season and 5-day clear weather forecast to minimize stream disturbance and reduce costs.
- Construct at or near the natural elevation of the stream bed to prevent potential flooding upstream of the crossing.
- Install temporary sediment control BMPs to minimize erosion of embankment into flow lines. Install Sediment Controls along the perimeter (sides) of the crossing.
- Vehicles and equipment shall not be driven, operated, fueled, cleaned, maintained, or stored in the streambed.
- Temporary water body crossings and encroachments shall be constructed to minimize scour. Cobbles used for temporary water body crossings or encroachments shall be clean, rounded river cobble.
- The exterior of vehicles and equipment that will encroach on the water body within the project shall be maintained free of grease, oil, fuel, and residues.
- Any temporary artificial obstruction placed within flowing water shall only be built from material, such as clean gravel, that will cause little or no siltation.
- Drip pans shall be placed under all vehicles and equipment placed on docks, barges, or other structures over water bodies when the vehicle or equipment is planned to be idle for more than one hour.
- Conceptual temporary stream crossings are shown in figures at the end of this section.

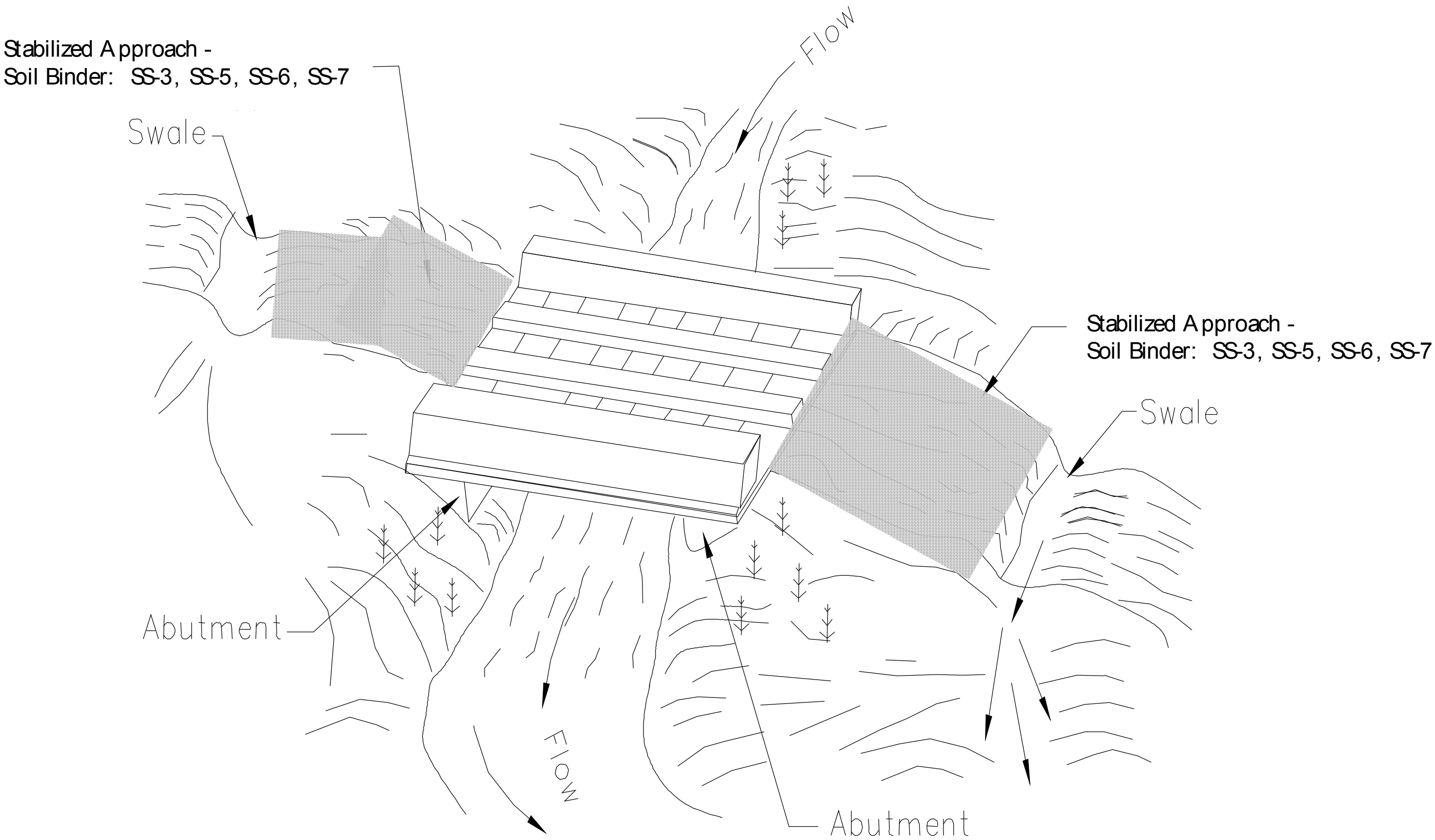
Specific Requirements:

- Culverts are relatively easy to construct and able to support heavy equipment loads.
- Dry Fords are the least expensive of the crossings, with maximum load limits.
- CCS allow designers to use either angular or naturally-occurring, rounded gravel, because the cells provide the necessary structure and stability. In fact, natural gravel is optimal for this technique, because of the habitat improvement it will provide after removal of the CCS.
- A gravel depth of 6 to 12 inches for a CCS structure is sufficient to support most construction equipment.
- An advantage of a CCS crossing structure is that relatively little rock or gravel is needed, because the CCS provides the stability.

- Bridges are generally more expensive to design and construct, but provides the least disturbance of the stream bed and constriction of the waterway flows.

Maintenance and Inspection

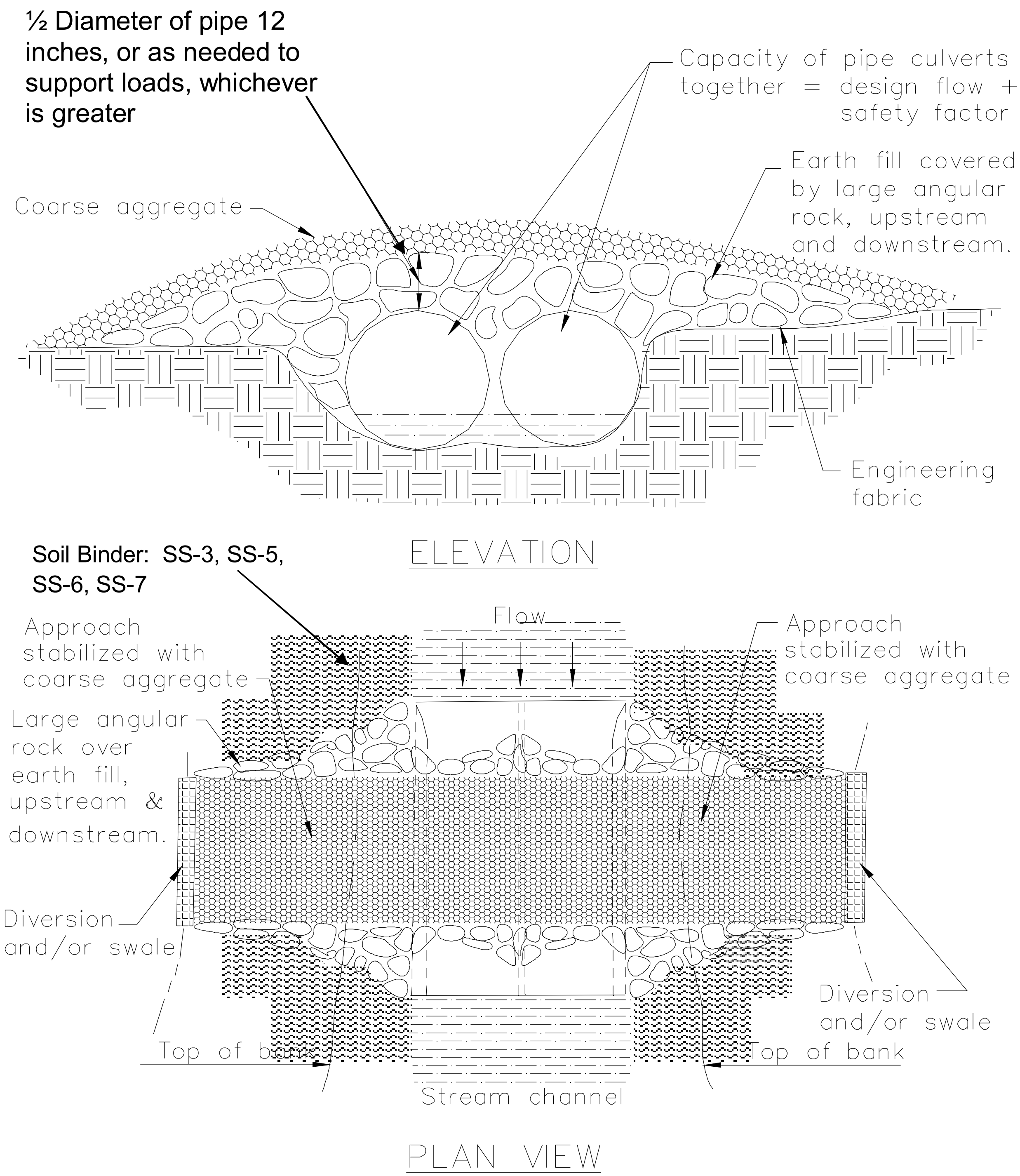
- Inspect streambed crossing weekly and before and after every rainfall events. During extended rainfall events, inspect streambed crossing at least once every 24 hours.
- Removal of debris behind fords, in culverts, and under bridges as directed by the Engineer.
- Replacement of lost protective aggregate from inlets and outlets of culverts.
- Checking for blockage in the channel, debris buildup in culverts or behind fords, and under bridges.
- Checking for erosion of abutments, channel scour, riprap displacement, or piping in the soil.
- Checking for structural weakening of the temporary crossing, such as cracks, and undermining of foundations and abutments.
- Removal of temporary crossing promptly when it is no longer needed or as directed by the Engineer.



NOTE:
Surface flow of road diverted by swale and/or dike.

TYPICAL BRIDGE CROSSING

NOT TO SCALE



TYPICAL CULVERT CROSSING
NOT TO SCALE

CELLULAR CONFINEMENT SYSTEM

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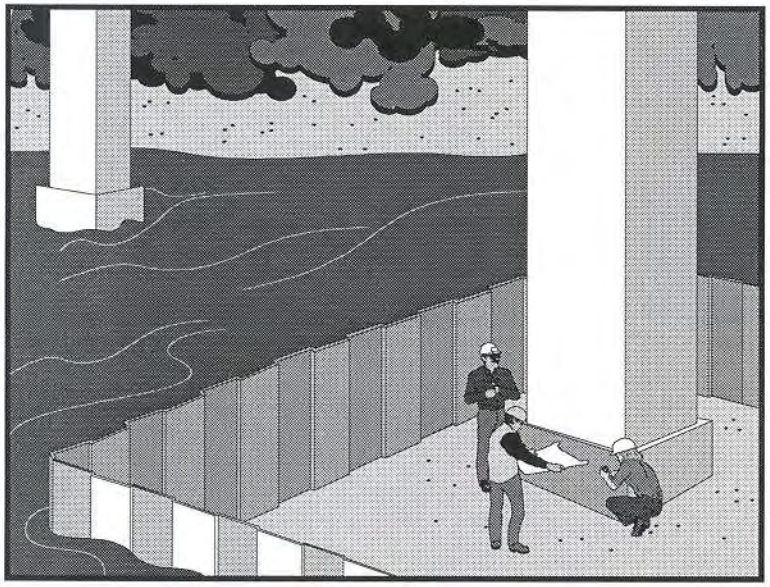
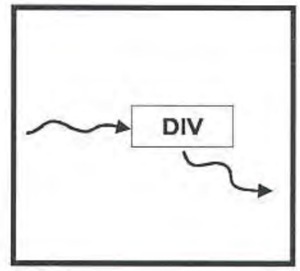
Clear Water Diversion

NS-5





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Clear water diversion consists of a system of structures and measures that intercept clear surface water runoff upstream of a project site, transport it around the work area, and discharge it downstream with minimal water quality degradation for either the project construction operations or the construction of the diversion. Clear water diversions are used in a waterway or storm drain system to enclose a construction area and reduce sediment pollution from construction work occurring in or adjacent to water. Isolation techniques are methods that isolate near shore work from a waterbody. Structures commonly used as part of this system include diversion ditches, berms, dikes, slope drains, rock, gravel bags, wood, sheet piles, aqua barriers, cofferdams, filter fabric or turbidity curtains, drainage and interceptor swales, pipes, or flumes.

Appropriate Applications

- Clear water diversions are appropriate for isolating construction activities occurring within or near a water body such as streambank stabilization, or channel, culvert, bridge, piers or abutment repair or construction. They may also be used in combination with other methods, such as clear water bypasses and/or pumps.

- Pumped diversions are suitable for intermittent and low flow streams. Excavation of a temporary bypass channel, or passing the flow through a pipe.

- Fully comply with the specific permit requirements or mitigation measures identified in the contract Special Provisions and all regulatory permits, such as Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit, California Department of Fish and Game Streambed Alteration Agreement, and US Forest Service Permits. Comply with all water quality monitoring and numerical-based water quality standards identified in the contract Special Provisions and all regulatory permits.

- The Contractor is cautioned that the Project involves work within and requires removal of portions of streambed or an active flood control channel which is subject to flows of high and uncontrolled magnitude. Although such flows would most likely occur during the storm season, from October 15 to April 15, there is the possibility that such occurrences can take place at other times of the year. The Contractor shall assume all risks associated with working in an active streambed channel.

- The Contractor shall consult with the National Weather Service to determine the possibility of storms.

- The Contractor shall be responsible for providing for the passage of all flows through the Work site, maintaining water quality as required by the permits by implementation of BMPs, and the safety personnel, equipment, and materials under its jurisdiction.

- The Contractor shall provide for the flow of water from all sources, including nuisance water, through Work site at all times.

Limitations

- Diversion/encroachment activities may constrict the waterway, which can obstruct flood flows and cause flooding or washouts. Diversion structures shall not be installed without identifying potential impacts to the stream channel.

- Between October 15th through April 15th the Contractor shall:
  - Maintain the capacity of the channel shall be maintained at 100% of design capacity.
  - Not conduct work, store materials/equipment, or operate equipment within the channel.
  - Completely remove all temporary surface water diversions structures from the channel.

- Diversion or isolation activities shall not completely dam stream flow.

- Dewatering and removal may require additional sediment control or water treatment (See NS-2, “Dewatering Operations”).

Standards and Specifications

- The Contractor shall submit a Surface Water Diversion Plan per the contract Special Provisions for all working within a streambed or channel.

- If the contract Special Provisions do not contain requirements for a Surface Water Diversion Plan, then the Contractor shall prepare a Surface Water Diversion Plan, per this BMP, and submit it to the Engineer for approval prior to conducting any work over a watercourse.

- The Surface Water Diversion Plan shall be designed by a professional Engineer registered with the State of California. The Surface Water Diversion Plan shall be included in the SWPPP.

- The Contractor shall design, construct, maintain, and remove a temporary surface water diversion system as specified herein. The Surface Water Diversion Plan shall contain at a minimum the following information:
  - A written description of the Surface Water Diversion System.
  - A site plan (drawn to scale) and diagrammatic representation of the diversion of water system, showing the location of all BMPs, equipment within the project limits (including check dams, pumps, piping details, discharge and sampling locations, power source, etc.).
  - The Plan will also include equipment specifications and all other information, as requested by the Agency, for the complete understanding and operation of the dewatering plan.
- The contractor shall demonstrate to the satisfaction of the Engineer that all components of the temporary surface water diversion system are fully functional prior to initiation of any work in associated portion of the channel.
- The temporary surface water diversion system shall be water-tight. If any nuisance water leaks occur within the work area, the Contractor shall immediately contain and re-direct/remove the nuisance water away from the work areas.
- The Contractor shall strictly confine all work and storage of materials and equipment with the boundaries of the temporary surface water diversion system.
- During storms, obstructions such as equipment and materials shall be removed from the channel.
- All temporary improvements installed by the Contractor for the diversion of water, not specified as a permanent improvement as part of the contract, shall be removed and the site restored.
- The system shall be routinely cleaned of silt/sediment as directed by the Engineer and any required repaired made immediately. If during the progress of work, the Agency determines that the Plan or implementation of the Plan is inadequate, the Contractor shall, at his expense, furnish any equipment, labor, materials, and outside services necessary to perform the work satisfactory to the Agency.
- Excavation equipment buckets may reach out into the water for the purpose of removing or placing fill materials. Only the bucket of the crane/ excavator/backhoe may operate in a water body. The main body of the crane/excavator/backhoe shall not enter the water body, except as necessary to cross the stream to access the work site.
- Implement guidelines presented in SS-12, Streambank Stabilization to minimize impacts to streambanks.

- All surrounding areas at the head wall and outfall structure shall be stabilized with SS-3, SS-4, SS-7, SS-12, or a combination of such if necessary.
- Stationary equipment such as motors and pumps, located within or adjacent to a water body, shall be positioned over drip pans.
- When any artificial obstruction is being constructed, maintained, or placed in operation, sufficient water shall, at all times, be allowed to pass downstream to maintain aquatic life downstream.
- The exterior of vehicles and equipment that will enter the streambed or channel shall be maintained free of grease, oil, fuel, and residues.
- Drip pans shall be placed under all vehicles and equipment, including vehicles or equipment will be idle for more than one hour.
- Where possible, avoid or minimize diversion/encroachment impacts by scheduling construction during periods of low flow or when the stream is dry. See also the contract Special Provisions for scheduling requirements. Scheduling shall also consider seasonal releases of water from dams, fish migration and spawning seasons, and water demands due to crop irrigation.
- Construct diversion structures with materials free of potential pollutants such as soil, silt, sand, clay, grease, or oil.

Temporary Diversions/Encroachments

- Construct diversion channels in accordance with BMP SS-9, "Earth Dikes/Drainage Swales, and Ditches."
- In high flow velocity areas, stabilize slopes of embankments and diversion ditches using an appropriate liner, in accordance with BMP SS-7, "Geotextiles, Plastic Covers & Erosion Control Blankets/Mats", or use rock slope protection.
- Where appropriate, use natural streambed materials such as large cobbles and boulders for temporary embankment/slope protection, or other temporary soil stabilization methods.
- Provide for velocity dissipation at transitions in the diversion, such as the point where the stream is diverted to the channel and the point where the diverted stream is returned to its natural channel. See also BMP SS-10, "Outlet Protection/Velocity Dissipation Devices."

Temporary Dry Construction Areas

- When dewatering behind temporary structures to create a temporary dry construction area (such as coffer dams), pass pumped water through a sediment settling device, tank or settling basin, before returning water to the water body; see also BMP NS-2, "Dewatering Operations."

- If pollutants (except sediment) are identified in the contract Special Provisions, the contractor shall fully comply with the contract Special Provisions. If pollutants (except sediment) are observed or identified, the contractor shall discharge any water and immediately notify the Engineer.

- Any substance used to assemble or maintain diversion structures, such as form oil, shall be non-toxic and non-hazardous.

- Any material used to minimize seepage underneath diversion structures, such as grout, shall be non-toxic, non-hazardous, and as close to a neutral pH as possible.

Isolation Techniques:

Isolation techniques are methods that isolate near shore work from a waterbody. Techniques include sheet pile enclosures, water-filled geotextile (Aqua Dam), gravel berm with impermeable membrane, gravel bags, coffer dams, and K-rail.

Filter Fabric Isolation Technique

A filter fabric isolation structure (See Figure 1D) is a temporary structure built into a waterway to enclose a construction area and reduce sediment pollution from construction work in or adjacent to water. This structure is composed of filter fabric, gravel bags, and steel t-posts.

Appropriate Applications:

- Filter fabric may be used for construction activities such as streambank stabilization, or culvert, bridge, pier or abutment installation. It may also be used in combination with other methods, such as clean water bypasses and/or pumps.

- This method involves placement of gravel bags or continuous berms to "key-in" the fabric, and subsequently staking the fabric in place.

- This is a method that should be used in relatively calm water, and can be used in smaller streams.

Limitations

- Do not use if the installation, maintenance and removal of the structures will disturb sensitive aquatic species of concern.

- Not appropriate for projects where dewatering is necessary.

- Not appropriate to completely dam streamflow.

Standards and Specifications:

- For the filter fabric isolation method, a non-woven or heavy-duty fabric is recommended over standard silt fence. Using rolled geotextiles allows non-standard widths to be used.

- Anchor filter fabric with gravel bags filled with clean, washed gravel. Do not use sand. If a bag should split open, the gravel can be left in the stream, where it can provide aquatic habitat benefits.

- Another anchor alternative is a continuous berm, made with the Continuous Berm Machine. This is a gravel-filled bag that can be made in very long segments. The length of the berms is usually limited to 20 ft for ease of handling.

Installation

- Place the fabric on the bottom of the stream, and place either a bag of clean, washed gravel or a continuous berm over the bottom of the fabric, such that a bag-width of fabric lies on the stream bottom. The bag should be placed on what will be the outside of the isolation area.

- Pull the fabric up, and place a metal t-post immediately behind the fabric, on the inside of the isolation area; attach the fabric to the post with three diagonal nylon ties.

- Continue placing fabric as described above until the entire work area has been isolated, staking the fabric at least every 6 ft.

Maintenance and Inspection:

- During construction and operation, inspect daily during the workweek.

- Schedule additional inspections during storm events.

- Immediately repair any gaps, holes or scour.

- Remove sediment buildup.

- Remove BMP upon completion of construction activity. Recycle or re-use if applicable.

Turbidity Curtain Isolation Technique

A turbidity curtain (refer to Figures 1A through 1D) is a fabric barrier used to isolate the near shore work area. The barriers are intended to confine the suspended sediment. The curtain is a floating barrier, and thus does not prevent water from entering the isolated area; rather, it prevents suspended sediment from getting out.

Appropriate applications:

Turbidity curtains should be used where sediment discharge to a stream is unavoidable. They are used when construction activities adjoin quiescent waters, such as lakes, ponds, lagoons, bays, and slow flowing rivers. The curtains are designed to deflect and contain sediment within a limited area and provide sufficient retention time so that the soil particles will fall out of suspension.

Limitations:

- Turbidity curtains shall not be used in flowing water; they are best suited for use in ponds, lakes, lagoons, bays, and very slow-moving rivers.
- Turbidity curtains should not be placed across the width of a channel.
- Removing sediment that has been deflected and settled out by the curtain may create a discharge problem through the re-suspension of particles and by accidental dumping by the removal equipment.

Standards and Specifications:

- Turbidity curtains should be oriented parallel to the direction of flow.
- The curtain should extend the entire depth of the watercourse in calm-water situations.
- In wave conditions, the curtain should extend to within 1 ft of the bottom of the watercourse, such that the curtain does not stir up sediment by hitting the bottom repeatedly. If it is desirable for the curtain to reach the bottom in an active-water situation, a pervious filter fabric may be used for the bottom 1 ft.
- The top of the curtain should consist of flexible flotation buoys, and the bottom shall be held down by a load line incorporated into the curtain fabric. The fabric shall be a brightly colored impervious mesh.
- The curtain shall be held in place by anchors placed at least every 100 ft.
- First place the anchors, then tow the fabric out in a furled condition, and connect to the anchors. The anchors should be connected to the flotation devices, and not to the bottom of the curtain. Once in place, cut the furling lines, and allow the bottom of the curtain to sink.
- Sediment that has been deflected and settled out by the curtain may be removed if so directed by the Engineer. Consideration must be given to the probable outcome of the removal procedure. It must be asked if it will create more of a sediment problem through re-suspension of the particles or by accidental dumping of material during removal. It is recommended that the soil particles trapped by the turbidity curtain only be removed if there has been a significant change in the original contours of the affected area in the watercourse.
- Particles should always be allowed to settle for a minimum of 6 to 12 hours prior to their removal or prior to removal of the turbidity curtain.

Maintenance and Inspection:

- The curtain shall be inspected daily for holes or other problems, and any repairs needed should be made promptly.

- Allow sediment to settle for 6 to 12 hours prior to removal of sediment or curtain. This means that after removing sediment, wait an additional 6 to 12 hours before removing the curtain.

- To remove, install furling lines along the curtain, detach from anchors, and tow out of the water.

K-rail River Isolation

This is temporary sediment control, or stream isolation method that uses K-rails (refer to Figure 2) to form the sediment deposition area, or to isolate the in-stream or near-bank construction area.

Barriers are placed end-to-end in a pre-designed configuration and gravel-filled bags are used at the toe of the barrier and also at their abutting ends to seal and prevent movement of sediment beneath or through the barrier walls.

Appropriate Applications:

- The K-rail isolation can be used in streams with higher water velocities than many other isolation techniques.

Limitations:

- The K-rail method does not allow for full dewatering.

Standards and Specifications:

- To create a floor for the K-rail, move large rocks and obstructions. Place washed gravel and gravel-filled bags to create a level surface for K-rail to sit.

- Place the bottom two K-rails adjacent to each other, and parallel to the direction of flow; fill the center portion with gravel bags. Then place the third K-rail on top of the bottom two; there should be sufficient gravel bags between the bottom K-rails such that the top one is supported by the gravel. Place plastic sheeting around the K-rails, and secure at the bottom with gravel bags.

- Further support can be added by pinning and cabling the K-rails together. Also, large riprap and boulders can be used to support either side of the K-rail, especially where there is strong current.

Maintenance and Inspection:

- The barrier shall be inspected at least once daily, and any damage, movement or other problems should be addressed immediately.

- Sediment should be allowed to settle for at least 6 to 12 hours prior to removal of sediment, and for 6 to 12 hours prior to removal of the barrier.

Stream Diversions

Stream diversions consist of a system of structures and measures that intercept an existing stream, upstream of the project, and transport it around the work area, and discharge it downstream (refer to Figure 3). The selection of which stream diversion technique to use depends upon the type of work involved, physical characteristics of the site, and the volume of water flowing through the project.

Appropriate Applications:

- Pumped diversions are appropriate in areas where de-watering is necessary.
- Dam-type diversions may serve as temporary access to the site.
- Where work areas require isolation from flows.

Limitations:

- Pumped diversions have limited flow capacity.
- Pumped diversions require frequent monitoring of pumps.
- Large flows during storm events can overtop dams.
- Flow diversion and re-direction with small dams involves in-stream disturbance and mobilization of sediment.

Standards and Specifications:

- Stream diversions shall be constructed only when there are no flowing or ponded water in the streambed.
- Installation guidelines will vary based on existing site conditions and type of diversion used.
- Diversions and pump capacity shall be sized to convey design flows rates.
- Adequate energy dissipation must be provided at the outlet to minimize erosion.
- Dam materials used to create dams upstream and downstream of diversion should be erosion resistant; materials such as steel plate, sheetpile, sandbags, continuous berms, inflatable water bladders, etc. would be acceptable.
- When constructing a diversion channel, begin excavation of the channel at the proposed downstream end, and work upstream. Once the watercourse to be diverted is reached, and the excavated channel is stable, breach the upstream end, and allow water to flow down the new channel. Once flow has been established in the diversion channel, install the diversion weir in the main channel; this will force all water to be diverted from the main channel.

Maintenance and Inspection:

- Inspect diversion/encroachment structures before and after significant storms, and at least once per week while in service. Inspect daily during the construction.
- Pumped diversions require frequent monitoring of pumps.
- Inspect embankments and diversion channels before and after significant storms, and at least once per week while in service for damage to the linings, accumulating debris, sediment buildup, and adequacy of the slope protection. Remove debris and repair linings and slope protection as required. Repair holes, gaps, or scour.
- Upon completion of work, the diversion or isolation structure should be removed and flow should be re-directed through the new culvert or back into the original stream channel. Recycle or re-use if applicable.

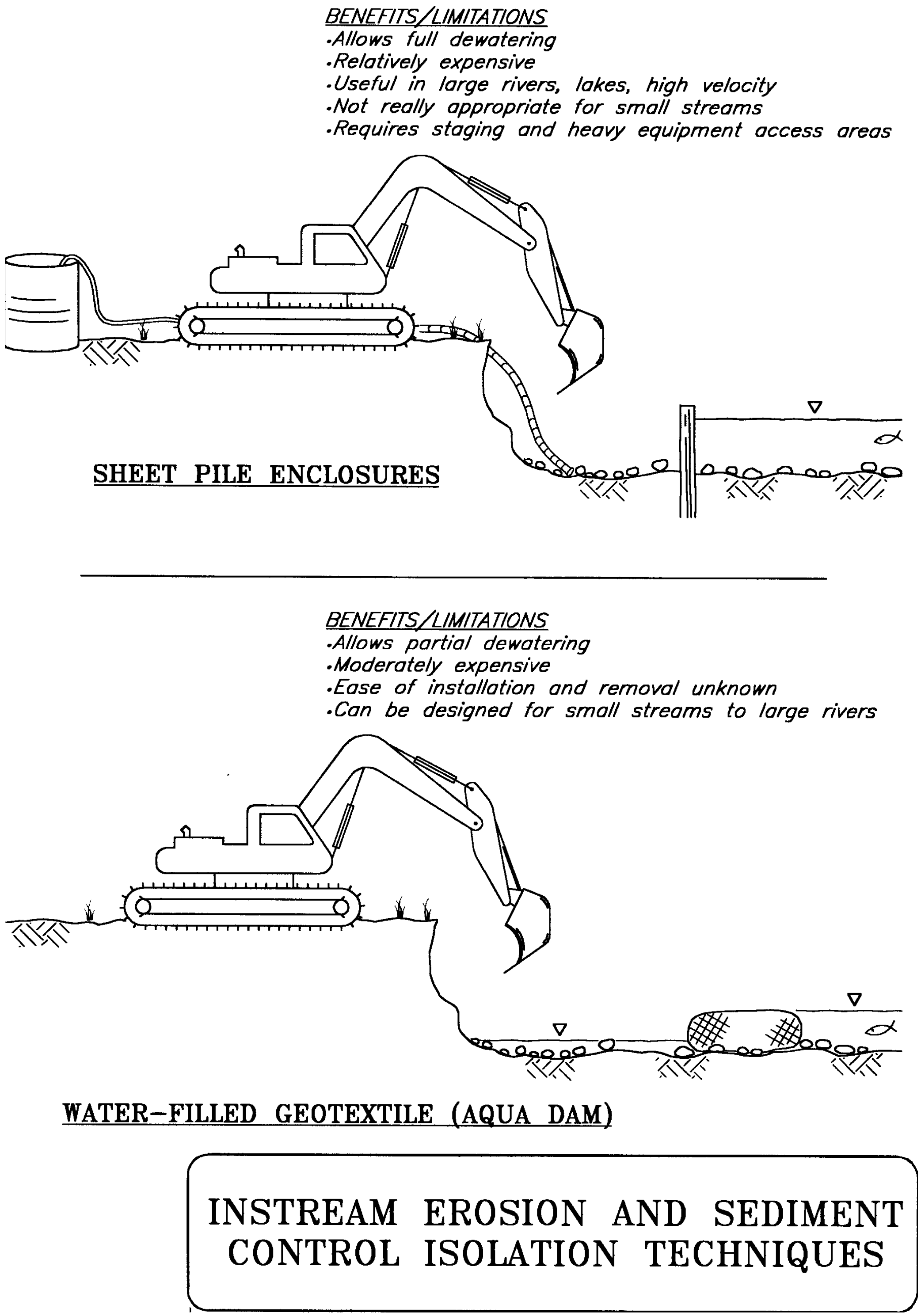
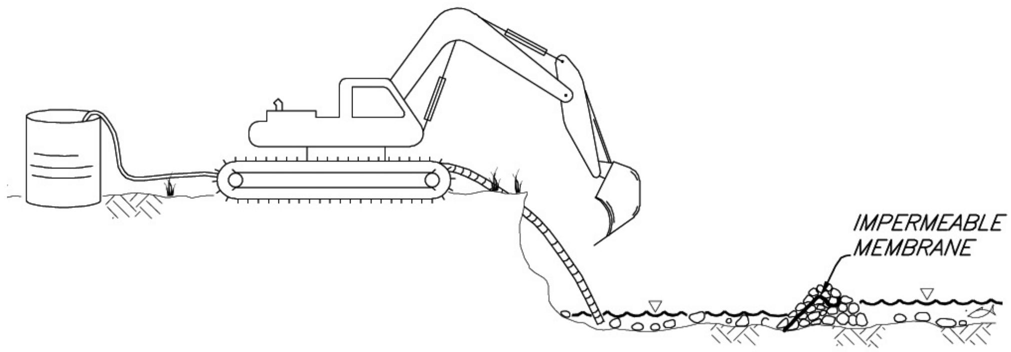

BENEFITS/LIMITATIONS
•Allows full dewatering
•Relatively expensive
•Useful in large rivers, lakes, high velocity
•Not really appropriate for small streams
•Requires staging and heavy equipment access areas
SHEET PILE ENCLOSURES
BENEFITS/LIMITATIONS
•Allows partial dewatering
•Moderately expensive
•Ease of installation and removal unknown
•Can be designed for small streams to large rivers
WATER-FILLED GEOTEXTILE (AQUA DAM)
INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1A

BENEFITS/LIMITATIONS
- Allows partial dewatering
- Relatively inexpensive
- Useful for small streams
- Minimal TSS when removed



NOTES:

Step 1. Install clean gravel with impermeable membrane

Step 2. Do work

Step 3. Decommission berm by removing impermeable membrane

Step 4. Pump work area. Head differential will cause water to flow into work area through gravel

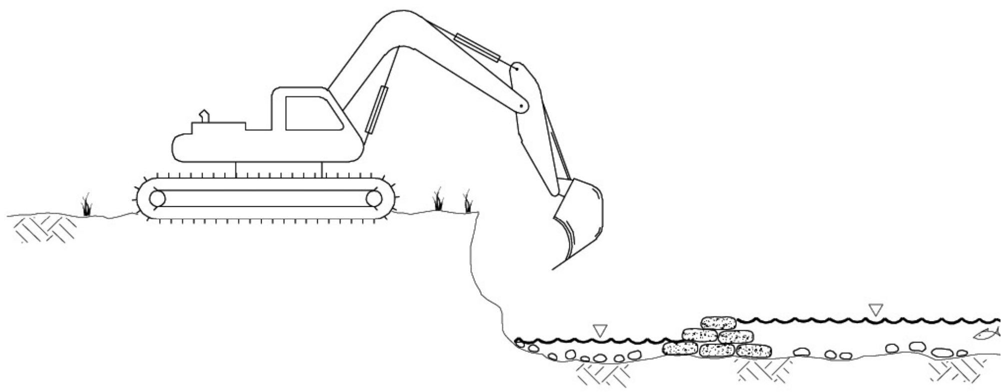
Step 5. Remove or spread gravel

GRAVEL BERM WITH IMPERMEABLE MEMBRANE

INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1B

BENEFITS/LIMITATIONS
- *Difficult to dewater*
- *Inexpensive*
- *Labor intensive to install and remove*
- *Use clean gravel*



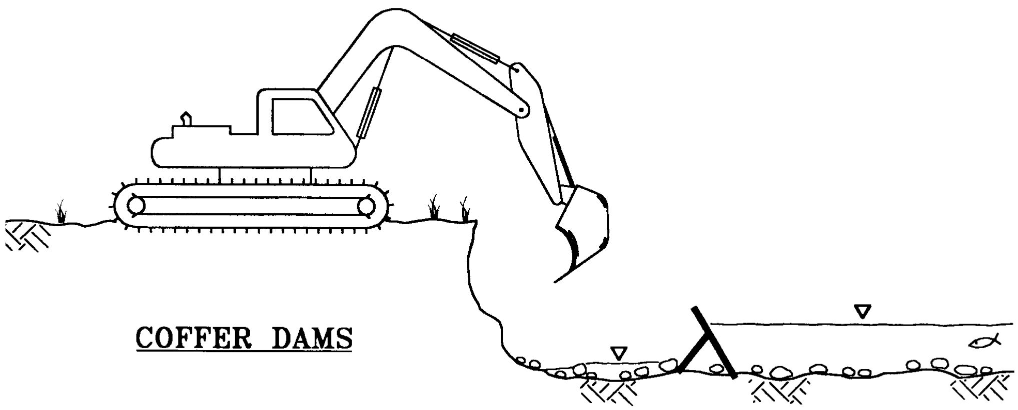
GRAVEL BAG TECHNIQUE

INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

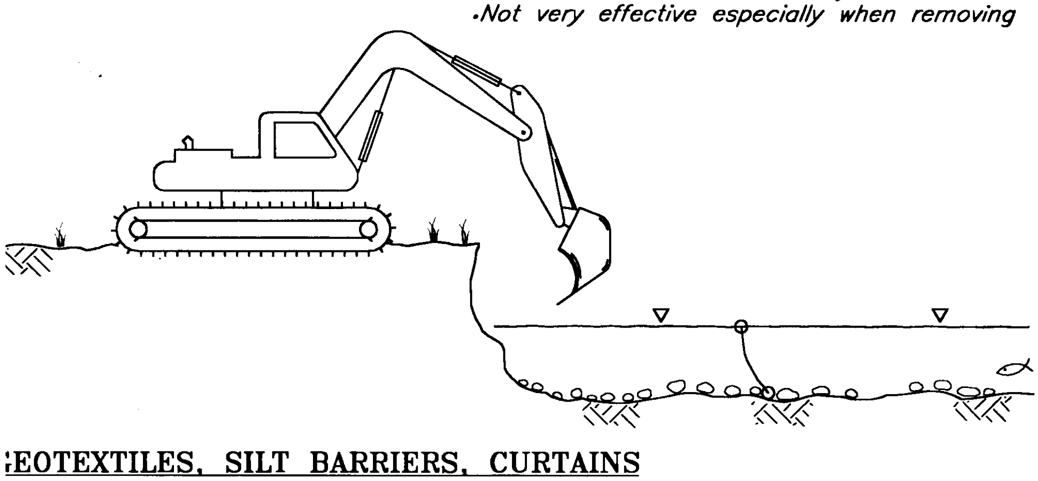
Figure 1C

Clear Water Diversion

BENEFITS/LIMITATIONS
- *Allows partial dewatering*
- *Many different types available*
- *Relatively expensive*
- *Can be designed for large and small streams*
- *Ease of installation and removal unknown*

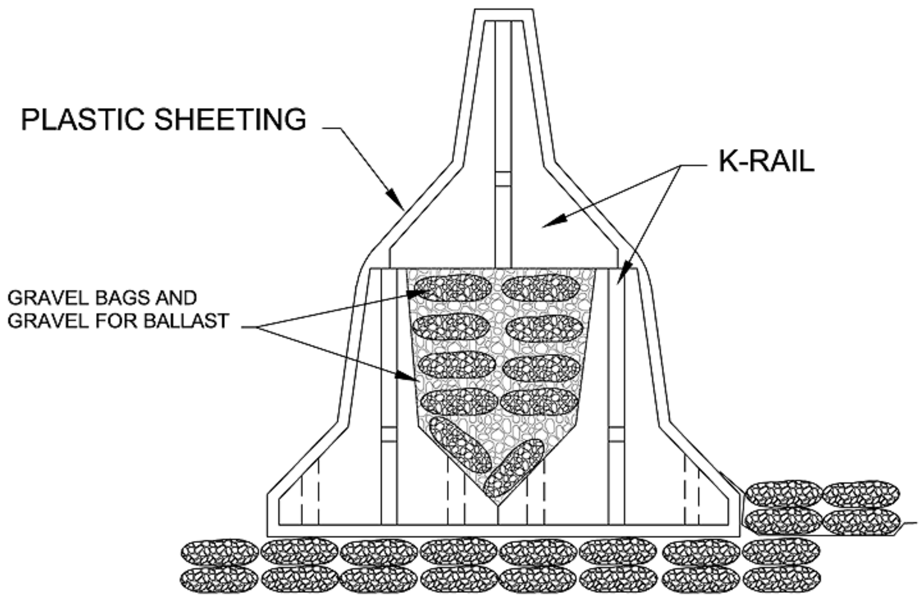


BENEFITS/LIMITATIONS
- *Does not allow dewatering*
- *Inexpensive*
- *Used in slow water lakes only*
- *Not very effective especially when removing*

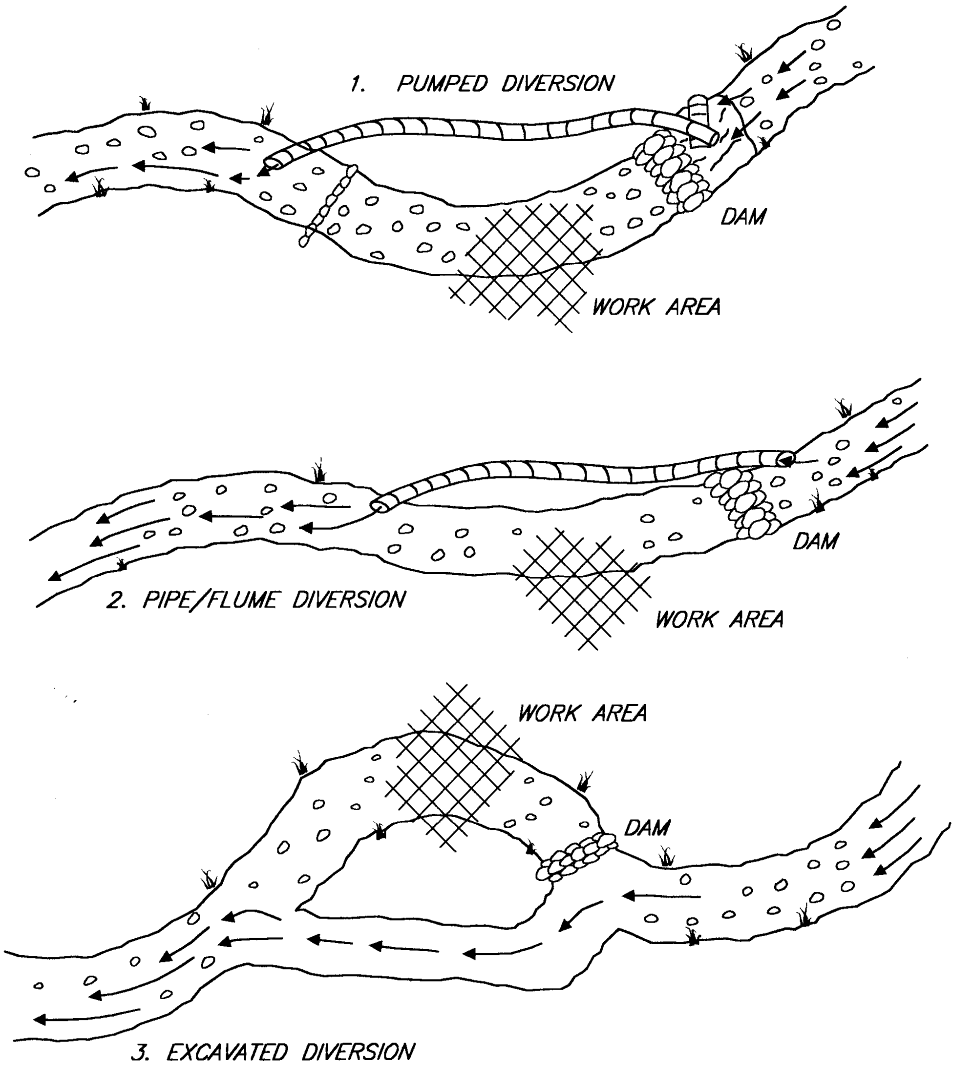


INSTREAM EROSION AND SEDIMENT CONTROL ISOLATION TECHNIQUES

Figure 1D



K-Rail Isolation
Figure 2

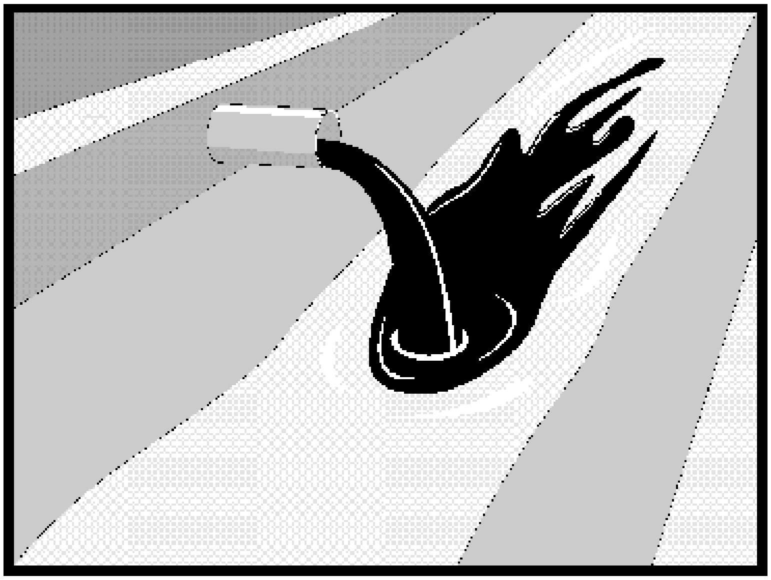


TYPICAL STREAM
DIVERSION TECHNIQUES

Figure 3

Illicit Connection/Illegal Discharge Detection and Reporting

NS-6



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices designed for construction contractors to recognize illicit connections or illegally dumped or discharged materials on a construction site and report incidents to the Engineer.

Appropriate Applications

Illicit connection/illegal discharge detection and reporting is applicable for all project sites and anytime an illicit connection or discharge is discovered or illegally dumped material is found on the construction site.

Illicit connections and illegal discharges or dumping, for the purposes of this BMP, refer to discharges and dumping caused by parties other than the contractor.

Limitations

None identified.

Standards and Specifications

- Procedures and practices presented in this BMP are general. Contractor shall use extreme caution, immediately notify the Engineer when illicit connections or illegal dumping or discharges are discovered, and take no further action unless directed by the Engineer.
- If pre-existing hazardous materials or wastes are known to exist onsite, the contractor's responsibility will be detailed in the contract Special Provisions.
- Inspect construction site before beginning the job for evidence of illicit connections or illegal dumping or discharges.
- Secure the project site in order to prevent illicit connections or illegal dumping or discharges once construction begins.

- Inspect construction site weekly during project execution for evidence of illicit connections or illegal dumping or discharges.
- Observe construction site perimeter for evidence or potential of illicitly discharged or illegally dumped material, which may enter the construction site.

Identification of Illicit Connections and Illegal Dumping or Discharges

- Unlabeled or non-identifiable material shall be assumed to be hazardous.
- Solids - Look for debris, or rubbish piles. Solid waste dumping often occurs on roadways with light traffic loads or in areas not easily visible to the public.
- Liquids – signs of illegal liquid dumping or discharge can include:
  - Visible signs of staining or unusual colors to the pavement or surrounding adjacent soils.
  - Pungent odors coming from the drainage systems.
  - Discoloration or oily substances in the water or stains and residues detained within ditches, channels or drain boxes.
  - Abnormal water flow during the dry weather season.
- Urban Areas - Evidence of illicit connections or illegal discharges is typically detected at storm drain outfall locations or at manholes. Signs of an illicit connection or illegal discharge can include:
  - Abnormal water flow during the dry weather season.
  - Unusual flows in subdrain systems used for dewatering.
  - Pungent odors coming from the drainage systems.
  - Discoloration or oily substances in the water or stains and residues detained within ditches, channels or drain boxes.
  - Excessive sediment deposits, particularly adjacent to or near other active construction sites.
- Rural Areas - Illicit connections or illegal discharges involving irrigation drainage ditches are detected by visual inspections. Signs of an illicit discharge can include:
  - Abnormal water flow during the dry weather season.
  - Non-standard junction structures.
  - Broken concrete or other disturbances at or near junction structures.

Reporting

- Notify the Engineer of any illicit connections and illegal dumping or discharge incidents at the time of discovery.

Cleanup and Removal

The Agency may direct contractor to clean up non-hazardous dumped or discharged material on the construction site.

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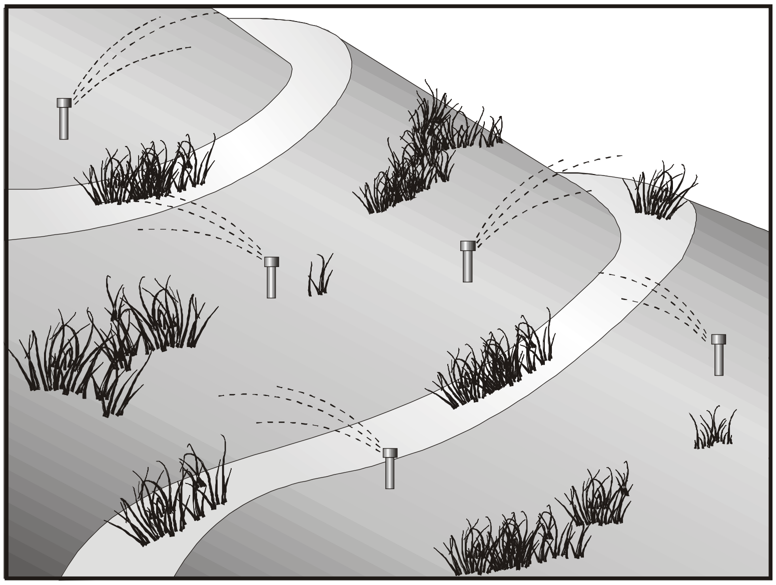
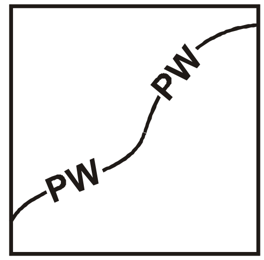
Potable Water/Irrigation

NS-7





Standard Symbol

BMP Objectives
- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Potable Water/Irrigation management consists of practices and procedures to manage the discharge of potential pollutants generated during discharges from irrigation water lines, landscape irrigation, lawn or garden watering, planned and unplanned discharges from potable water sources, water line flushing, hydrant flushing and any other water.

Appropriate Applications

Implement this BMP whenever the above activities or discharges occur or could occur at or enter or run-on to a construction site.

Limitations

- None identified.

Standards and Specifications

- Do not allow potable water/irrigation activities to allow discharge to the storm drain system or receiving waters.
- Engineer approval is required prior to commencing any washing activities that could discharge to a permeable or impermeable surface, the storm drain or receiving waterbody.
- Shut off the water source to broken lines, sprinklers, or valves as soon as possible to prevent excess water flow.
- Install appropriate BMPs to protect downstream storm water drainage systems and watercourses from water pumped or bailed from trenches excavated to repair water lines or other reason.
- Dechlorinate all water lines with a by properly neutralizing chemical such as sulfur dioxide, see Appendix B of the American Water Works Association (AWWA) C651. Disposal of heavily chlorinated water shall comply with all applicable law and requirements of Federal, State, County, or other local agencies.

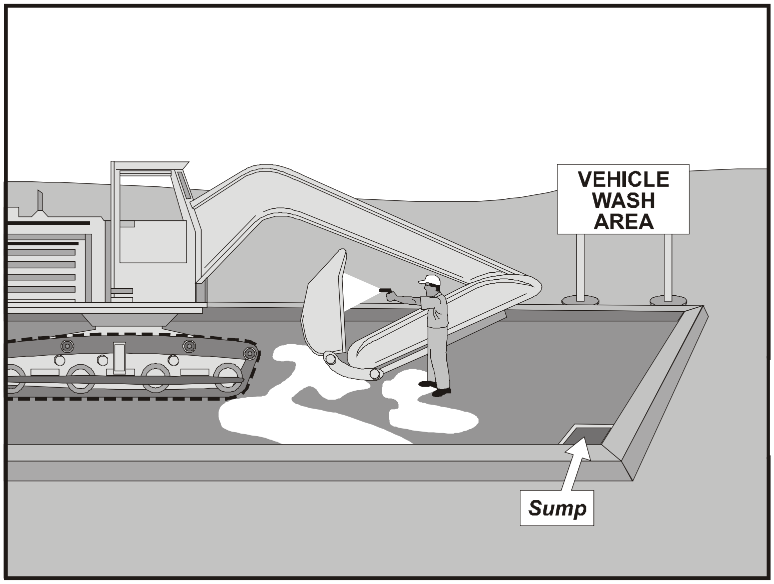
Potable Water/Irrigation

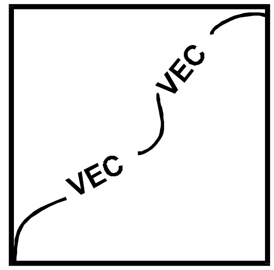
Maintenance and Inspection

- Inspect potable water and irrigation systems weekly, and before and after every rainfall events. During extended rainfall events, inspect all entrances, exits, access roads at least once every 24 hours.
- Repair broken water lines immediately or as directed by the Engineer.
- Inspect irrigated areas for signs of erosion and/or discharge. If erosion or discharge are observed, take corrective action to stop discharge and erosion immediately or as directed by the Engineer.
- Inspect irrigated areas within the construction limits for excess watering. Adjust watering times and schedules to ensure that the appropriate amount of water is being used and to minimize runoff. Consider factors such as soil structure, grade, time of year, and type of plant material in determining the proper amounts of water for a specific area.

Vehicle and Equipment Cleaning

NS-8





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Vehicle and equipment cleaning procedures and practices are used to minimize or eliminate the discharge of pollutants from vehicle and equipment cleaning operations to the ground, storm drain system or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment cleaning is performed.

Limitations

- Sediment control BMPs (SC-1 through SC-10) are not adequate to prevent the discharge of pollutants generated from vehicle and equipment cleaning.

Standards and Specifications

- On-site vehicle and equipment washing is discouraged.
- Prevent disposal of any rinse or wash waters or materials onto impervious or pervious site surfaces or into the storm drain system or watercourses.
- Cleaning of vehicles and equipment with soap, solvents or steam shall not occur on the project site unless the Engineer has been notified in advance and the resulting wastes are fully contained and disposed of offsite in conformance with all applicable laws and regulations. Resulting wastes and by-products shall not be discharged or buried and must be captured and recycled or disposed according to the requirements of WM-6, "Hazardous Waste Management," depending on the waste characteristics. Minimize use of solvents. The use of diesel for vehicle and equipment cleaning is prohibited.
- Vehicle and equipment wash water shall be contained to prevent it from entering the storm drain inlets or watercourses and shall not be discharged on site. Protect drain inlets (SC-10 is not adequate) by covering with plastic to completely block the inlet and do not allow any discharge. Remove plastic after cleaning operations are completed and the water has been disposed of properly.

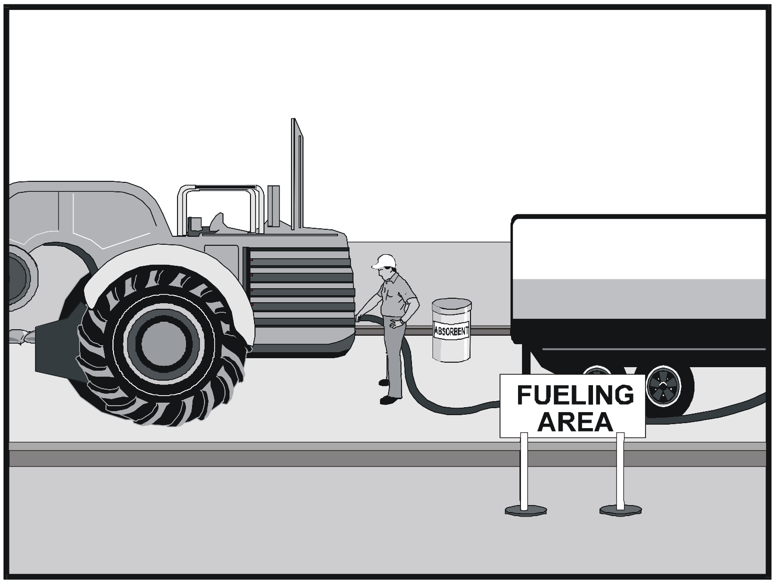
- All vehicles/equipment that regularly enter and leave the construction site shall be cleaned off-site.
- Prevent oil, grease or fuel from leaking onto the ground (impervious or pervious site surfaces) or into the storm drains or surface waters.
- Clean up leaks or spills immediately and dispose of properly in accordance with WM-4.
- When vehicle/equipment washing/cleaning must occur onsite, cleaning area shall have the following characteristics, and shall be approved by the Engineer:
  - Located away from storm drain inlets, drainage facilities, or watercourses.
  - Paved with concrete or asphalt and bermed to contain wash waters and to prevent run-on and runoff.
  - Configured with a sump to allow collection and disposal of wash water.
  - Wash waters shall not be discharged to storm drains or watercourses.
  - Used only when necessary.
- When cleaning vehicles/equipment with water:
  - Use as little water as possible. High pressure sprayers may use less water than a hose, and shall be considered.
  - Use positive shutoff valve to minimize water usage.

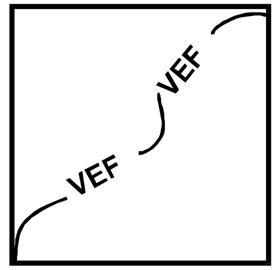
Maintenance and Inspection

- Inspect all entrances, exits, access roads daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect all entrances, exits, access roads at least once every 24 hours.
- Monitor employees and subcontractors throughout the duration of the construction project to ensure appropriate practices are being implemented.
- Remove liquids and sediment as needed or as directed by the Engineer.

Vehicle and Equipment Fueling

NS-9





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Vehicle and equipment fueling procedures and practices are designed to minimize or eliminate the discharge of fuel spills and leaks onto the ground (impervious or pervious site surfaces) or into storm drain systems or to watercourses.

Appropriate Applications

These procedures are applied on all construction sites where vehicle and equipment fueling takes place.

Limitations

- Onsite vehicle and equipment fueling shall only be used where it's impractical to send vehicles and equipment off-site for fueling.

Standards and Specifications

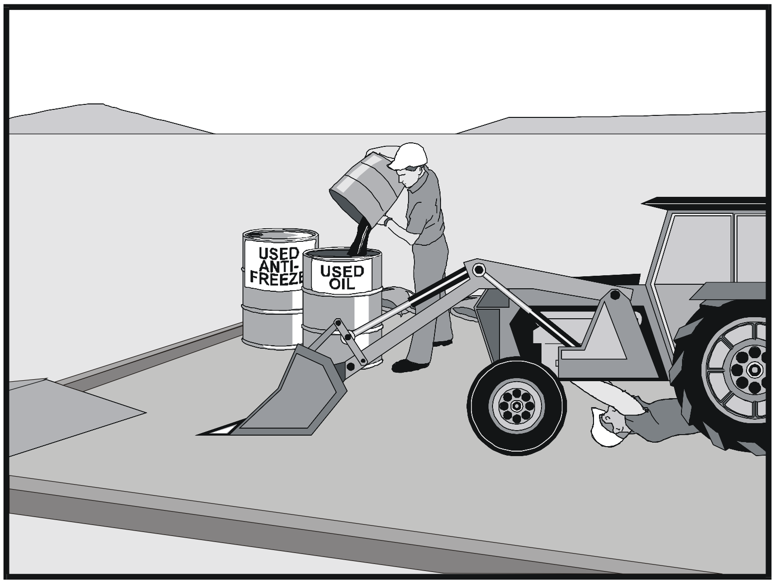
- The contractor shall select and designate an area to be used for fueling. The fueling area shall be identified in the SWPPP or approved by the Engineer for non-SWPPP projects.
- Prevent oil, grease, or fuel to leak in to the ground, offsite, storm drains, surface waters, or water courses.
- Absorbent spill clean-up materials and spill kits shall be available in fueling areas and on fueling trucks and shall be disposed of properly after use.
- Drip pans or absorbent pads shall be used during vehicle and equipment fueling.
- Dedicated fueling areas shall be protected with berms and/or dikes from storm water run-on and runoff, and shall be located at least 50 ft from downstream drainage facilities and watercourses. Fueling must be performed on level-grade areas.
- Nozzles used in vehicle and equipment fueling shall be equipped with an automatic shut-off to control drips and spills. Fueling operations shall not be left unattended.

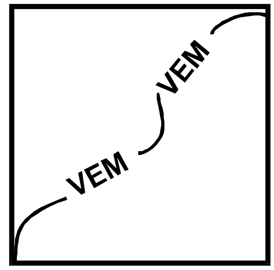
- Comply with applicable local Air Quality Management District regulations with berms and/or dikes District's (AQMD) regulations. Ensure nozzles are secured upright when not in use.
- Fuel tanks shall not be "topped-off."
- Vehicles and equipment shall be inspected on each day of use for leaks. Leaks shall be repaired immediately or problem vehicles or equipment shall be removed from the project site.
- Absorbent spill clean-up materials shall be available in fueling and maintenance areas and used on small spills instead of hosing down or burying techniques. The spent absorbent material shall be removed promptly and disposed of properly.
- Federal, state, and local requirements shall be observed for any stationary above ground storage tanks. Refer to WM-1, "Material Delivery and Storage."
- Mobile fueling of construction equipment throughout the site shall be minimized. Whenever practical, equipment shall be transported to the designated fueling area.

Maintenance and Inspection

- Inspect all fueling areas and operations daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect all entrances, exits, access roads at least once every 24 hours.
- Fueling areas and storage tanks shall be inspected regularly.
- Keep an ample supply of spill cleanup material on the site.
- Immediately cleanup spills and properly dispose of contaminated soil and cleanup materials in accordance with WM-4.

Vehicle and Equipment Maintenance NS-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ○ Materials and Waste Management

Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of pollutants to the storm drain systems or to watercourses from vehicle and equipment operation, maintenance, and modification procedures.

Appropriate Applications

These procedures are applied on all construction projects for storage, operation, and maintenance of heavy equipment and vehicles.

Limitations

- None identified.

Standards and Specifications

- Place all vehicles or equipment to be maintained or stored in a designated and dedicated area.
- Use off-site maintenance facilities whenever practical.
- The vehicles or equipment maintenance and storage areas shall be identified in the SWPPP or approved by the Engineer for non-SWPPP projects.
- Dedicated maintenance areas shall be protected from storm water run-on and runoff, and shall be located at least 50 ft from downstream drainage facilities and watercourses.
- Prevent oil, grease, or fuel to leak in to ground (impervious or pervious site surfaces), storm drains, or watercourses.
- Clean spills and leaks immediately and dispose of leaked materials and cleanup waste properly in accordance with WM-4.
- Drip pans or absorbent pads shall be used during all vehicle and equipment maintenance work
- All maintenance areas are required to have spill kits (see WM-4) and/or use other spill protection devices.

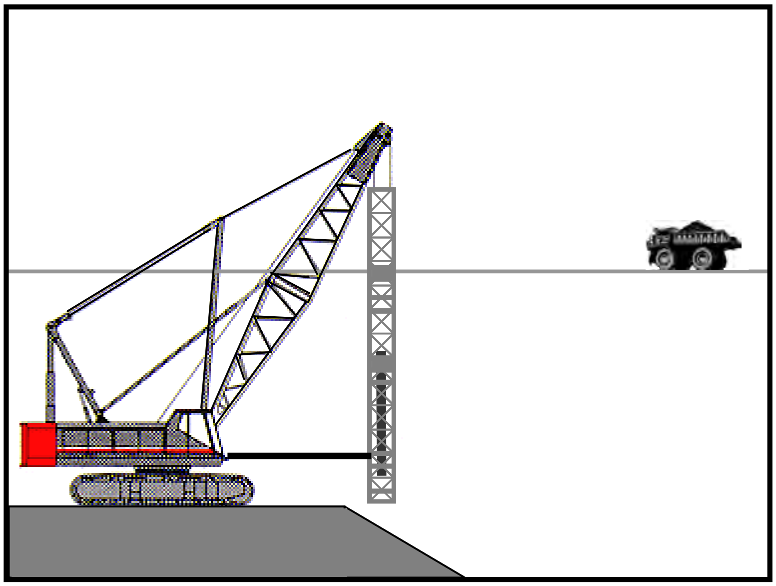
- Absorbent spill clean-up materials shall be available in maintenance areas and shall be disposed of properly after use.
- For long-term projects, consider constructing roofs or using portable tents over maintenance areas.
- Properly dispose of used oils, fluids, lubricants, and spill cleanup materials.
- Do not dump oil, fuels and lubricants onto the ground (impervious or pervious site surfaces), storm drain system, or watercourses.
- Properly dispose or recycle used batteries.
- Do not bury used tires.
- Repair fluid and oil leaks immediately.
- Provide spill containment dikes or secondary containment around stored oil and chemical drums per WM-1.

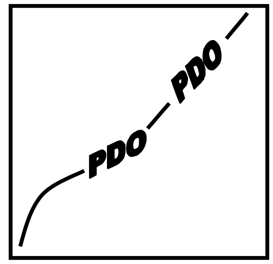
Maintenance and Inspection

- Inspect all vehicle and equipment maintenance areas weekly, and before and after every rainfall events. During extended rainfall events, inspect all vehicle and equipment maintenance areas at least once every 24 hours.
- Maintain waste fluid containers in leak proof condition.
- Vehicles and equipment shall be inspected on each day of use. Leaks shall be repaired immediately or the problem vehicle(s) or equipment shall be removed from the project site. Spills shall be cleaned up in accordance with BMP WM-04 Spill Prevention and Control.
- Inspect equipment for damaged hoses and leaky gaskets routinely. Repair or replace as needed and clean up any spills or leaks immediately.
- Wastes generated from cleanups shall be disposed of in accordance with BMP WM-04 Spill Prevention and Control in compliance with all applicable laws and regulations.

Pile Driving Operations

NS-11





Standard Symbol

BMP Objectives

○ Soil Stabilization
○ Sediment Control
○ Tracking Control
○ Wind Erosion Control
● Non-Storm Water Management
● Materials and Waste Management

Definition and Purpose

The construction and retrofit of bridges and retaining walls often include driving piles for foundation support and shoring operations. Driven piles are typically constructed of concrete, steel, or timber. Driven sheet piles are used for shoring and cofferdam construction. Proper control and use of equipment, materials, and waste products from pile driving operations will reduce the discharge of potential pollutants to the storm drain system or watercourses.

Appropriate Applications

These procedures apply to all construction sites where permanent and temporary pile driving operations (impact and vibratory), including operations using pile shells for construction of cast-in-steel-shell and cast-in-drilled-hole piles.

Limitations

- None identified.

Standards and Specifications

- Use drip pans or absorbent pads under all pile driving equipment during use or storage. Plastic sheeting is not a substitute for drip pans or absorbent pads. Refer to BMPs NS-9 “Vehicle and Equipment Fueling” and NS-10 “Vehicle and Equipment Maintenance.”

- All hydraulic hose connections shall be “capped and bagged” when disconnected.

- Have spill kits and cleanup materials available at all locations of pile driving. Refer to BMP WM-4 “Spill Prevention and Control.”

- Implement other BMPs as applicable, such as WM-5 “Solid Waste Management,” WM-6 “Hazardous Waste Management,” and WM-10 “Liquid Waste Management.”

- When not in use, store pile driving equipment away from concentrated flows of storm water, drainage courses, and inlets. Protect hammers and other hydraulic attachments from run-on by placing them on and covering them with plastic sheeting or a comparable material.

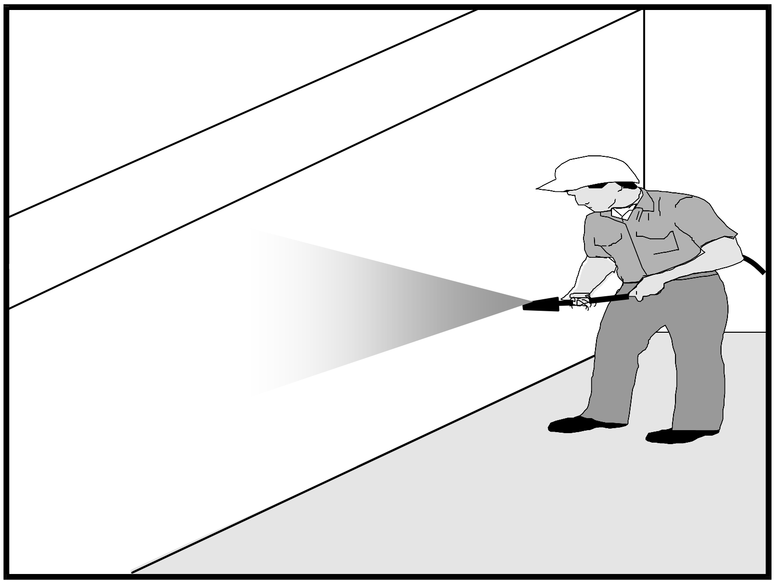
- Use less hazardous products, e.g. vegetable oil instead of hydraulic fluid, when practicable.

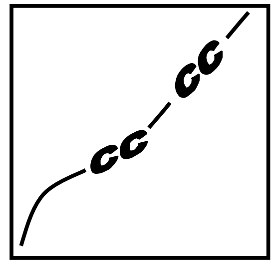
Maintenance and Inspection

- Inspect all pile driving equipment daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect all pile driving equipment areas at least once every 24 hours.

Concrete Curing

NS-12





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Concrete curing is used in the construction of structures such as bridges, retaining walls, and pump houses. Concrete curing includes the use of both chemical and water methods. Proper procedures minimize pollution of runoff during concrete curing.

Appropriate Applications

All concrete elements of a structure (e.g., footings, columns, abutments, stems, soffit, deck) are subject to curing requirements.

Limitations

- None identified.

Standards and Specifications

Chemical Curing

- Prevent over-spray or drift of curing compounds by applying the curing compound close to the concrete surface. Apply an amount of compound that covers the surface, but does not allow any runoff of the compound.
- Use proper storage and handling techniques for concrete curing compounds. Refer to BMP WM-1, "Material Delivery and Storage."
- Protect drain inlets prior to the application of curing compounds.
- Refer to WM-4, "Spill Prevention and Control."
- Apply cure water in a manner the does not produce runoff or result in a non-storm-water discharge.
- Prevent cure water from discharging to the ground, storm drain system and watercourses to collection areas for removal as approved by the Engineer and in accordance with all applicable permits, laws and regulations.
- Utilize wet blankets or a similar method that maintains moisture while minimizing the use and possible discharge of water.

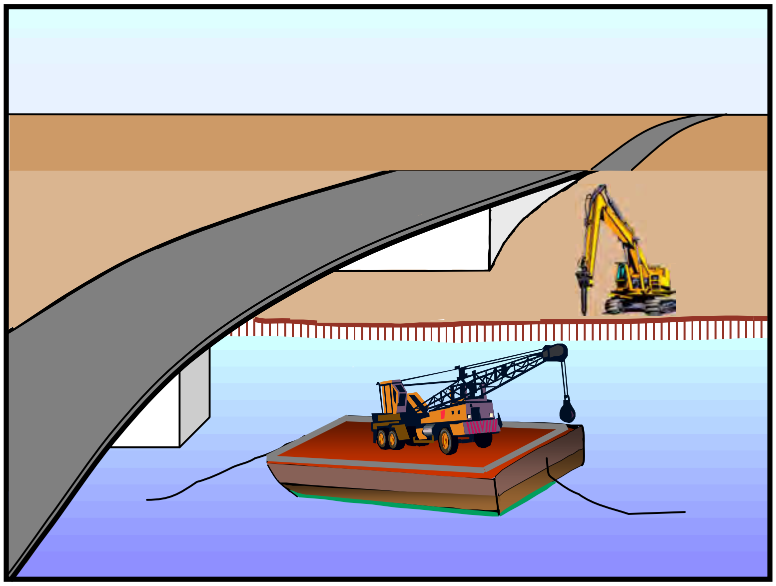
Concrete Curing

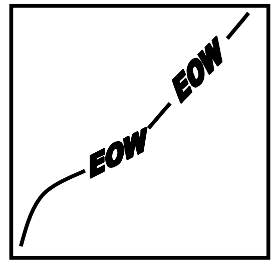
Maintenance and Inspection

- Inspect all concrete curing operations and equipment weekly, and before and after every rainfall events. During extended rainfall events, inspect all concrete curing operations and equipment at least once every 24 hours.
- Ensure that employees and subcontractors implement appropriate measures for storage, handling, and use of curing compounds.
- Inspect cure containers and spraying equipment for leaks. Repair leaks immediately.

Material and Equipment Use Over Water

NS-13





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures for the proper use, storage, and disposal of materials and equipment on bridges, barges, boats, temporary construction pads, or similar locations that minimize or eliminate the discharge of potential pollutants to a watercourse.

Appropriate Applications

These procedures shall be implemented for construction materials and wastes (solid and liquid) and any other materials that may be detrimental if released. Applies where materials and equipment are used on bridges, barges, boats, docks, and other platforms over or adjacent to a watercourse.

Limitations

- Fully comply with the specific permit requirements or mitigation measures identified in the contract Special Provisions and all regulatory permits, such as Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit, California Department of Fish and Game Streambed Alteration Agreement, and US Forest Service Permits. Comply with all water quality monitoring and numerical-based water quality standards identified in the contract Special Provisions and all regulatory permits.

Standards and Specifications

- The Contractor shall submit to the Engineer a Debris Containment and Collection Plan per the contract Special Provisions for debris produced when working over or adjacent to watercourses.
- If the contract Special Provisions do not contain requirements for a Debris Containment and Collection Plan, then the Contractor shall prepare a Debris Containment and Collection Plan, per this BMP, and submit it to the Engineer for approval prior to conducting any work over a watercourse.
- The Debris Containment and Collection Plan shall be designed by a professional Engineer registered with the State of California. The Debris Containment and Collection Plan shall be included in the SWPPP.

- The Debris Containment and Collection Plan shall contain at a minimum the following information:
  - Debris containment method
  - Diagrammatic Plans showing locations of equipment, drums/bins, and any other containment apparatus
  - Emergency Response and Spill Response Plan
  - Working drawings of any containment system
  - Loads applied to the existing bridge structure by any containment structure
  - Provisions for ventilation and air movement for visibility and worker safety
  - Manufacturers' instructions on the proper use of equipment.
- The debris containment method shall fully contain all water, debris, and visible dust produced. Including all water, debris, and visible dust produced from abrasive blasting or any other blast cleaning methods.
- The containment structure shall be supported with either rigid or flexible supports. The rigid or flexible containment materials on the containment structure shall retain airborne particles, but may allow air flow through the containment materials. Flexible materials shall be supported and fastened to prevent escape of abrasive and blast materials due to whipping from traffic or wind and to maintain the clearances.
- All joints shall be sealed. Sealing may be by overlapping of seams when using flexible materials or by using tape, caulking, or other sealing measures.
- If at any time during the execution of the work, the containment system fails to contain all water, debris, or dust , the Contractor shall immediately suspend all operations except those intended to minimize adverse impact to the environment. Operations shall not resume until modifications have been made to correct the cause of the failure.
- Debris produced when cleaning shall not be temporarily stored on the ground or pavement. Debris accumulated inside the containment system shall be removed before the end of each work shift. Debris shall be stored in approved, leak proof containers and shall be handled in such a manner that no spillage will occur. Do not allow demolished material to enter waterway.
- Drip pans shall be placed under all vehicles and equipment placed on bridges, docks, barges, or other structures over water bodies when the vehicle or equipment is expected to be idle for more than one hour. Ensure that an adequate supply of spill cleanup materials is available.

- Refer to BMPs WM-1, "Material Delivery and Storage" and WM-4, "Spill Prevention and Control."
- Maintain equipment in accordance with BMP NS-10, "Vehicle and Equipment Maintenance." If a leaking line cannot be repaired, remove equipment from over the water and the construction site.
- Provide watertight curbs or toe boards to contain spills and prevent materials, tools, and debris from leaving the bridges, barge, platform, dock, etc.
- Secure all materials to prevent discharges to receiving waters via wind.
- Identify types of spill control measures to be employed, including the storage of such materials and equipment. Ensure that staff are trained regarding the deployment and access of control measures and that measures are being used.
- Comply with all necessary permits required for construction within or near the watercourse, such as RWQCB, U.S. Army Corps of Engineers, Department of Fish and Game and other local permitting agencies.
- Discharges to waterways shall be reported to the Engineer immediately upon discovery. A written discharge notification must follow within 5 days.
- Refer to BMP NS-15, "Structure Demolition/Removal Over or Adjacent to Water."

Maintenance and Inspection

- Inspect materials and equipment and containment methods daily and document weekly and before and after rainfall events. During extended rainfall events, inspect materials and equipment and containment methods at least every 24 hours.
- Inspect equipment for leaks and spills on a daily basis. Repairs leaks and clean up spills immediately.
- Ensure that employees and subcontractors implement appropriate measures for storage and use of materials and equipment.
- Inspect and maintain all associated BMPs and perimeter controls to ensure continuous protection of the watercourse.

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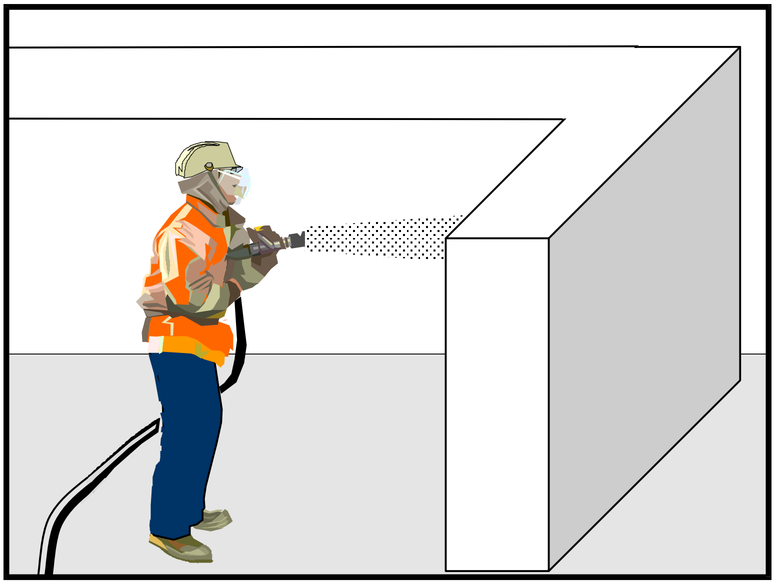
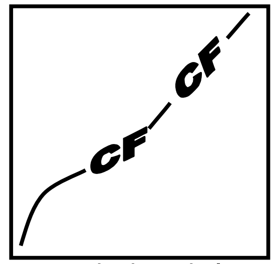
Concrete Finishing

NS-14





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Concrete finishing methods are used for bridge deck rehabilitation, paint removal, curing compound removal, final surface finish appearances, and other construction operations that remove or add to concrete surfaces. Methods include sand blasting, shot blasting, grinding, high pressure water blasting, or other method. Proper procedures minimize the impact that concrete finishing methods may have on runoff.

Appropriate Applications

These procedures apply to all construction sites where concrete finishing operations are performed.

Limitations

- None identified

Standards and Specifications

- If the contract Special Provisions do not contain requirements for a Debris Containment and Collection Plan, then the Contractor shall prepare a Debris Containment and Collection Plan, per this BMP, and submit it to the Engineer for approval prior to conducting any work over a watercourse.
- Submit MSDS of all shot blasting material not previously disclosed in submittals to the Engineer for approval 7 days prior to operation.
- Collect and properly dispose of water and solid waste from high-pressure water blasting operations in accordance with spill disposal procedures in WM-4.
- Do not allow slag or other shot blasting material to contact the soil or surrounding areas. Protect all areas with plastic sheeting to prevent discharge to soil or surrounding areas.
- Protect inlets during sandblasting operations by covering them with filter fabric during finishing operations.

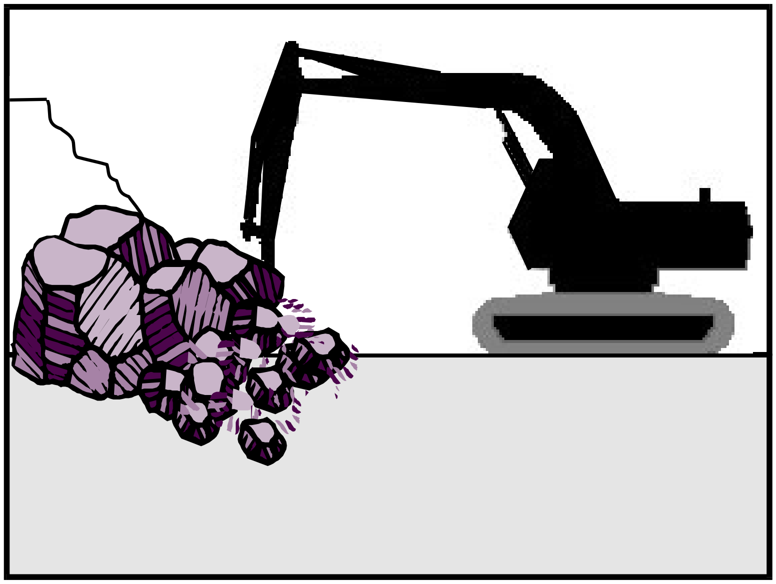
- Refer to BMP WM-8, "Concrete Waste Management."
- Minimize the drift of dust and blast material as much as possible by keeping the blasting nozzle close to the surface.
- When blast residue contains a potentially hazardous waste, refer to BMP WM-6, "Hazardous Waste Management."
- Debris produced when cleaning shall not be temporarily stored on the ground or pavement. Debris accumulated inside the containment system shall be removed before the end of each work shift. Debris shall be stored in approved, leak proof containers and shall be handled in such a manner that no spillage will occur.
- The Contractor shall disposed of the debris generated at a facility equipped to recycle the debris, is subject to the following requirements:
  - An exclusively recyclable material (ERM) such as Copper slag abrasive blended by the supplier with a calcium silicate compound shall be used for blast cleaning.
  - If cleaning or finishing metal surfaces, the debris produced shall be tested by using Title 22 of the California Code of Regulations CAM Metals Method, and 40 CFR Part 268 Method. The Contractor to confirm that the Soluble Threshold Limit Concentrations (STLC), the Total Threshold Limit Concentrations (TTLC), and the Toxicity Characteristic Leaching Procedure (TCLP) of the heavy metals are below regulatory limits and the debris may be transported to the recycling facility as a non-hazardous waste.
  - The Contractor shall make all arrangements with the recycling facility and perform any testing required by the recycling facility operator, or in compliance with regulations.
  - The Contractor shall specify to the Agency, the name, location and Statement of Qualifications (SOQs) of the recycling facility for review and approval by the Agency.

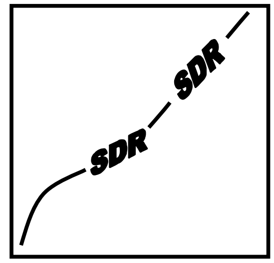
Maintenance and Inspection

- Inspect concrete finishing operations weekly and before and after rainfall events. During extended rainfall events, inspect concrete finishing operations at least every 24 hours.

Structure Demolition/Removal Over or Adjacent to Water

NS-15





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures to protect water bodies from debris and wastes associated with structure demolition or removal over or adjacent to watercourses.

Appropriate Applications

Full bridge demolition and removal, partial bridge removal (e.g., barrier rail, edge of deck), concrete channel removal, outfall structure construction/repair, or any other structure removal that could potentially affect water quality.

Limitations

- Fully comply with the specific permit requirements or mitigation measures identified in the contract Special Provisions and all regulatory permits, such as Regional Water Quality Control Board (RWQCB) 401 Certification, U.S. Army Corps of Engineers 404 permit, California Department of Fish and Game Streambed Alteration Agreement, and US Forest Service Permits. Comply with all water quality monitoring and numerical-based water quality standards identified in the contract Special Provisions and all regulatory permits.

Standards and Specifications

- The Contractor shall submit to the Engineer a Debris Containment and Collection Plan per the contract Special Provisions for debris produced when working over or adjacent to watercourses.
- If the contract Special Provisions do not contain requirements for a Debris Containment and Collection Plan, then the Contractor shall prepare a Debris Containment and Collection Plan, per this BMP, and submit it to the Engineer for approval prior to conducting any work over a watercourse.
- The Debris Containment and Collection Plan shall be designed by a professional Engineer registered with the State of California. The Debris Containment and Collection Plan shall be included in the SWPPP.

- The Debris Containment and Collection Plan shall contain at a minimum the following information:
  - Debris containment method
  - Diagrammatic Plans showing locations of equipment, drums/bins, and any other containment apparatus
  - Emergency Response and Spill Response Plan
  - Working drawings of any containment system
  - Loads applied to the existing bridge structure by any containment structure
  - Provisions for ventilation and air movement for visibility and worker safety
  - Manufacturers' instructions on the proper use of equipment.
- The debris containment method shall fully contain all water, debris, and visible dust produced. Including all water, debris, and visible dust produced from abrasive blasting or any other blast cleaning methods.
- The containment structure shall be supported with either rigid or flexible supports. The rigid or flexible containment materials on the containment structure shall retain airborne particles, but may allow air flow through the containment materials. Flexible materials shall be supported and fastened to prevent escape of abrasive and blast materials due to whipping from traffic or wind and to maintain the clearances.
- All joints shall be sealed. Sealing may be by overlapping of seams when using flexible materials or by using tape, caulking, or other sealing measures.
- If at any time during the execution of the work, the containment system fails to contain all water, debris, or dust , the Contractor shall immediately suspend all operations except those intended to minimize adverse impact to the environment. Operations shall not resume until modifications have been made to correct the cause of the failure.
- Debris produced when cleaning shall not be temporarily stored on the ground or pavement. Debris accumulated inside the containment system shall be removed before the end of each work shift. Debris shall be stored in approved, leak proof containers and shall be handled in such a manner that no spillage will occur. Do not allow demolished material to enter waterway.
- Refer to BMPs WM-1, "Material Delivery and Storage" and WM-4, "Spill Prevention and Control."
- Drip pans shall be placed under all vehicles and equipment placed on bridges, docks, barges, or other structures over water bodies when the vehicle or equipment is expected to be idle for more than one hour. Ensure that an adequate supply of spill cleanup materials is available.

- Maintain equipment in accordance with BMP NS-10, "Vehicle and Equipment Maintenance." If a leaking line cannot be repaired, remove equipment from over the water and the construction site.
- Refer to BMP NS-5, "Clear Water Diversion" to direct water away from work areas.
- Use attachments on construction equipment such as backhoes to catch debris from small demolition operations.
- Stockpile accumulated debris and waste generated during demolition away from watercourses and in accordance with BMP WM-3, "Stockpile Management."
- Ensure safe passage of wildlife, as necessary.
- Discharges to waterways shall be reported to the Engineer immediately upon discovery. A written discharge notification must follow within 5 days.
- For structures containing hazardous materials (e.g., lead paint or asbestos) refer to BMP WM-6, "Hazardous Waste Management." For demolition work involving soil excavation around lead-painted structures, refer to BMP WM-7, "Contaminated Soil Management."

Ventilated Containment Structure

- Multiple flap overlapping door tarps shall be used at entry ways to the ventilated containment structure to prevent dust or debris from escaping.
- Baffles, louvers, flapper seals or ducts shall be used at make-up air entry points to the ventilated containment structure to prevent escape of abrasives and resulting surface preparation debris.
- The ventilation system in the ventilated containment structure shall be of the forced input air flow type with fans or blowers.
- Negative air pressure shall be employed within the ventilated containment structure and will be verified by visual methods by observing the concave nature of the containment materials while taking into account wind effects or by using non-hazardous smoke or other visible means to observe air flow. The input air flow shall be properly balanced with the exhaust capacity throughout the range of operations.
- The exhaust air flow of the ventilation system in the ventilated containment structure shall be forced into dust collectors (wet or dry) or bag houses with HEPA collection efficiency.

Maintenance and Inspection

- Inspect containment methods daily and document weekly and before and after rainfall events. During extended rainfall events, inspect containment methods at least every 24 hours.
- Any debris-catching devices shall be emptied regularly. Collected debris shall be removed and stored away from the watercourse and protected from run-on and runoff.

Temporary Batch Plant

NS-16

---TBP---

Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

A temporary batch plant is often needed during the construction of roads, bridges, and other large structures in remote areas. Their purpose is for the manufacture of Portland Cement Concrete (PCC), asphalt concrete (AC), slurries, and grouts. These temporary facilities generally consist of fly ash, lime, and cement; heated tanks of liquid asphalt; sand and gravel material storage areas; mixing equipment; above ground storage tanks for concrete additives and water; and designated areas for sand and gravel truck unloading, concrete truck loading, and concrete truck washout. Proper control and use of equipment, materials, and waste will reduce the discharge of potential pollutants to the underlying ground or surrounding areas, offsite, to the storm drain system or watercourses, reduce air emissions, and mitigate noise impacts.

Appropriate Applications

These controls are required on construction sites where temporary batch plant facilities are employed.

Limitations

■

Standards and Specifications

General Requirements

- ■ Temporary batch plants may be subject to the General Industrial NPDES Permit. Compliance with this permit requires the submittal of a Notice of Intent (NOI) to the State Water Resources Control Board (SWRCB).
- ■ Proper planning, design, and construction of the facilities shall be implemented to minimize potential water quality, air quality, and noise impacts associated with the use of temporary batch plants.
- ■ Temporary batch plant shall comply with all County or City ordinances, the Air Resources Board (ARB), Air Quality Management District (AQMD), and Regional Water Quality Control Board (RWQCB) may require alternative mitigation measures for temporary batch plants.
- ■ Temporary batch plants shall be managed to comply with AQMD Portable Equipment Registration requirements, South Coast AQMD Rule 403.

Location and Design

- Temporary batch plants and access roads shall be properly located and designed to reduce water quality impacts to receiving water bodies. Batch plants shall be located a minimum of 50 feet from watercourses, drainage courses, and drain inlets. Batch plants shall be located to minimize the potential for storm water to run onto the site.
- Construct continuous interior AC or PCC berms around the batch plant equipment to facilitate proper run-on, containment and cleanup of releases. Rollover or flip top curb or dikes shall be placed at entrance and exit points.
- Direct runoff from the paved portion of the batch plants into a sump and pipe to a lined washout area or dewatering tank.
- Direct storm water and non-storm water runoff from unpaved portions of the batch plant facility to catchment ponds or tanks.
- Construct and remove concrete washout facilities in accordance with WM-8, Concrete Waste Management.
- A recommended layout of a typical batch plant and associated BMPs is located at the end of this BMP description sheet. If the layout planned is different than attached layout, a complete drawing shall be submitted to the engineer for approval.

Operational Requirements

- Washout of concrete trucks shall be conducted in a designated area, in accordance with WM-8, Concrete Waste Management.
- Do not dispose of concrete offsite or into drain inlets, the storm water drainage system, or watercourses. There shall be no discharge, spills or leaks of concrete waste into the underlying soil or onto surrounding areas.
- Equipment washing shall occur in a designated area in accordance with WM-8. Washing equipment, tools, or vehicles for removal of PCC shall be conducted in accordance with non-storm water management BMPs, NS-7, Potable Water/Irrigation, an NS-8, Vehicle and Equipment Cleaning.
- All dry material transfer points shall be ducted through a fabric or cartridge type filter unless there are no visible emissions from the transfer plant.
- Equip all bulk storage silos, including auxiliary bulk trailers, with a fabric or cartridge type filters.
- Maintain silo vent filters in proper operating condition.
- Equip silos and auxiliary bulk storage trailers with dust-tight service hatches.
- Fabric dust collectors (except for vent filters) shall be equipped with an operational pressure differential gauge to measure the pressure drop across

the filters.

- All transfer points shall be equipped with a wet suppression system to control fugitive particulate emissions unless there are no visible emissions.

- There shall be no visible emissions beyond the property line, while the equipment is being operated.

- Collect dust emissions from the loading of open-bodied trucks at the drip point of dry batch plants, or dust emissions from the drum feed for central mix plants.

- Equip silos and auxiliary bulk storage trailers with a visible and/or audible warning mechanism to warn operators that the silo or trailer is full.

- All open-bodied vehicles transporting material shall be loaded with a final layer of wet sand and the truck shall be covered with a tarp to reduce emissions.

Tracking Controls

- Related roads (batch truck and material delivery truck roads) and areas between stockpiles and conveyor hoppers shall be stabilized (TC-2, Stabilized Construction Roadway), or paved with a cohesive hard surface that can be repeatedly swept, maintained intact, and cleaned as necessary to control dust emissions.

- Trucks shall not track PCC from plants onto public roads. Use appropriate practices from TC-1 Stabilized Construction Entrance/Exit and/or TC-3 Entrance/Outlet Tire Wash, to prevent tracking of sediment from the site.

Material Storage Controls

- BMP WM-1, Material Delivery and Storage, shall be implemented at all batch plants using concrete components or compounds. Cover and contain materials as required by the contract Special Provisions.

- BMP WM-2, Material Use shall be conducted in a way to prevent the discharge of materials to the storm drain system or watercourses.

- Prevent finer materials from being dispersed into the air during operations, such as unloading of cement delivery trucks.

- Stockpiles shall be covered and bermed with perimeter sediment barriers per WM-3, Stockpile Management. Provide secondary containment for all liquid materials (as per WM-1). Handle solid and liquid waste in accordance with WM-5, Solid Waste Management, WM-10, Liquid Waste Management, and WM-8, Concrete Waste Management.

- Maintain adequate supplies of spill cleanup materials and train staff to respond to spills per WM-4, Spill Prevention and Control.

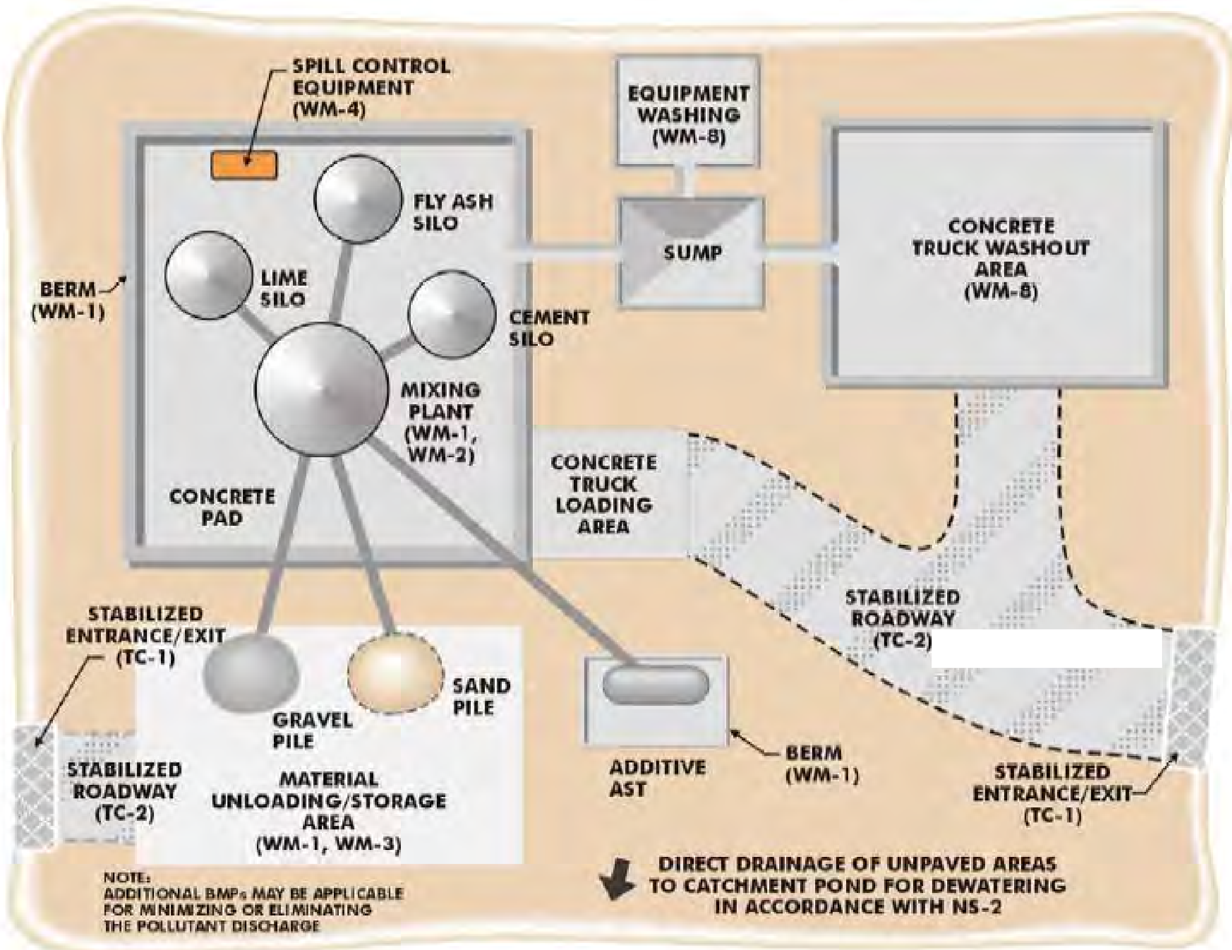
- Immediately clean up spilled cement and fly ash and contain or dampen so that dust or emissions from wind erosion or vehicle traffic are minimized.

Equipment Maintenance BMPs

- Equipment shall be maintained to prevent fluid leaks and spills per NS-9, Vehicle and Equipment Fueling, and NS-10, Vehicle and Equipment Maintenance.
- Incorporate other BMPs such as WM-5, Solid Waste Management, WM-6, Hazardous Waste Management, and WM-10, Liquid Waste Management.

Maintenance and Inspection

- Inspect all components of the temporary batch plant operations and equipment weekly, and before and after every rainfall events. During extended rainfall events, inspect all components of the temporary batch plant operations and equipment at least once every 24 hours.
- Inspect and verify that controls are in place prior to the commencement of associated activities.
- Inspect and repair equipment, including damaged hoses, fittings, and gaskets.



Typical Temporary Batch

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SECTION 8

WASTE MANAGEMENT AND

MATERIAL POLLUTION CONTROL BMPS

Waste management and material pollution control BMPs consist of source control measures to prevent non-storm water pollution by limiting or preventing potential pollutants at the source before they come into contact with storm water. These waste management and material pollution control BMPs are also referred to as "good housekeeping practices" which involve day-to-day operations of the construction site and contractor's yard in order to maintain a clean, orderly, and safe construction site. Waste Management and Material Pollution Control BMPs are shown on Table 8-1.

Table 8-1
Waste Management and
Material Pollution Control BMPs

ID	BMP Name
Material Pollution Control	
WM-1	Material Delivery and Storage
WM-2	Material Use
WM-3	Stockpile Management
Waste Management	
WM-4	Spill Prevention and Control
WM-5	Solid Waste Management
WM-6	Hazardous Waste Management
WM-7	Contaminated Soil Management
WM-8	Concrete Waste Management
WM-9	Sanitary/Septic Waste Management
WM-10	Liquid Waste Management

8.1. Material Pollution Control BMPs

Material pollution control BMPs (also referred as materials handling) consist of implementing procedural and structural BMPs for the handling, storage, and use of construction material to prevent the discharge of those materials to the ground, paved surfaces, storm drain system or watercourses. The objective of material pollution control BMPs is to limit or prevent potential pollutants at the source before they come into contact with storm water and prevent contamination to the underlying soil.

8.2. Waste Management BMPs

Waste management BMPs consists of implementing procedural and structural BMPs for the handling, storage, and disposal of construction waste to prevent the release of those wastes to the storm drain system or watercourses. The objective of waste management BMPs is to limit or prevent potential pollutants at the source before they come into contact with storm water and prevent contamination to the underlying soil..

8.2.1 Hazardous Waste Management

The handling, storage, and disposal of all hazardous waste or other waste that requires special handling shall be in full compliance with the contract Special Provisions. All Contractor operations shall be in full compliance with the all applicable laws and regulations that govern the management of hazardous and other waste.

If suspected hazardous waste or other waste that requires special handling is encountered on the construction site and the contract Special Provisions do **not** include provisions for the management of such waste, the Contractor shall immediately notify the Engineer for direction.

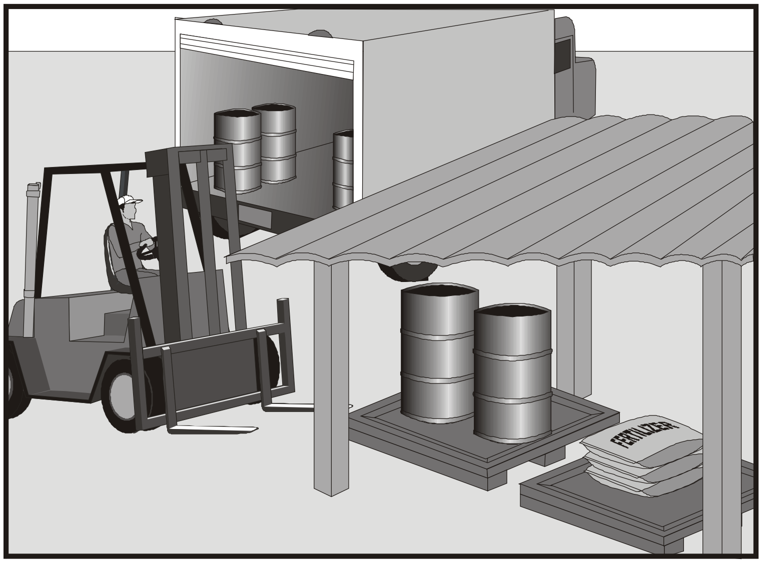
8.2.2 Contaminated Soil Management

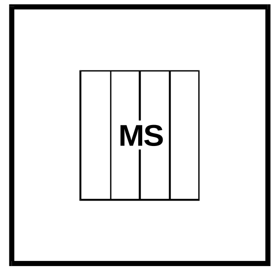
The handling, storage, and disposal of all contaminated soil shall be in full compliance with the contract Special Provisions. All Contractor operations shall be in full compliance with all applicable laws and regulations that govern the management of contaminated soil.

If suspected contaminated soil is encountered on the construction site and the contract Special Provisions do **not** include provisions for the management of contaminated soil, the Contractor shall immediately notify the Engineer for direction.

Material Delivery and Storage

WM-1





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures and practices for the proper handling and storage of materials in a manner that minimizes or eliminates the discharge of these materials to the ground, storm drain system or to watercourses.

Appropriate Applications

These procedures are implemented at all construction sites with delivery and storage of but not limited to the following:

- Hazardous chemicals such as:
  - Acids/limes
  - glues,
  - adhesives,
  - paints/solvents, and
  - curing compounds.
- Soil stabilizers and binders.
- Fertilizers.
- Detergents.
- Plaster.
- Petroleum products such as fuel, oil, and grease.
- Asphalt and concrete components.
- Pesticides and herbicides.
- Other materials that may be detrimental if released to the environment.

Limitations

None identified.

Standards and Specifications

General

- Train employees and subcontractors on the proper material delivery and storage practices.
- Temporary storage areas shall be located away from vehicular traffic.
- Material Safety Data Sheets (MSDS) shall be supplied to the Engineer for all materials stored or used on the project.

Material Storage Areas and Practices

- Store chemicals in watertight containers (with appropriate secondary containment to prevent any spillage or leakage) or in a storage shed (completely enclosed).
- Minimize exposure of construction materials to precipitation.
- Liquids, petroleum products, and substances listed in 40 CFR Parts 110, 117, or 302 shall be stored in approved containers and drums and shall be placed in temporary containment facilities for storage.
- Each temporary containment facility shall have a permanent cover and side wind protection or be covered when not being used and prior to and during rain events.
- A temporary containment facility shall provide for a spill containment volume able to contain precipitation from a 24-hour, 25-year storm event, plus 110% of the capacity of the largest container within its boundary.
- A temporary containment facility shall be impervious to the materials stored therein for a minimum contact time of 72 hours.
- A temporary containment facility shall be maintained free of accumulated rainwater and spills. In the event of spills or leaks, accumulated rainwater and spills shall be collected and placed into drums. These liquids shall be handled as a hazardous waste unless testing determines them to be non-hazardous. All collected liquids or non-hazardous liquids shall be sent to an approved disposal site in accordance with WM-5 and WM-6.
- Sufficient separation shall be provided between stored containers to allow for spill cleanup and emergency response access.
- Incompatible materials, such as chlorine and ammonia, shall not be stored in the same temporary containment facility.
- Materials shall be stored in their original containers and the original product labels shall be maintained in place in a legible condition. Damaged or otherwise illegible labels shall be replaced immediately. Unlabeled containers

shall not be stored onsite and shall be disposed of immediately in accordance with WM-5 and WM-6.

- Bagged and boxed materials shall be stored on pallets and shall not be allowed on the ground. To provide protection from wind and rain, bagged and boxed materials shall be covered when not being actively used and prior to rain events. Broken boxes or bags shall be immediately contained or disposed of properly in accordance with WM-5 and WM-6.
- Stockpiles shall be protected in accordance with BMP WM-3, "Stockpile Management."
- Minimize the material inventory stored on-site (e.g., only a few days supply).
- Have proper storage instructions posted at all times in an open and conspicuous location.
- Do not store hazardous chemicals, drums, or bagged materials directly on the ground. Dry items shall be placed on a pallet and covered. Liquids shall be placed in secondary containment and covered.
- Contain all fertilizers and other landscape materials when they are not actively being used.
- Stack erodible landscape material on pallets and cover stored landscaped materials when not being used or applied.
- Keep ample supply of appropriate spill clean up material near storage areas.

Material Delivery Practices

- Keep an accurate, up-to-date inventory of material delivered and stored on-site.
- Employees trained in emergency spill clean-up procedures shall be present when dangerous materials or liquid chemicals are unloaded.

Spill Clean-up

- Contain and clean up all liquid or dry spills or leaked material immediately and dispose of properly in accordance with WM-5 or WM-6.
- If residual materials are on the ground after construction is complete, properly remove and dispose any hazardous materials or contaminated soil in accordance with WM-5 and WM-6.
- Use BMP WM-4, "Spill Prevention and Control," for cleanup procedures of spills of chemicals and/or hazardous materials.

Maintenance and Inspection

- Inspect all material delivery and storage areas weekly, and before and after every rainfall events. During extended rainfall events, inspect all material delivery and storage areas at least once every 24 hours.
- Storage areas shall be kept clean, well organized, and equipped with ample clean-up supplies as appropriate for the materials being stored.
- Perimeter controls, containment structures, covers, and liners shall be repaired or replaced as needed to maintain proper function.

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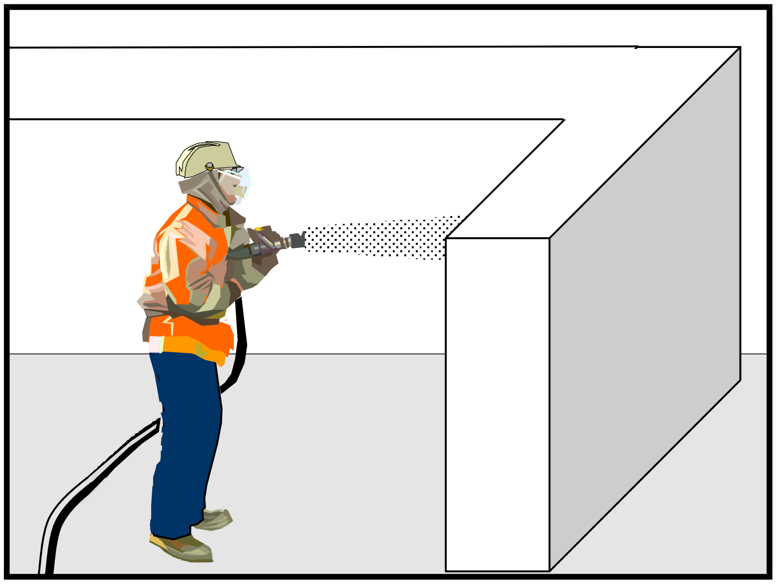
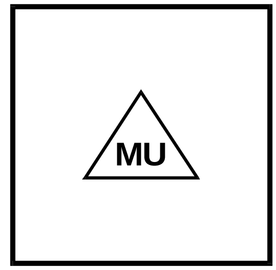
Material Use

WM-2





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices for use of construction material in a manner that minimizes or eliminates the discharge of these materials to the ground, storm drain system or to watercourses.

Appropriate Applications

This BMP applies to all construction sites. These procedures apply but are not limited to when the following materials are used or prepared on site:

- Hazardous chemicals such as:
  - Acids/lime,
  - glues,
  - adhesives,
  - paints/solvents, and
  - curing compounds.
- Soil stabilizers and binders.
- Fertilizers.
- Detergents.
- Plaster.
- Petroleum products such as fuel, oil, and grease.
- Asphalt and concrete components.
- Pesticides and herbicides.
- Other materials that may be detrimental if released to the environment.

Limitations

- Safer alternative building and construction products may not be available or suitable in every instance.

Standards and Specifications

- Material Safety Data Sheets (MSDS) shall be supplied to the Engineer for all materials stored or used on the project.
- Latex paint and paint cans, used brushes, rags, absorbent materials, and drop cloths, when thoroughly dry and are no longer hazardous, may be disposed of with other construction debris.
- Do not remove the original product label, it contains important safety and disposal information. Use the entire product before disposing of the container.
- Mix paint indoors, or in a containment area. Never clean paintbrushes or rinse paint containers into a street, gutter, storm drain or watercourse. Dispose of any paint thinners, residue and sludge(s), that cannot be recycled, as hazardous waste.
- For water-based paint, clean brushes to the extent practical, and rinse to a drain leading to a sanitary sewer where permitted, or into a concrete washout pit. For oil-based paints, clean brushes to the extent practical and filter and reuse thinners and solvents.
- Use recycled and less hazardous products when practical. Recycle residual paints, solvents, non-treated lumber, and other materials.
- Use materials only where and when needed to complete the construction activity. Use safer alternative materials as much as possible. Reduce or eliminate use of hazardous materials on-site when practical.
- Do not over-apply fertilizers and pesticides. Prepare only the amount needed. Strictly follow the recommended usage instructions. Apply surface dressings in smaller applications, as opposed to large applications, to allow time for it to work in and to avoid excess materials being carried off-site by runoff.
- Discontinue the application of any erodible landscape material within 2 days before a forecasted rain event or during periods of precipitation.
- Apply erodible landscape material at quantities and application rates according to manufacture recommendations or based on written specifications by knowledgeable and experienced field personnel.
- Application of herbicides and pesticides shall be performed by a licensed applicator.
- Contractors are required to complete the “Report of Chemical Spray Forms” when spraying herbicides and pesticides.
- Keep an ample supply of spill clean up material near use areas. Train employees in spill clean up procedures.

- Avoid exposing applied materials to rainfall and runoff unless sufficient time has been allowed for them to dry.

Maintenance and Inspections

- Inspect all material use areas weekly, and before and after every rainfall events. During extended rainfall events, inspect all material use areas at least once every 24 hours.

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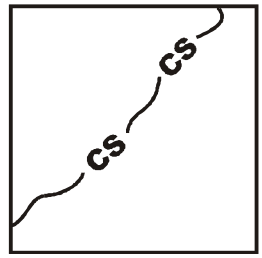
Stockpile Management

WM-3



Standard Symbol

BMP Objectives

- ● Soil Stabilization
- ● Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ○ Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Stockpile management procedures and practices are designed to reduce or eliminate air and storm water pollution from stockpiles of soil, and paving materials such as portland cement concrete (PCC) rubble, asphalt concrete (AC), asphalt concrete rubble, aggregate base, aggregate subbase or pre-mixed aggregate, asphalt binder (so called "cold mix" asphalt), green waste and other materials and wastes.

Appropriate Applications

Implemented in all projects that stockpile soil and other materials and wastes.

Limitations

- None identified

Standards and Specifications

- Protection of stockpiles is a year-round requirement.
- Locate stockpiles a minimum of 50 ft away from concentrated flows of storm water, drainage courses, and inlets.
- Implement wind erosion control practices as appropriate on all stockpiled material. For specific information see BMP WE-1, "Wind Erosion Control".
- All stockpiles shall comply with AQMD Rule 403 requirements.
- Contaminated soil shall not be stockpiled on the project site and be managed in accordance with BMP WM-7, "Contaminated Soil Management."
- Bagged materials should be placed on pallets and covered.
- Do not stockpile pressure treated wood. Pressure treated wood shall be managed in accordance with the contact Special Provisions.

Protection of Stockpiles not Actively Being Used

- Cover and contain loose stockpiled construction materials that are not actively being used (i.e. soil, aggregate, base materials, green waste, etc.) at all times.

Protection of Active Stockpiles

- ***Soil stockpiles and waste stockpiles:***
  - Soil stockpiles shall be covered and protected with a temporary perimeter sediment barrier.
- ***Stockpiles of portland cement concrete rubble, asphalt concrete, asphalt concrete rubble, aggregate base, or aggregate subbase:***
  - The stockpiles shall be covered and protected with a temporary perimeter sediment barrier.
- ***Stockpiles of "cold mix":***
  - Cold mix stockpiles shall be placed on and covered with plastic or comparable material.
- ***Stockpiles of green waste:***
  - Green waste shall be covered and protected with a temporary perimeter sediment barrier.

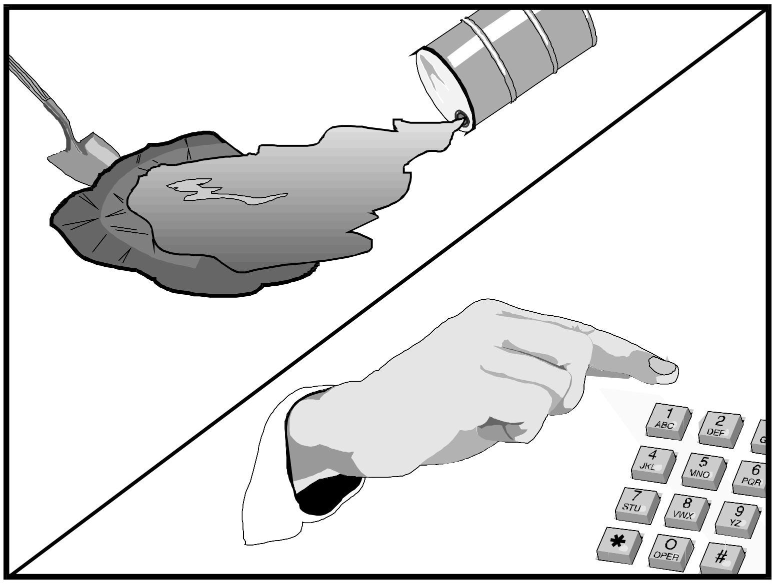
Plastic materials shall be limited when more sustainable products exist. If plastic is used, materials more resistant to photo degradation shall be considered.

Inspection and Maintenance

- Inspect all active and non-active stockpiles weekly, and before and after every rainfall events. During extended rainfall events, inspect all active and non-active stockpiles at least once every 24 hours.
- Repair and/or replace perimeter controls and covers as needed, or as directed by the Engineer, to keep them functioning properly. Sediment shall be removed when sediment accumulation reaches one-third (1/3) of the barrier height. Covers shall be repaired or replaced when they do not cover the entire stockpile or are no longer effective.

Spill Prevention and Control

WM-4



Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These procedures and practices are implemented to prevent, control and clean-up spills in a manner that minimizes or prevents the discharge of spilled material to the permeable or impermeable ground surface, drainage system or watercourses.

Appropriate Application

This best management practice (BMP) applies to all construction projects. Spill control procedures are implemented anytime liquids or dry materials or wastes (including chemicals, hazardous or non-hazardous substances) are stored or used onsite. Substances may include, but are not limited to:

- Soil stabilization products/binders.
- Dust Palliatives.
- Herbicides/Pesticides, Fertilizers
- Deicing/anti-icing chemicals.
- Sanitary wastes
- Fuels, Lubricants, Other petroleum distillates
- Paint solvents and thinners
- Vehicle fluids
- Asphalt and Portland Cement products

Limitations

- Procedures and practices presented in this BMP are general. The Contractor shall identify appropriate practices for the specific materials or wastes used or stored on-site.

Standards and Specifications

- Spills of materials and wastes shall be contained and cleaned up immediately.
- Spills identified during a rain event shall be covered and protected from storm water run-until they can be cleaned up.
- Spills shall not be buried, or washed or cleaned up with water.
- Water shall not be used to clean up spills. Dry methods such as rags and absorbents shall be used. Water used for decontaminating sampling equipment shall not be allowed to enter storm drains or watercourses and shall be collected.
- All collected spill cleanup waste shall be disposed of in accordance with BMP WM-6, "Hazardous Waste Management."
- Water overflow or minor water spillage shall be contained and shall not be allowed to discharge into drainage facilities or watercourses.
- Proper storage, clean-up and spill reporting instruction for hazardous materials stored or used on the project site shall be posted at all times in an open, conspicuous and accessible location.
- Waste storage areas shall be kept clean, well organized and equipped with ample clean-up supplies as appropriate for the materials being stored. Perimeter controls, containment structures, covers and liners shall be repaired or replaced as needed to maintain proper function.

Education

- Educate employees and subcontractors on what a "significant spill" is for each material they use, and what is the appropriate response for "significant" and "insignificant" spills.
- Educate employees and subcontractors on potential dangers to humans and the environment from spills and leaks.
- Hold regular meetings to discuss and reinforce appropriate disposal procedures (incorporate into regular safety meetings).
- Establish a continuing education program to train new employees.
- The Contractor shall oversee and enforce proper spill prevention and control measures and shall ensure appropriate personnel are assigned and trained for spill cleanup.

Cleanup and Storage Procedures

- Equipment and materials for cleanup of spills shall be available on site and spills and leaks shall be cleaned up immediately and disposed of properly.
- Sewage pipeline breaks or spills shall be handled in accordance with the contract special provisions, if applicable. The required plan for sewage spills shall be referenced and described in Section 500.4.6 of the SWPPP, if applicable.
- Minor Spills
  - Minor spills typically involve small quantities of oil, gasoline, paint, etc., which can be controlled by the first responder at the discovery of the spill.
  - Use absorbent materials on small spills. Water shall not be used to clean up spills. Do not bury the spill or spilled materials.
  - Remove the absorbent materials promptly and dispose of properly.
  - The practice commonly followed for a minor spill is:
    - Contain the spread of the spill.
    - Recover spilled materials.
    - Clean the contaminated area and/or properly dispose of contaminated materials.
- Semi-Significant Spills
  - Semi-significant spills still can be controlled by the first responder along with the aid of other personnel such as laborers and the foreman, etc. This response may require the cessation of all other activities.
  - Clean up spills immediately:
    - Notify the project foreman immediately. The foreman shall notify the Engineer.
    - Contain spread of the spill.
    - If the spill occurs on paved or impermeable surfaces, clean up using "dry" methods (absorbent materials, cat litter and/or rags). Contain the spill by encircling with absorbent materials and do not let the spill spread widely.
    - If the spill occurs in dirt areas, immediately contain the spill by constructing an earthen dike. Dig up and properly dispose of contaminated soil.
    - If the spill occurs during rain, cover spill with tarps or other material to prevent contaminating runoff.

- Significant/Hazardous Spills
  - For significant or hazardous spills that cannot be controlled by personnel in the immediate vicinity, the following steps shall be taken:
  - Notify the Engineer immediately and follow up with a written report.
  - Notify the local emergency response by dialing 911. In addition to 911, the contractor will notify the proper county officials. It is the contractor's responsibility to have all emergency phone numbers at the construction site. The Los Angeles County Fire Department Health Hazardous Material Division should be called at (323)890-4317 or after hours Call: 911 or (323)881-2455 (Health Haz Mat).
  - For spills of federal reportable quantities, in conformance with the requirements in 40 CFR parts 117.3 and 302.4, the contractor shall notify the National Response Center at (800) 424-8802.
  - The services of a spills contractor or a Haz-Mat team shall be obtained immediately. Construction personnel shall not attempt to clean up the spill until the appropriate and qualified staff has arrived at the job site.
  - Other agencies which may need to be consulted include, but are not limited to, the Coast Guard, the Highway Patrol, the City/County Police Department, Department of Toxic Substances, California Division of Oil and Gas, Cal/OSHA, RWQCB, etc.

Disposal Procedures

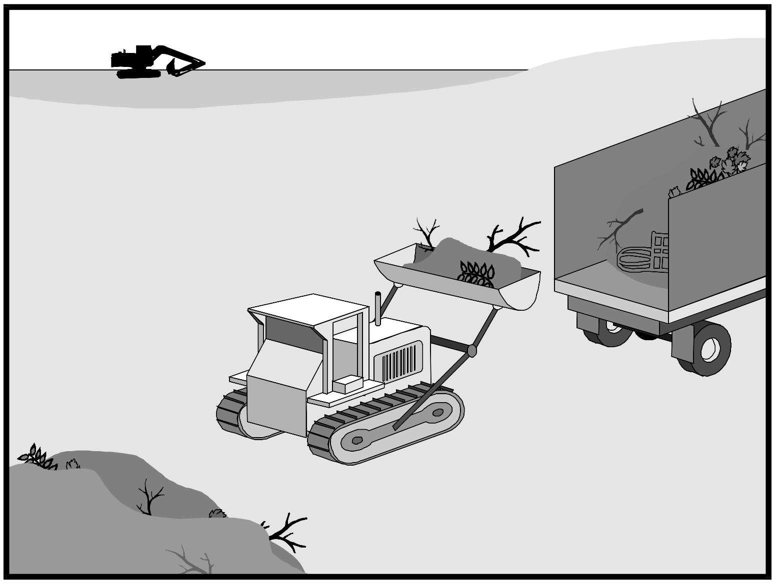
- Proper disposal is disposal offsite in accordance with all applicable laws and regulations.
- Used clean up materials, contaminated materials, and recovered spill material that is no longer suitable for the intended purpose shall be stored and disposed of in accordance with WM-6, "Hazardous Waste Management" BMPs.
- Waste that is not hazardous and is not defined as waste that requires special handling under California Code of Regulations, Title 22 Division 4.5, Title 23, Division 3, Chapter 3, and Title 27, Division 2, Subdivision 1 shall be disposed of in accordance WM-5 Solid Waste Management.

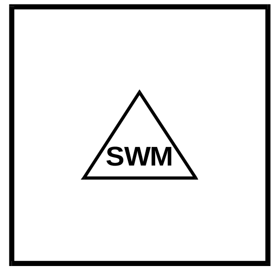
Maintenance and Inspection

- Inspect the project site for spills daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect project site for spills at least once every 24 hours.
- Verify that spill control clean-up materials are located near material storage, unloading, and use areas.
- Update spill prevention and control plan and stock appropriate clean-up materials whenever changes occur in the types of chemicals used or stored onsite.

Solid Waste Management

WM-5





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Solid waste management procedures and practices are designed to minimize or eliminate the discharge of pollutants offsite, to the ground, drainage systems or watercourses.

Appropriate Applications

Solid waste management procedures and practices are implemented on all construction sites that generate solid wastes.

Solid wastes include but are not limited to:

- Construction wastes including brick, dry mortar, timber, steel and metal scraps, sawdust, pipe and electrical cuttings, inert equipment parts, styrofoam and other materials used to transport and package construction materials.
- Planting wastes, including vegetative material, plant containers, and packaging materials.
- Litter and debris including food containers, beverage cans, coffee cups, paper bags, plastic wrappers, and smoking materials, including litter generated by the public and other contractors.

Limitations

- Solid waste that requires special handling and disposal because of a potential hazard to human health, the environment, or water quality shall be handled and disposed of in accordance with WM-6.

Standards and Specifications

Education

- The Contractor shall oversee and enforce proper solid waste procedures and practices.
- Educate employees and subcontractors on solid waste storage and disposal procedures. Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).

- Require that employees and subcontractors follow solid waste handling and storage procedures.

- Prohibit littering by employees, subcontractors, and visitors.

- Wherever possible, minimize production of solid waste materials.

Collection, Storage, and Disposal

- Prevent discharges from waste disposal containers to the ground, offsite or storm water drainage system or receiving water.

- Litter and debris shall be removed from drainage grates, trash racks, and ditch lines immediately.

- The contractor shall provide covered and watertight dumpsters of sufficient size and numbers to contain the solid waste generated on the construction site including waste generated by the public. Cover waste disposal containers at all times.

- Trash containers/dumpsters shall be provided in the Contractor's yard, field trailer areas, and at locations where workers congregate for lunch and break periods or where directed by the Engineer. Additional containers and more frequent pickup and removal are required during the demolition phase of construction.

- Trash containers/dumpsters shall be empty once every two weeks. Full trash containers/dumpsters shall be empty within two days of being full. The contents of the containers/dumpsters and all solid waste shall be disposed of outside the right-of-way in conformance with all applicable laws and regulations.

- Litter stored in containers shall be handled and disposed of by licensed disposal contractors.

- Solid waste disposal haulers and facilities shall be approved by the Engineer. The Contractor shall be responsible for signing any manifests for solid waste disposal.

- Solid waste containers shall be located at least 50 ft from drainage facilities and watercourses and shall not be located in areas susceptible to flooding or ponding.

- Waste container washout on the construction site is not allowed.

- Additional containers and more frequent pickup and removal are required during the demolition phase of construction.

- Segregate potentially hazardous waste from non-hazardous construction site waste.

- Liquid wastes (e.g., used oils, solvents, and paints) and chemicals (e.g., acids, pesticides, additives, curing compounds) and solid waste that is hazardous shall not be disposed of in containers designated for solid waste. See BMP WM-6, "Hazardous Waste Management" for proper disposal procedures.

- Salvage or recycle vegetation debris, packaging and/or surplus building materials when practical. Wood pallets, cardboard boxes, and construction scraps can be recycled.

Maintenance and Inspection

- Inspect the project site for solid waste management daily and document weekly, and before and after every rainfall events. During extended rainfall events, inspect project site for solid waste management at least once every 24 hours.

- Inspect solid waste disposal facilities to identify any waste that should be handled and disposed of under WM-6 Hazardous Waste Management. Typically, inspect for used oily rags, used absorbent, used oil containers, and other wastes that require special handling and disposal.

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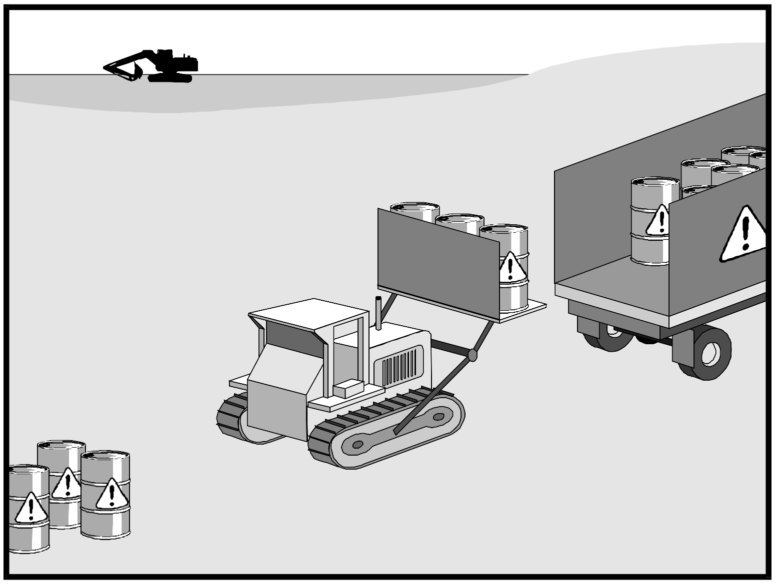
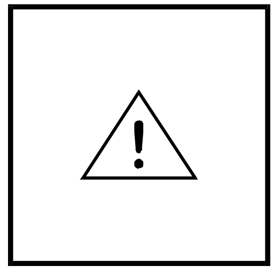
Hazardous Waste Management





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices to minimize or eliminate the discharge of pollutants from contractor generated waste or waste illegally dumped on site by others, that is hazardous waste, or waste that is otherwise not allowed to be disposed of as solid waste, to the ground, storm drain systems or to watercourses.

Appropriate Applications

- This best management practice (BMP) applies to all construction sites. This applies to hazardous waste, non-hazardous waste, designated waste and any other waste that requires special disposal practices due to a potential threat to human health, the environment, or water quality, or as identified by the Engineer. It can be solid, liquid or gaseous waste that is regulated and requires special handling and disposal.

- Hazardous waste management applies to median and shoulder soils of roadways that have been contaminated by aerially deposited lead (ADL). Refer to contract Special Provisions.

- Hazardous waste management practices are implemented on construction sites that generate waste from but not limited to:
  - Petroleum Products,
  - Asphalt Products,
  - Concrete Curing Compounds,
  - Herbicides/Pesticides,
  - Acids/bases,
  - Paints/Stains,
  - Solvents,
  - Wood Preservatives,

- Any materials deemed a hazardous waste in California Code of Regulations, Title 23, Division 3, Chapter 15, Title 22 Division 4.5, or listed in 40 CFR Parts 110, 117, 261, or 302, or
- Any materials deemed designated waste or non-hazardous waste in California Code of Regulations, Title 27 Division 2, Subdivision 1.

Limitations

- This BMP does not relieve the Contractor from responsibility for compliance with federal, state, and local laws regarding storage, handling, transportation, and disposal of hazardous wastes.
- This BMP does not cover waste addressed specifically by the contract Special Provisions.

Standards and Specifications

Education

- Educate employees and subcontractors on proper hazardous waste storage and disposal procedures.
- Educate employees and subcontractors on safety procedures and potential dangers to humans and the environment from hazardous wastes.
- Educate employees and subcontractors in identification of hazardous and solid waste.
- Hold regular meetings to discuss and reinforce hazardous waste management procedures (incorporate into regular safety meetings).
- The Contractor's Qualified SWPPP Practitioner (QSP) or BMP manager for projects without SWPPPs shall oversee and enforce proper hazardous waste management procedures and practices.
- Make sure that hazardous waste is collected, removed, and disposed of only at authorized disposal areas.

Storage Procedures

- All hazardous wastes shall be stored in a secured area and in approved, sealed, and leak-proof containers with sealed lids constructed of a suitable material and shall be labeled as required by Title 22 CCR, Division 4.5 and 49 CFR Parts 172,173, 178, and 179.
- All hazardous waste shall be stored, transported, and disposed as required in Title 22 CCR, Division 4.5 and 49 CFR 261-263.
- Waste containers shall be stored in temporary containment facilities that shall comply with the following requirements:
  - Temporary containment facility shall provide a spill containment volume able to contain precipitation from a 24-hour, 25 year storm event, plus the greater of 10% of the aggregate volume of all containers or 100% of the capacity of the largest container within its boundary, whichever is greater.

- Temporary containment facility shall be impervious to the materials stored there for a minimum contact time of 72 hours.
- Temporary containment facilities shall be covered and maintained free of accumulated rainwater and spills. In the event of spills or leaks accumulated rainwater and spills shall be immediately placed into drums after each rainfall. These liquids shall be handled as a hazardous waste unless testing determines them to be non-hazardous. Non-hazardous liquids shall be sent to an approved disposal site.
- Sufficient separation shall be provided between stored containers to allow for spill cleanup and emergency response access.
- Incompatible materials, such as chlorine and ammonia, shall not be stored in the same temporary containment facility.
- Temporary containment facilities shall be covered at all times. Covered facilities may include use of plastic tarps for small facilities or constructed roofs with overhangs. A storage facility having a solid cover and sides is preferred to a temporary tarp. Storage facilities shall be equipped with adequate ventilation.

■ Drums shall not be overfilled and wastes shall not be mixed.

■ Containers of dry waste shall be stored on pallets.

■ Paint brushes and equipment for water and oil based paints shall be cleaned within a contained area and shall not be allowed to contaminate site soils, watercourses or drainage systems. Waste paints, thinners, solvents, residues, and sludges that cannot be recycled or reused shall be disposed of as hazardous waste. When thoroughly dry, latex paint and paint cans, used brushes, rags, absorbent materials, and drop cloths shall be disposed of as solid waste.

■ Ensure that hazardous waste collection containers and spill kits are available at all hazardous waste storage areas.

■ Designate hazardous waste storage areas on site away from storm drains or watercourses and away from moving vehicles and equipment to prevent accidental spills. All hazardous wastes shall be protected from traffic and equipment.

■ Minimize production or generation of hazardous materials and hazardous waste on the construction site.

■ Use containment berms in fueling and maintenance areas and where the potential for spills is high.

■ Segregate potentially hazardous waste from non-hazardous construction site debris.

- Keep liquid or semi-liquid hazardous waste in appropriate containers (closed drums or similar) and under cover.
- Clearly label all hazardous waste containers with the waste being stored and the date of accumulation.
- Clean up spills of waste immediately.
- Do not mix different types wastes. For example, do not mix solids and liquids and do not mix hazardous and non-hazardous, nor designated and non-hazardous.

Disposal Procedures

- These disposal procedures apply to waste disposal unless specifically stated otherwise in the contract Special Provisions.
- If directed by the Engineer, the Contractor shall collect an appropriate number of samples of waste generated and shall have the sample analyzed by a Department of Health Services (DHS) certified laboratory in order to meet waste profiling requirements of the disposal facility.
- The Contractor shall complete all required waste profile forms. The "Generator" of the hazardous waste shall be identified by the Engineer. If the spill/leak of hazardous water is caused by the Contractor or Contractor's operations, the Contractor shall be identified as the "Generator" of the hazardous waste.
- A copy of a completed and typed draft Hazardous Waste Manifest for the transportation of hazardous waste, including the correct EPA ID Number, shall be submitted to the Engineer for approval prior to transporting the hazardous waste off-site. The Engineer shall provide the EPA ID Number. If the Contractor is identified as the Generator, then the Contractor shall obtain the EPA ID Number. Hazardous waste shall not be transported off-site unless the Hazardous Waste Manifest has been signed by the Generator.
- A copy of a completed and typed draft Non-Hazardous Waste Manifest for the transportation of non-hazardous waste shall be submitted to the Engineer for approval prior to transporting the non-hazardous waste off-site. Non-Hazardous waste shall not be transported off-site unless the Non-Hazardous Waste Manifest has been signed by the Generator.
- Waste shall be transported by a licensed hazardous waste transporter to an authorized and licensed disposal facility or recycling facility.
- Hazardous waste as defined by California Code of Regulations, Title 22 CCR, Division 4.5 and Title 23, Division 3, Chapter 15 or as determined by the Engineer shall not be stored on site unless covered by the contract Special Provisions.

- Hazardous waste, non-hazardous waste, designated waste and other waste that presents a potential threat to human health, the environment or water quality shall be disposed in accordance with all applicable laws and regulations including but not limited to California Code of Regulations, Title 22 Division 4.5, Title 23, Division 3, Chapter 3, and Title 27, Division 2, Subdivision 1.

- Make sure that toxic liquid wastes (e.g., used oils, solvents, and paints), chemicals (e.g., acids, pesticides, additives, curing compounds), and any other wastes that have special handling and disposal requirements under California Code of Regulations, Title 22 Division 4.5, Title 23, Division 3, Chapter 3, and Title 27, Division 2, Subdivision 1 are not disposed of in dumpsters designated for solid waste or construction debris.

- Dispose of rainwater accumulated in secondary containment as hazardous waste.

Maintenance and Inspection

- The Contractor's Site-Specific Health and Safety Officer (SHSO) or Safety Office (based on contract Special Provisions) shall monitor on-site hazardous waste storage and disposal procedures.

- Inspect the project site for non-hazardous and hazardous waste weekly, and before and after every rainfall events. During extended rainfall events, inspect project site for non-hazardous and hazardous waste at least once every 24 hours.

- Waste storage areas shall be kept clean, well organized, and equipped with ample clean-up supplies as appropriate for the materials being stored.

- Storage areas shall be inspected in conformance with the contract Special Provisions and the SWPPP.

- Perimeter controls, containment structures, covers, and liners shall be repaired or replaced as needed to maintain proper function.

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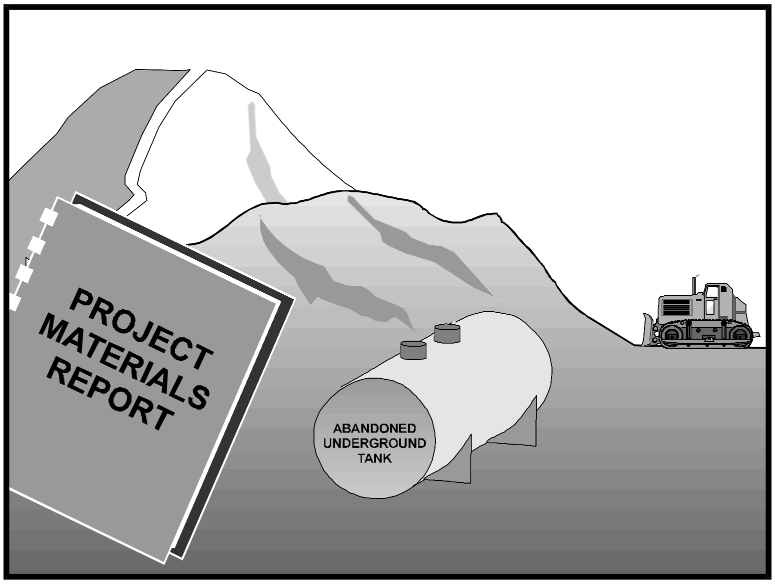
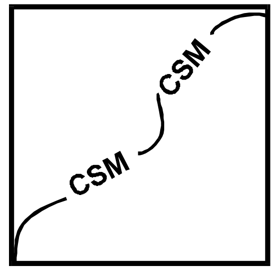
Contaminated Soil Management

WM-7





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices to minimize or eliminate the discharges of pollutants to the drainage system or to watercourses from contaminated soil.

Appropriate Applications

- Contaminated soil management is implemented on construction projects in highly urbanized or industrial areas where soil contamination may have occurred due to spills, illicit discharges, and leaks from underground oil pipelines and storage tanks.

Limitations

- The procedures and practices presented in this best management practice (BMP) are general. The contractor shall identify appropriate practices and procedures for the specific contaminants known to exist or discovered on site.

Standards and Specifications

- Contaminated soils are often identified during project planning and development with known locations identified in the contract Special Provisions.
- If contaminated soils are encountered on the project site and are not identified in the contract Special Provisions. The Engineer shall solely characterize the extent, volume, and type of contaminated soil.
- All soil sampling will be conducted by the Engineer.

Education

- The Contractor shall comply with the Agency-approved Site-Specific Health and Safety Plan (refer to contract Special Provisions).
- Prior to performing any excavation work at the locations containing material classified as hazardous, employees and subcontractors shall complete a safety training program which meets 29 CFR 1910.120 and 8 CCR 5192 covering the potential hazards as identified.

- Educate employees and subcontractors in identification of contaminated soil.
  - Detected or undetected spills and leaks.
  - Acid or alkaline solutions from exposed soil or rock formations high in acid or alkaline forming elements.
  - Look for contaminated soil as evidenced by discoloration, odors, differences in soil properties, abandoned underground tanks or pipes, or buried debris.

Handling Procedures for Contaminated Soils

- To minimize on-site storage, contaminated soil shall be disposed of properly in accordance with all applicable regulations. All hazardous waste storage will comply with the requirements in Title 22, CCR, Sections 6626.250 to 66265.260.
- Contaminated soils or hazardous material shall not be stockpiled on the project site.
- Contaminated material and hazardous material on exteriors of transport vehicles shall be removed and placed either into the current transport vehicle or the excavation prior to the vehicle leaving the exclusion zone.
- Procure all permits and licenses, pay all charges and fees, and give all notices necessary and incident to the due and lawful prosecution of the work, including registration for transporting vehicles carrying the contaminated material and the hazardous material.
- Collect water from decontamination procedures and treat and/or dispose of it at an appropriate disposal site.
- Collect non-reusable protective equipment, once used by any personnel, and dispose of at an appropriate disposal site.
- Install temporary security fence to surround and secure the exclusion zone. Remove fencing when no longer needed.
- Excavation, transport, and disposal of contaminated material and hazardous material/waste shall be in accordance with the rules and regulations of the following agencies (the specifications of these agencies supersede the procedures outlined in this BMP):
  - United States Department of Transportation (USDOT).
  - United States Environmental Protection Agency (USEPA).
  - California Environmental Protection Agency (CAL-EPA).
  - California Division of Occupation Safety and Health Administration (CAL-OSHA).
  - Local regulatory agencies.

Procedures for Underground Storage Tank Removals

- Prior to commencing tank removal operations, obtain the required underground storage tank removal permits and approval from the federal, state, and local agencies, which have jurisdiction over such work.
- Arrange to have tested, as directed by the Engineer, any liquid or sludge found in the underground tank prior to its removal to determine if it contains hazardous substances.
- Following the tank removal, take soil samples beneath the excavated tank and perform analysis as required by the local agency representative(s).
- The underground storage tank, any liquid and/or sludge found within the tank, and all contaminated substances and hazardous substances removed during the tank removal shall be transported to disposal facilities permitted to accept such waste.

Water Control

- Take all necessary precautions and preventive measures to prevent the flow of water, including ground water, from mixing with hazardous substances or underground storage tank excavations. Such preventative measures may consist of, but are not limited to: berms, cofferdams, grout curtains, freeze walls, and seal course concrete or any combination thereof.
- If water does enter an excavation and becomes contaminated, such water, when necessary to proceed with the work, shall be transported off-site and disposed at a recycling or disposal facility approved by the Engineer.

Maintenance and Inspection

- The Contractor's Site-Specific Health and Safety Officer (SHSO) or Safety Office (based on contract Special Provisions) shall monitor contaminated soil excavation and disposal procedures.
- Inspect the areas of known contaminated soil weekly, and before and after every rainfall events. During extended rainfall events, inspect areas of known contaminated soil at least once every 24 hours.
- Confirm that areas of known contaminated soil are secure and not being tracked or impacting water quality.

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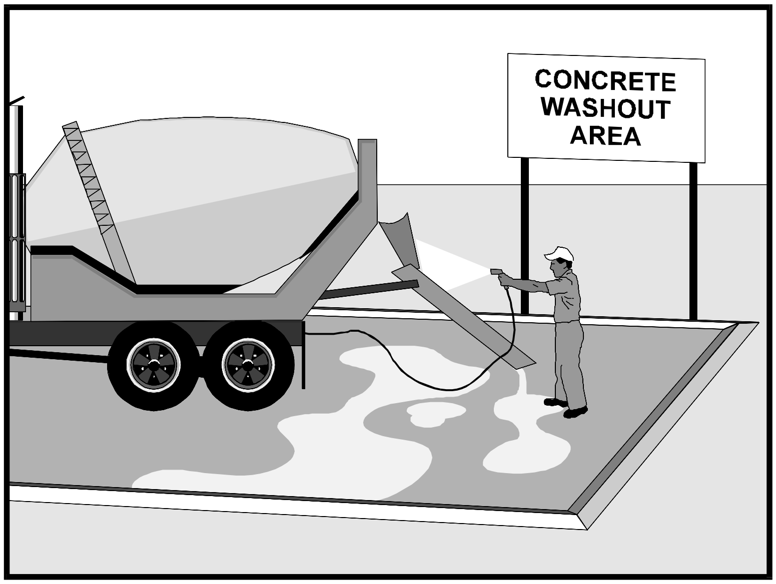
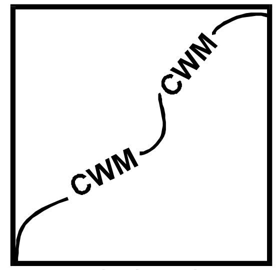
Concrete Waste Management

WM-8





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

These are procedures and practices that are designed to minimize or eliminate the discharge of concrete waste and similar materials to the ground, storm drain systems or watercourses.

Appropriate Applications

- ■ Concrete waste management procedures and practices are implemented on construction projects where concrete is used as a construction material or where concrete dust and debris result from demolition activities.
- ■ Where slurries containing Portland cement concrete (PCC) or asphalt concrete (AC) are generated, such as from sawcutting, coring, grinding, grooving, and hydro-concrete demolition.
- ■ Where concrete trucks and equipment are washed on site, when approved by the Engineer. Refer to NS-8, “Vehicle and Equipment Cleaning."
- ■ Where grout and mortar-mixing stations are used.

Limitations

- ■ None identified.

Standards and Specifications

- ■ Concrete washout areas and other washout areas shall not discharge or leak onto the underlying soil or to the surrounding areas.
- ■ Watertight concrete washout bins are recommended.

Education

- ■ Educate all employees, subcontractors, and suppliers on the concrete waste management requirements described herein.
- ■ The Contractor’s Qualified SWPPP Practitioner (QSP) or BMP Manager (based on the contract Special Provisions) shall oversee and enforce concrete waste management procedures.

Concrete Demolition Wastes

- Stockpile concrete demolition wastes in accordance with BMP WM-3, "Stockpile Management."
- Disposal of hardened PCC and AC waste outside the site to an appropriate facility (in accordance with WM-5) or as directed by Engineer if allowed to incorporate onsite.

Concrete Slurry Waste Management and Disposal

- PCC and AC waste shall not be allowed to discharge to the ground or enter storm drainage systems or watercourses.
- A sign shall be installed adjacent to each temporary concrete washout facility to inform concrete equipment operators to utilize the proper facilities as shown on Page 6.
- Residue from saw cutting, coring and grinding operations shall be picked up by means of a vacuum device. Residue shall not be allowed to flow across the pavement and shall not be left on the surface of the pavement. See also BMP NS-3, "Paving and Grinding Operations."
- Vacuumed slurry residue shall be disposed of in accordance with BMP WM-5, "Solid Waste Management." Slurry residue shall be disposed of immediately offsite or temporarily stored in a facility as described in "Onsite Temporary Concrete Washout Facility, Concrete Transit Truck Washout Procedures" below), or within an impermeable containment vessel or bin approved by the Engineer.

Onsite Temporary Concrete Washout Facility, Concrete Transit Truck Washout Procedures

- Temporary concrete washout facilities shall be located a minimum of 50 ft from storm drain inlets, open drainage facilities, and watercourses, unless determined infeasible by the Engineer. Each facility shall be located away from construction traffic or access areas to prevent disturbance or tracking.
- A sign shall be installed adjacent to each washout facility to inform concrete equipment operators to utilize the proper facilities. The sign shall be installed as shown on page 6.
- Temporary concrete washout facilities shall be constructed above or below grade, or placed in watertight bins or containers. Temporary concrete washout facilities shall be constructed and maintained in sufficient quantity and size to contain all liquid and concrete waste generated.
- Wash concrete from mixer chutes into approved concrete washout facility. Perform washout of concrete mixers, delivery trucks, and other delivery systems in designated areas only.

- Pump excess concrete in concrete pump bin back into concrete mixer truck.

- Concrete washout from concrete pumper bins can be washed into concrete pumper trucks and discharged into designated washout area or properly disposed offsite.

- Once concrete wastes are washed into the designated area and allowed to harden, the concrete shall be broken up, removed, and disposed of in conformance with applicable federal, state and local regulations (WM-5).

- Washout facilities will be covered 24 hours prior to a 50% or more chance of rain. If not covered prior to rain, washouts shall be covered during rain event. No water will be allowed to overflow from washout and any accumulated rain water will be handled and disposed of as washout water.

Temporary Concrete Washout Facility Type "Above Grade"

- Temporary concrete washout facility Type "Above Grade" shall be constructed as shown on Page 6 or 7, with a minimum length and minimum width of 10 ft, but with sufficient quantity and volume to contain all liquid and concrete waste generated by washout operations. .

- Straw bales, wood stakes, and sandbag materials shall conform to the provisions in BMP SC-9, "Straw Bale Barrier" and BMP SC-8, "Sandbag Barrier."

- Plastic lining material shall be a minimum of 10-mil polyethylene sheeting and shall be free of holes, tears or other defects that compromise the impermeability of the material. Liner seams shall be installed in accordance with manufacturers' recommendations. No seams in the plastic are allowed at the bottom of the washout.

Temporary Concrete Washout Facility (Type Below Grade)

- Temporary concrete washout facility Type "Below Grade" shall be constructed as shown on page 7, with a recommended minimum length and minimum width of 10 ft. The quantity and volume shall be sufficient to contain all liquid and concrete waste generated by washout operations. The length and width of a facility may be increased, at the Contractor's expense, upon approval of the Engineer. Lath and flagging shall be commercial type.

- Plastic lining material shall be a minimum of 10-mil polyethylene sheeting and shall be free of holes, tears or other defects that compromise the impermeability of the material. Liner seams shall be installed in accordance with manufacturers' recommendations. No seams in the plastic material are allowed at the bottom of the washout.

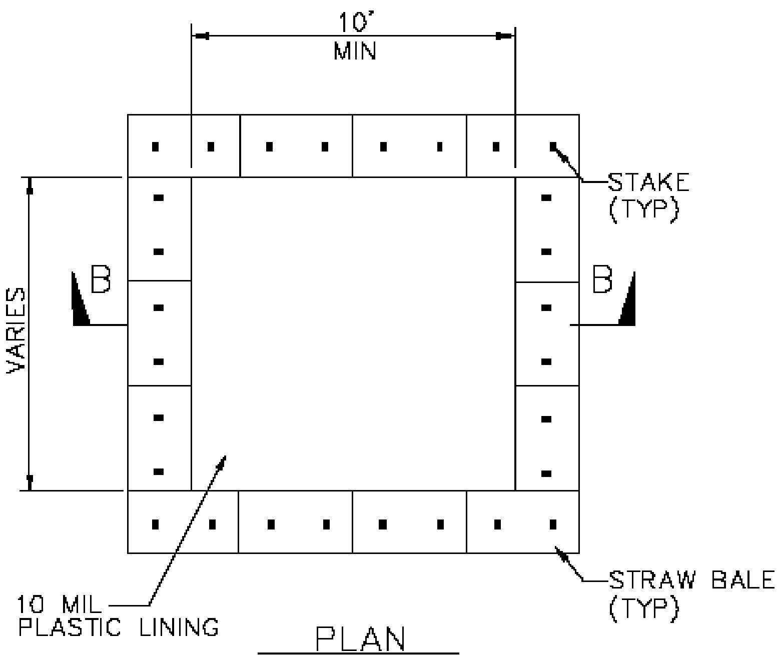
- The soil base shall be prepared free of rocks or other debris that may cause tears or holes in the plastic lining material.

Removal of Temporary Concrete Washout Facilities

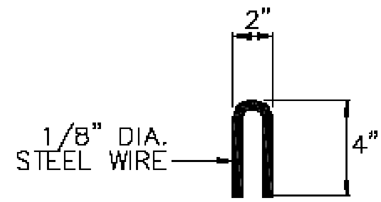
- When temporary concrete washout facilities are no longer required for the work and as washouts are filled, as determined by the Engineer, the hardened concrete shall be removed and disposed of in conformance with applicable federal, state and local regulations. Disposal of PCC dried residues, slurries or liquid waste shall be disposed of in conformance with all applicable laws and regulations. Materials used to construct temporary concrete washout facilities shall become the property of the Contractor, shall be removed from the site of the work, and shall be disposed of in conformance with all applicable laws and regulations.
- Holes, depressions or other ground disturbance caused by the removal of the temporary concrete washout facilities shall be backfilled and repaired.

Maintenance and Inspection

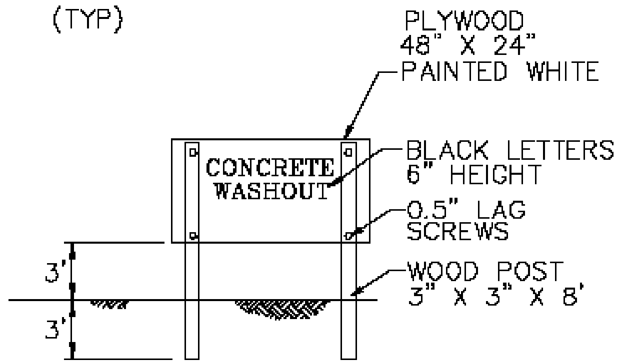
- Inspect temporary concrete washout facilities weekly, and before and after every rainfall events. During extended rainfall events, inspect temporary concrete washout facilities at least once every 24 hours.
- Temporary concrete washout facilities shall be maintained to provide adequate holding capacity with a minimum freeboard of 4 inches for above grade facilities and 12 inches for below grade facilities. Maintaining temporary concrete washout facilities shall include removing and disposing of hardened concrete and returning the facilities to a functional condition. Hardened concrete materials shall be removed and disposed of in conformance with applicable federal, state and local regulations.
- Existing facilities must be cleaned, or new facilities must be constructed and ready for use once the washout is 75% full.
- Temporary concrete washout facilities shall be inspected for damage (i.e. tears in polyethylene liner, missing sandbags, etc.). Damaged facilities shall be repaired immediately.



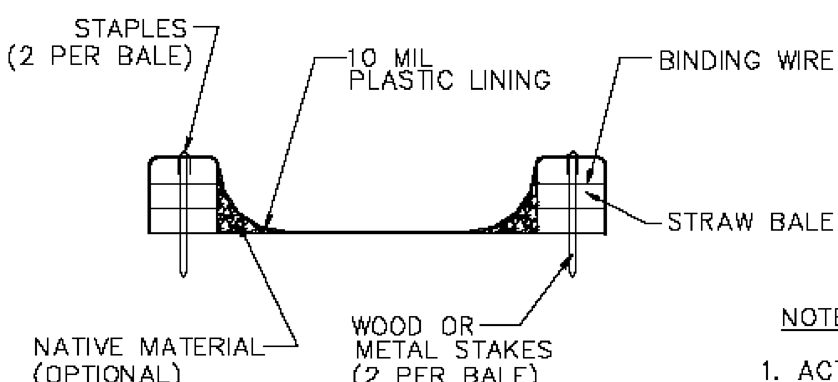
PLAN
NOT TO SCALE
TYPE "ABOVE GRADE"
WITH STRAW BALES



STAPLE DETAIL



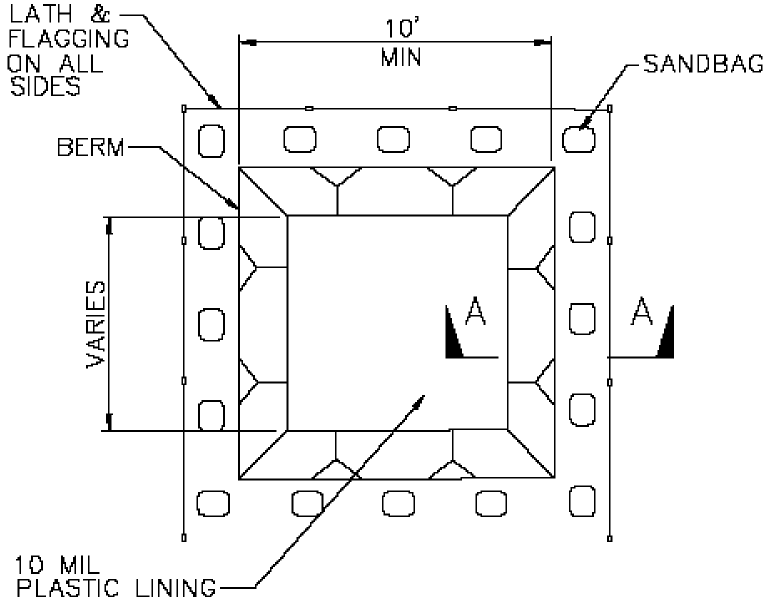
CONCRETE WASHOUT
SIGN DETAIL
(OR EQUIVALENT)



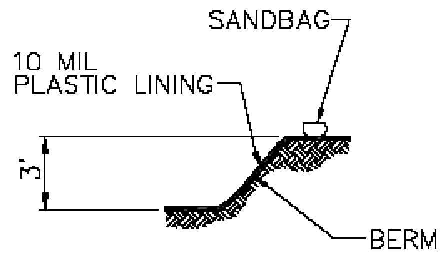
SECTION B–B
NOT TO SCALE

NOTES

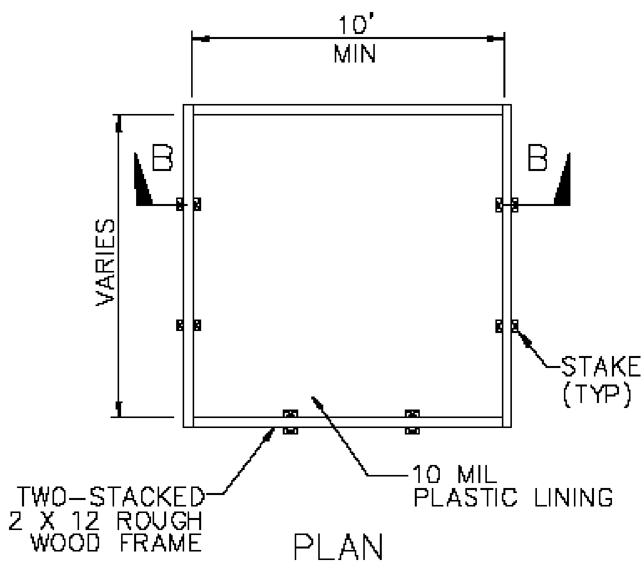
1. ACTUAL LAYOUT DETERMINED IN FIELD.
2. THE CONCRETE WASHOUT SIGN SHALL BE INSTALLED WITHIN 30 FT. OF THE TEMPORARY CONCRETE WASHOUT FACILITY.



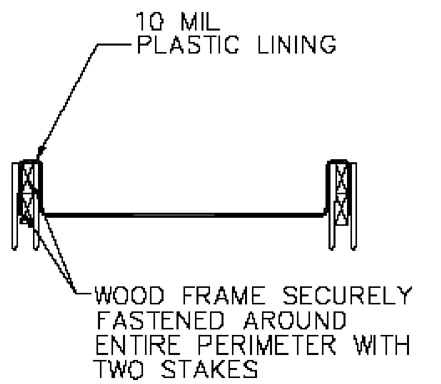
PLAN
NOT TO SCALE
TYPE "BELOW GRADE"



SECTION A–A
NOT TO SCALE



PLAN
NOT TO SCALE
TYPE "ABOVE GRADE"



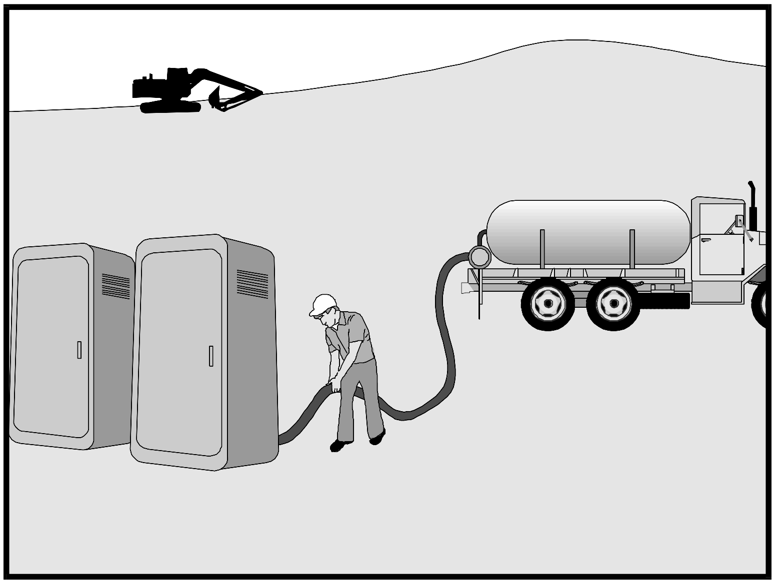
SECTION B–B
NOT TO SCALE

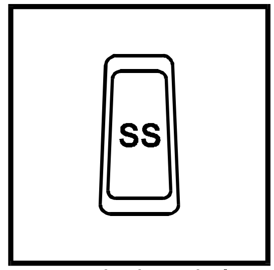
NOTES

1. ACTUAL LAYOUT DETERMINED IN FIELD.
2. THE CONCRETE WASHOUT SIGN SHALL BE INSTALLED WITHIN 30 FT. OF THE TEMPORARY CONCRETE WASHOUT FACILITY.

Sanitary/Septic Waste Management

WM-9





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures and practices to minimize or eliminate the discharge of construction site sanitary/septic waste materials to the storm drain system or to watercourses.

Appropriate Applications

Sanitary/septic waste management practices are implemented on all construction sites that use temporary or portable sanitary/septic waste systems.

Limitations

- None identified.

Standards and Specifications

Education

- Educate employees, subcontractors, and suppliers on sanitary/septic waste storage and disposal procedures.
- Educate employees, subcontractors, and suppliers of potential dangers to humans and the environment from sanitary/septic wastes.
- Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).

Storage and Disposal Procedures

- Ensure the containment of sanitation facilities (e.g., portable toilets) to prevent discharges of pollutants to the ground surface, storm water drainage system or receiving water.
- Clean or replace sanitation facilities and inspect them regularly for leaks and spills.
- Temporary sanitary facilities shall be located away from drainage facilities, watercourses, and from traffic circulation. When subjected to high winds or risk, temporary sanitary facilities shall be secured to prevent overturning.

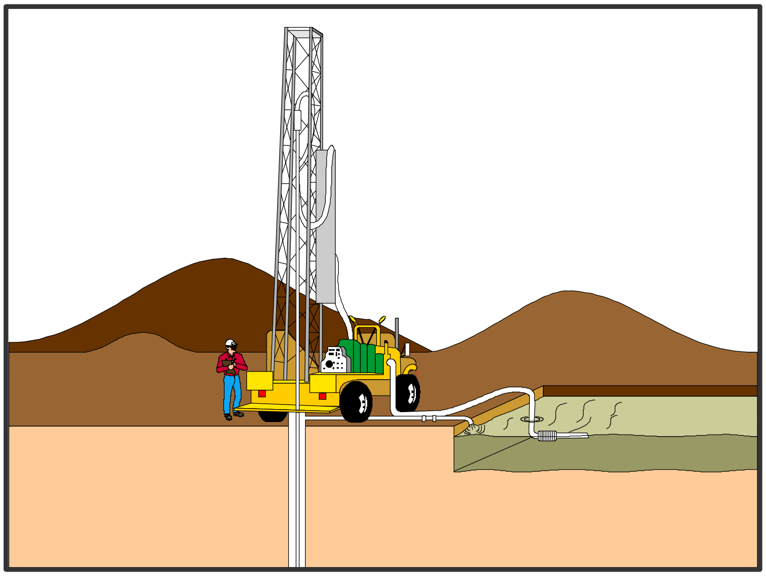
- Wastewater shall not be discharged or buried on the construction site.
- Sanitary and septic systems that discharge directly into sanitary sewer systems, where permissible, shall comply with the local health agency, city, county, and sewer district requirements.
- Properly connect temporary sanitary facilities that discharge to the sanitary sewer system to avoid illicit discharges.
- Ensure that sanitary/septic facilities are maintained in good working order by a licensed service.
- Use only reputable, licensed sanitary/septic waste haulers.
- Clean up spills and leaks immediately. Spills and leaks shall not be covered or buried onsite. Contaminated soil shall be disposed of properly in accordance with permits, laws and regulations.

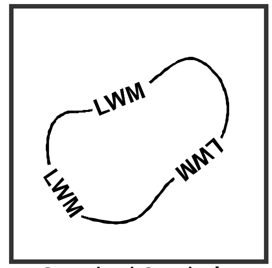
Maintenance and Inspection

- Inspect sanitary and septic waste facilities weekly, and before and after every rainfall events. During extended rainfall events, inspect sanitary and septic waste facilities at least once every 24 hours.

Liquid Waste Management

WM-10





Standard Symbol

BMP Objectives

- ○ Soil Stabilization
- ○ Sediment Control
- ○ Tracking Control
- ○ Wind Erosion Control
- ● Non-Storm Water Management
- ● Materials and Waste Management

Definition and Purpose

Procedures and practices to prevent discharge of pollutants to the ground, storm drain system or to watercourses as a result of the creation, collection, and disposal of non-hazardous liquid wastes.

Appropriate Applications

Liquid waste management is applicable to construction sites that generate any non-hazardous byproducts, residuals, or wastes not limited to the following:

- Drilling slurries and drilling fluids.
- Grease-free and oil-free wastewater and rinse water.
- Dredgings.
- Other non-storm water liquid discharges not permitted by separate permits.

Limitations

- Disposal of some liquid wastes may be subject to requirements of other permits secured by the Agency (e.g., National Pollutant Discharge Elimination System [NPDES] permits, Army Corps of Engineers permits, RWQCB Water Quality Certifications, Coastal Commission permits, etc.).
- Does not apply to groundwater dewatering operations (refer to contract Special Provisions)
- Does not apply to dewatering operations (see BMP NS-2, “Dewatering Operations”), solid waste management (see BMP WM-5, “Solid Waste Management”), hazardous wastes (see BMP WM-6, “Hazardous Waste Management”), or concrete slurry residue (see BMP WM-8, “Concrete Waste Management”).
- Does not apply to approved non-storm water discharges permitted by any NPDES permit secured by the Agency. Typical permitted non-storm water discharges can include: fire hydrant flushing, irrigation of vegetative erosion control measures, pipe flushing and testing, water to control dust,

uncontaminated ground water from dewatering fire hydrant flushing, irrigation of vegetative erosion control measures, pipe flushing and testing, or water to control dust.

Standards and Specifications

General Practices

- Instruct employees and subcontractors how to safely differentiate between non-hazardous liquid waste and potential or known hazardous liquid waste. Educate employees and subcontractors on liquid waste generating activities, and liquid waste storage and disposal procedures. Hold regular meetings to discuss and reinforce disposal procedures (incorporate into regular safety meetings).

- Instruct employees, subcontractors, and suppliers that it is unacceptable for any liquid waste to discharge to the ground, or enter any storm drainage structure, waterway, or receiving water.

- Verify with the Engineer which non-storm water discharges are permitted. Some listed discharges may be prohibited if the Agency determines the discharge to be a source of pollutants.

- Apply the NS-8, "Vehicle and Equipment Cleaning" BMP for managing wash water and rinse water from vehicle and equipment cleaning operations.

Containment of Liquid Wastes

- Drilling residue and drilling fluids shall not be allowed to discharge to the ground, or enter storm drains and watercourses and shall be disposed of in conformance with all applicable laws and regulations.

- Liquid wastes generated as part of an operational procedure, such as water-laden dredged material and drilling mud, shall be contained and not allowed to discharge to the ground or to flow into drainage channels or receiving waters prior to treatment and meeting water quality requirements.

- Contain liquid wastes in a controlled area, such as a sediment basin, watertight roll-off bin, or portable tank.

- Containment devices must be structurally sound and leak free.

- Containment devices must be of sufficient quantity or volume to completely contain the liquid wastes generated.

- Take precautions to avoid spills or accidental releases of contained liquid wastes. Apply the education measures and spill response procedures outlined in BMP WM-4, "Spill Prevention and Control."

- Do not locate containment areas or devices where accidental release of the contained liquid can threaten health or safety, or discharge to water bodies, channels, or storm drains.

- Contain and properly dispose off-site all liquid wastes running off a surface such as wash water and rinse water from cleaning walls or pavement.

- Do not allow liquid wastes to flow or discharge uncontrolled to the ground, storm drain system or watercourse. Use temporary dikes or berms to intercept flows and direct them to a containment area.

- Use a sediment trap (see BMP SC-3, "Sediment Trap") for capturing and treating the liquid waste stream, or capture in a containment device and allow sediment to settle.

Disposal of Liquid Wastes

- All liquid waste must be disposed of offsite. If liquid waste is allowed to be discharged to the storm drain system in accordance with permits, laws and regulations, the discharge shall be approved by the Engineer,

- Dispose of liquid wastes as required in the contract Special Provisions or per the Water Quality Reports, NPDES permits, Environmental Impact Reports, 401 Water Quality Certifications or 404 permits, local agency discharge permits, etc., or as specified in the contract Special Provisions.

- Liquid wastes, such as from dredged material, may require testing and certification whether it is hazardous or not before a disposal method can be determined. Sampling is the responsibility of the Contractor unless specified in the contract Special Provisions.

- For disposal of hazardous waste, see BMP WM-6, "Hazardous Waste Management."

- If necessary, further treat liquid wastes prior to disposal. Treatment may include, though is not limited to, sedimentation, filtration, and chemical neutralization.

Maintenance and Inspection

- Inspect all liquid waste management facilities weekly, and before and after every rainfall events. During extended rainfall events, inspect liquid waste management facilities at least once every 24 hours.

- Inspect containment areas and capturing devices frequently for damage, and repair as needed. Remove deposited solids in containment areas and capturing devices as needed, and at the completion of the task. Dispose of any solids as described in BMP WM-5, "Solid Waste Management."

RB-AR33499

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Appendix A
Abbreviations, Acronyms, and Definition of Terms

Abbreviations

ac	acre
ºC	Degrees Celsius
cfs	cubic feet per second
cy	cubic yards
dia	diameter
d_o	outer diameter
e.g.	for example
eq.	equation
etc.	et cetera
ºF	Degrees Fahrenheit
ft	feet
ft^3	cubic feet
g	gram
gal	gallon
gpm	gallons per minute
hr	hour
i.e.	such as
in	inches
L_a	apron length
lb	pound
lf	linear feet
m	meter
mils	thousandths of an inch
min	minimum
max	maximum
mm	millimeter
nts	not to scale
oz	ounce
psi	pounds per square inch
R	radius
s	second
sec^{-1}	per second
typ	typical
UV	ultraviolet
yd	yard
y^2	square yards
y^3	cubic yards

Acronyms

AC	Asphalt Concrete
ABS	Acrylonitrile Butadiene Styrene
ADL	Aerially Deposited Lead
AQMD	Air Quality Management District
APP	Accumulated Precipitation Procedure
AST	aboveground storage tank
ASTM	American Society of Testing Materials
BAT	Best Available Technology
BCT	Best Conventional Technology
BMP	Best Management Practice
BFM	bonded fiber matrix
BOD	biological oxygen demand

CAL-EPA	California Environmental Protection Agency
CAL-OSHA	California Occupational Safety and Health Administration
CASQA	California Stormwater Quality Association
CCR	California Code of Regulations
CCS	Cellular confinement system
CMP	Corrugated Metal Pipe
CFR	Code of Federal Regulations
DHS	California Department of Health Services
DSA	Disturbed Soil Area
EC	erosion control
ECU	Environmental Compliance Unit
ESA	Environmentally Sensitive Area
FEMA	Federal Emergency Management Agency
Haz Mat	hazardous material
HDPE	high density polyethylene
L:W	Length versus Width
MS4	Municipal Separate Storm Sewer System
MSDS	Material Safety Data Sheet
MUSLE	Modified Universal Soil Loss Equation
OSHA	Occupational Safety and Health Administration
PCC	Portland Cement Concrete
PLS	pure live seed
PVC	Polyvinyl Chloride
QSP	Qualified SWPPP Practitioner
RECP	rolled erosion control product
RWQCB	California Regional Water Quality Control Board
SCS	Soil Conservation Service
SSP	Standard Special Provisions
SWMP	Storm Water Management Plan
SWPPP	Storm Water Pollution Prevention Plan
SWRCB	California State Water Resources Control Board
TSS	to6tal suspended solids
V:H	Vertical versus Horizontal
USDA	United States Department of Agriculture
USDOT	United States Department of Transportation
US EPA	United States Environmental Protection Agency
USLE	Universal Soil Loss Equation
WDID	Waste Discharge Identification
WDR	Waste Discharge Requirement
WPCD	water pollution control drawing

Definition of Terms

Active Areas of Construction: All areas subject to land surface disturbance activities related to the project including, but not limited to, the project site, project staging areas, immediate access areas and storage areas. All previously active areas are still considered active areas until final stabilization is complete. [The construction activity Phases are the Preliminary Phase, Grading and Land Development Phase, Streets and Utilities Phase, and the Vertical Construction Phase.]

Antecedent Moisture: Amount of moisture present in soil prior to the application of a soil stabilization product.

Best Management Practice (BMP): BMPs are scheduling of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants. BMPs also include treatment requirements, operating procedures, and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. Any program, technology, process, siting criteria, operating method, measure, or device that controls, prevents, removes, or reduces pollution.

Construction Activity: Includes clearing, grading, or excavation and contractor activities that result in soil disturbance.

Construction Site: The area involved in a construction project as a whole including but not limited to the project site, storage areas, access roads, staging areas, drainage areas.

Contamination: An impairment of the quality of the waters of the state by waste to a degree that creates a hazard to the public health through poisoning or through the spread of disease including any equivalent effect resulting from the disposal of waste, whether or not waters of the state are affected.

Contractor: Party responsible for carrying out the contract per plans and specifications. The contract Special Provisions contain storm water protection requirements the contractor must address.

Degradability: Method by which the chemical components of a soil stabilization product are degraded over time.

Discharge: Any release, spill, leak, pump, flow, escape, dumping, or disposal of any liquid, semi-solid or solid substance.

Disturbed Areas: Areas that have been purposefully cleared, grubbed, excavated, or graded by the contractor; ground surface that has been disrupted by construction activities, including construction access/roads, producing significant areas of exposed soil and soil piles. Staging and storage sites are considered as part of the total disturbed land area, whether located on or off the project site.

Drying Time: Time it takes for a soil stabilization product to dry or cure for it to become erosion control effective.

Engineer: Agency representative on a construction project. The Engineer may be the inspector or engineer representing the Agency on site.

Environmental Protection Agency (EPA): Federal Agency that issues the regulations to control pollutants in storm water runoff discharges (The Clean Water Act and NPDES permit requirements).

Erosion: The process, by which soil particles are detached and transported by the actions of wind, water, or gravity.

Erosion Control Effectiveness: The ability of a particular product to reduce soil erosion relative to the amount of erosion measured for bare soil. Percentage of erosion that would be reduced as compared to an untreated or control condition.

Exempt Construction Activities: Activities exempt from the Construction General Permit, including routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility; and emergency construction activities required to protect public health and safety. Local permits may not exempt these activities.

Existing vegetation: Any vegetated area that has not already been cleared and grubbed.

Fair Weather Prediction: When there is no precipitation in the forecast between the current calendar day and the next working day. The National Weather Service NOAA Weather Radio forecast shall be used. The contractor may propose an alternative forecast for use if approved by the Resident Engineer.

Feasible: Economically achievable or cost-effective measures which reflect a reasonable degree of pollutant reduction achievable through the application of available nonpoint pollution control practices, technologies, processes, site criteria, operating methods, or other alternatives.

General Permit: The General Permit for Storm Water Discharges Associated with Construction Activity (Order No. 99-08-DWQ, NPDES Permit CAS000002) issued by the State Water Resources Control Board.

Good Housekeeping: A common practice related to the storage, use, or cleanup of materials, performed in a manner that minimizes the discharge of pollutants.

Local permit: See MS4 Permit.

Longevity: The time the soil erosion product maintains its erosion control effectiveness.

Mode of Application: Type of labor or equipment that is required to install the product or technique.

MS4 Permit: Regional Water Quality Control Board (RWQCB) – Los Angeles Region, adopted Order No. 01-182, NPDES Permit No. CAS004001, Waste Discharge Requirements for Municipal Storm Water and Urban Runoff Discharge within the County of Los Angeles, and Incorporated Cities Therein. This is commonly referred to as MS4 permit or local NPDES permit.

National Pollutant Discharge Elimination System (NPDES) Permit: A permit issued pursuant to the Clean Water Act that requires the discharge of pollutants to waters of the United States from storm water be controlled.

Native: Living or growing naturally in a particular region. Compatibility and competitiveness of selected plant materials with the environment.

Non-active Construction Area: Any area not considered to be an active construction area. Active construction areas become non-active construction areas whenever construction activities are expected to be discontinued for a period of 14 days or longer.

Non-Storm Water Discharges: Discharges that do not originate from precipitation events. They can include, but are not limited to, discharges of process water, air conditioner

condensate, non-contact cooling water, vehicle wash water, water truck water, sanitary wastes, concrete washout water, paint wash water, irrigation water, or pipe testing water.

Permit: The Construction General Permit or local MS4 NPDES permit, whichever or both are applicable to the construction project.

Pollution: The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water. An alteration of the quality of the water of the state by waste to a degree, which unreasonably affects either the waters for beneficial uses or facilities that serve these beneficial uses.

Qualified SWPPP Practitioner (QSP): Individual assigned responsibility for non-storm water and storm water visual observations, sampling and analysis, and responsibility to ensure full compliance with the contract Special Provisions and implementation of all elements of the SWPPP.

Receiving Waters: All surface water bodies within the County of Los Angeles.

Regional Water Quality Control Board (RWQCB): California agencies that implement and enforce Clean Water Act Section 402(p) NPDES permit requirements, and are issuers and administrators of these permits as delegated by EPA. There are nine regional boards working with the State Water Resources Control Board.

Residual Impact: The impact that a particular practice might have on construction activities once they are resumed on the area that was temporarily stabilized.

Runoff Control BMPs:
Measures used to slow and convey concentrated flow, dissipate velocity to prevent or minimize erosion and sediment discharges.

Runoff Effect: The effect that a particular soil stabilization product has on the production of storm water runoff. Runoff from an area protected by a particular product may be compared to the amount of runoff measured for bare soil.

Run-on: Discharges that originate offsite and flow onto the property of a separate project site.

Run-on Control BMPs - Measures used to divert run-on from offsite and runoff within the project site.

Sediment: Solid particulate matter, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment Control BMPs: Practices that trap soil particles after they have been eroded by rain, flowing water, or wind. They include those practices that intercept and slow or detain the flow of storm water to allow sediment to settle and be trapped (e.g., silt fence, sediment basin, fiber rolls, etc.).

Statewide Permit: The National Pollutant Discharge Elimination System (NPDES) Permit, Statewide Storm Water Permit and Waster Discharge Requirements (WDRs) for the State of California Department of Transportation (Caltrans). Order No. 99-06-DWQ, NPDES No. CAS000003.

State Water Resources Control Board (SWRCB): California agency that implements and enforces Clean Water Act Section 402(p) NPDES permit requirements, is issuer and administrator of these permits as delegated by EPA. Works with the nine Regional Water Quality Control Boards.

Storm Drain System: Streets, gutters, inlets, conduits, natural or artificial drains, channels and watercourses, or other facilities that are owned, operated, maintained and used for the purpose of collecting, storing, transporting, or disposing of storm water.

Storm Water: Rainfall runoff, snow melt runoff, and surface runoff and drainage. It excludes infiltration and runoff from agricultural land.

Storm Water Pollution Prevention Plan (SWPPP): A plan required by the Permit that includes site map(s), an identification of construction/contractor activities that could cause pollutants in the storm water, and a description of measures or practices to control these pollutants. It must be prepared and approved in accordance with the contract special provisions and the LACDPW SWPPP Preparation Manual before construction begins.

Temporary Construction Site BMPs: Construction Site BMPs that are required only temporarily to address a short-term storm water contamination threat. For example, silt fences are located near the base of newly graded slopes that have a substantial area of exposed soil. Then, during rainfall, the silt fences filter and collect sediment from runoff flowing off the slope.

Waste Discharge Identification Number (WDID): The unique project number issued by the SWRCB upon receipt of the notice of intent (NOI).

Appendix B
Best Management Practices (BMP) Checklist

General

- The BMP Checklist is available as a separate Excel file.
- Use this BMP Checklist for documenting all inspections. This BMP Checklist meets the Construction General Permit requirements for BMP inspections, storm event inspections, and non-storm water inspections (quarterly inspections).
- In order to properly fill out the BMP Checklist, these instructions must be followed. The BMP Checklist does not provide instruction on how to conduct the inspection and fill out the BMP Checklist. BMP design, implementation, and maintenance for the BMPs numbered and named on the BMP Checklist are detailed in the BMP Fact Sheets attached to Sections 3 through 8 of this BMP Manual.
- For SWPPP projects, the BMP Checklist shall be completed and signed by the Contractor's Qualified SWPPP Practitioner (QSP).
- Evaluate BMPs for adequacy and proper maintenance and whether additional BMPs are required in accordance with the contract Special Provisions and the Construction General Permit (Order No. 2009-0009-DWQ).
- All paved areas that provide access to the project site shall be inspected daily. The question, "Are all paved roads that provide access to the project inspected daily for tracking of sediment and other debris?" shall be answered.
- If the answer is "no" to any of the questions listed in Columns B, C, or D of the BMP Checklist, describe the corrective action(s) to be taken and implementation dates of when corrective actions are completed. Should more space be needed to describe corrective actions, identify the corrective action numerically and use additional sheets as necessary.
- The inspection type is documented to ensure and document that inspections are conducted with the required frequency. Check either "Weekly," "Pre-storm," "Post-storm," "During" or "Other." If "other" is checked, describe what type of inspection in the space provided. For example, if an inspection is conducted more frequently that once per week, the "Other" box should be checked and the inspector shall fill in "additional weekly" for the inspection type. Another example would be a consultant or oversight inspection or audit.

Project Information

- The Project Name and Project ID Number shall be obtained from the front cover of the contract Special Provisions.
- The PCA number is an internal LACDPW billing number not necessary for the Contractor to fill in. The Office Engineer and Area Supervisor and signature are not necessary for the Contractor to fill in.
- If the BMP Checklist is used for a catch basin cleanout contract, referred to specific BMPs that may apply: SS-1, SS-7, SS-10, NS-6, WM-2, WM-4, WM-5, WM-6.

Inspector's name, title, and signature

- For SWPPP projects, the inspector shall be Contractor's Qualified SWPPP Practitioner (QSP). The QSP name, title and signature are required. For projects that do not require a SWPPP, the inspector is the Contractor staff responsible for the BMPs.

SWPPP Projects

- Whether the project requires a SWPPP is determined by Section 7-8.6 of the Contract Special Provisions. SWPPP projects are required to answer the question in Column "A" whether each BMP is included in the SWPPP. Projects that do not require a SWPPP are not required to answer the question in Column "A."
- Whether SWPPP revisions are necessary shall be based on the entire inspection and review of the SWPPP.
- The inspector shall review the SWPPP prior to an inspection in order to determine whether a SWPPP amendment is necessary.
- If the SWPPP adequately addresses installed BMPs and BMPs required for the project, and if the SWPPP matches the site, answer "no" to indicate that amendments to the SWPPP are NOT necessary.
- If the SWPPP does not match the actual construction site conditions or if corrective actions need to be made on the site that do not match the current SWPPP, answer "yes" to indicate that SWPPP amendments are necessary. If "yes" is checked, include SWPPP amendments as part of the corrective actions for the associated BMPs in the BMP Checklist Section 1 thru 6.
  - For example, if during an inspection a drain inlet is identified that was not shown on the project SWPPP, the question regarding whether the SWPPP revisions are necessary should be answered "yes." Then, under Section 2, SC-10 Storm Drain Inlet Protection, not only should any deficiencies, corrective actions and implementation dates for the BMP inspected be noted, but an additional deficiency, corrective action, and implementation date should be noted to amend the SWPPP to include the additional drain inlet location.
  - For another example, if the Contractor implements an additional BMP, approved by the Engineer, such as a fiber roll to break up slope lengths, and fiber rolls were not previously selected, included and described in the SWPPP, the corrective actions under SC-5 Fiber Rolls shall include a revision to the SWPPP to add fiber rolls.

Inspection date, time, and date the inspection report was written

- The inspection report shall be completed the same day that the inspection was conducted. In order to document that the inspection was completed the same day, both the inspection date and report date are required.
- The report number is a consecutive number from the first inspection conducted on the project.

Stage of construction, activities completed, and approximate area of the site exposed. (SWPPP Projects Only)

- The area of construction exposed shall be approximated in acres. Exposed areas include but are not limited to:

  Clearing of the land both for access (i.e. access roads) as well as preparing the site for construction,
  Construction of access roads and existing unpaved roads,
  excavation and grading of the site,
  equipment staging, maintenance, and construction easement areas if they occur on top of a soil surface,
  material and/or soil staging or stockpiles if atop a soil surface (not if atop an impervious surface such as concrete or asphalt),
  area of asphalt or concrete pavement removal if it is removed entirely to the soil surface,
  area related to demolition and removal of existing structures if the work is to the soil surface,
  concrete truck clean-out or other construction activity areas if on top of a soil surface

- The stage of construction shall be documented by checking one or more of the boxes on the BMP Checklist for utilities, grading/excavating/drilling, paving/general construction, vertical, or final landscaping/stabilization.

- The activities completed shall be filled in. This information is project-specific and shall be updated for each inspection as construction progresses. For example, if sawcutting operations were completed and the project was working on utilities, write "sawcutting" as a completed activity. If paving operations were completed and the project was in landscaping, write "paving" as a completed activity. If the project had completed a portion of paving but was still conducting paving, write a percentage of paving as a completed activity (e.g., "40% paving"). There may be more than one activity completed. For example, if the excavation, backfill, and utility work were completed and the project was being paved, write "excavation, backfill and utility work" as completed activities.

Weather Information (SWPPP Projects Only)

- If it is raining or drizzling during the inspection answer "yes" to was precipitation present during inspection. Otherwise, answer "no."

- The beginning time of the storm event shall be documented when the rain event starts during working hours. If the rain event begins outside work hours, include an estimate of the start time. For example, if it started raining after leaving the site at 3:00 p.m. and before arriving at 7:00 a.m., the beginning must be estimated.

- The elapsed time since the last rain event shall be obtained by reviewing the previous rain event BMP Checklists and counting the days in between events.

- Rainfall/Rain gauge information shall be monitored daily during a rain event. The inches of rain that has fallen shall be obtained from the Los Angeles County Department of Public Works, Water Resources Division, Hydrology Precipitation Map. The rain gauge for the past 24 hours shall be obtained from the website. Select the closest rain gauge station to the project site location at http://ladpw.org/wrd/precip/alert_rain/ and click on the 24-hour tab at the top of the page. Record the rain in inches and the name of the selected rain gauge station on the BMP Checklist. The rain gauge shall be monitored at the same time each day.

- Estimate the time of the duration of the rain event for the day the inspection was conducted.

Odors, sheens, turbidity, floating or suspended material or discoloration

- Inspect water discharges for any odors, sheens, turbidity, floating or suspended material or discoloration on the surface. Answer "yes" or "no" to whether there are any odors, sheens, turbidity, floating or suspended materials or discoloration noticed during the inspection. If there is no water discharge noticed, answer not applicable "N/A." If "yes" is the answer identify the source and describe in the space provided.
  - For example, if a sheen is noticed on the surface of the discharge, look upgradient to find and identify the location of the oil/grease/fuel that may have been the source of the sheen and document the findings. The source may have been a leaking vehicle or equipment. The corrective action shall be documented under the BMP Checklist section that addresses vehicles and equipment (See Section 5, NS-8, NS-9, and NS-10)

Description of any BMPs evaluated and any deficiencies noted as well as locations.

- Answer whether each BMP is deployed on site, whether the BMPs are adequately designed and implemented, and whether the BMPs are maintained and effective.
- Locations, deficiencies, corrective actions and implementation dates shall be noted in the space allotted or additional sheets shall be attached. The locations may be referenced to the SWPPP water pollution control drawings (WPCDs) or called out specifically.
  - For example, if the Storm Drain Inlet Protection BMPs are implemented on all drain inlets as shown on the WPCDs, reference to the WPCDs would be adequate.
- If BMPs need maintenance, the locations of each BMP deficiency (e.g., BMP that requires maintenance) shall be identified.
  - For example, "the gravel bag barrier along South St. between Broad Ave. and Park Ave. has broken bags that require replacement."

Corrective actions required and the associated implementation dates.

- The corrective actions may include implementation of BMPs, maintenance, repair or replacement.
  - For example, the stockpile BMPs under WM-3 may have plastic covers on stockpiles that are no actively being used that have been displaced and need to be replaced. The corrective action shall require a cover and berm for

stockpiles not actively being used. In addition, once the corrective actions have been implemented, the implementation date shall be entered.

- Corrective actions identified on the BMP Checklist shall be implemented by the end of the day of the inspection. If the corrective actions are not completed the same day, enforcement action will be taken. If 2 days can be allowed to complete a corrective action, a Notice of BMP Noncompliance form shall be completed and issued to the Contractor. If 2 days cannot be allowed, the Engineer may implement other enforcement actions or begin monetary penalties immediately.
- The corrective action for SWPPP amendment may require more time than "by the end of day." In case a corrective action requires more time than the end of the day, the inspector must track the implementation and document that the SWPPP was amended to complete the BMP Checklist. SWPPP amendments must be completed in accordance with the contract Special Provisions Section 7-8.6.3.7.
- The BMP Checklist must indicate implementation dates of when corrective actions are completed.

Photographs taken during the inspection, if any.

- Photographs if taken during the inspection shall be documented at the end of the inspection form and attached. If more space is needed, attach additional sheets.

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LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS
CONSTRUCTION DIVISION

BEST MANAGEMENT PRACTICES (BMP) CHECKLIST INSTRUCTIONS

PURPOSE: To verify the Contractor's effective implementation and maintenance of Best Management Practices (BMPs), and compliance with the project's Storm Water Pollution Prevention Plan (SWPPP).

PROCEDURE: The LACDPW Staff shall thoroughly evaluate each project site and complete all sections of the form. The detailed instructions for filling out the BMP Checklist included in the BMP Manual and Staff Guide must be followed. The BMP Checklist must be signed by the LACDPW Staff inspector and the Area Supervisor.

The LACDPW Staff shall indicate on the checklist, which BMPs are identified in the Contractor's County certified SWPPP with the actual BMPs being deployed on the project. The LACDPW Staff shall indicate whether the BMPs are adequately designed and implemented, maintained and effective. The location, deficiency, corrective action and implementation date must be provided under the comments for any BMP not adequately designed, implemented or maintained and effective.

When one or more of the BMPs have not been effectively designed, implemented or maintained, the LACDPW Staff shall:

1. Verbally discuss the problem with the Contractor's Qualified SWPPP Practitioner (QSP).
2. If the problem is not resolved by the end of the same working day, the LACDPW Staff shall complete a Notice of BMP Noncompliance form which directs the Contractor to take immediate action to implement or maintain the BMP on the project and/or to make appropriate amendments to the project SWPPP. See Notice of BMP Noncompliance form for further instructions if not corrected by end of day.

FREQUENCY: Weekly and before, during and after each storm.

DISTRIBUTION: Original report shall be forwarded to the Office Engineer with each week's project records. A copy shall be retained in the field project files and a copy shall be given to the Contractor.

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LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS

BEST MANAGEMENT PRACTICES (BMP) CHECKLIST

Project Name: ____________ PCA No.: Report No: ________
Contractors Name: ____________ Project ID No.: Inspection Time: ________
Inspector: ____________ Title:_Environmental Compliance Inspection Date: ________
Signature: ____________ Office Engineer:___ Report Date:____________

Area Supervisor: ____________
Signature: ____________
Approximate area of construction exposed (acres):_

Does this project require a SWPPP? ☐ Yes ☐ No
If yes, complete Columns A, B, C, and D. If no, complete Columns B, C, and D.
Are SWPPP amendments necessary? ☐ Yes ☐ No ☐ N/A

Are all paved roads that provide access to the project inspected daily for tracking of sediment and other debris? ☐ Yes ☐ No

Inspection Type: ☐ Weekly ☐ Pre-Storm ☐ Post-Storm ☐ During ☐ Other____________________________

Stage of construction: ☐ Utilities ☐ Grading/excavation/drilling ☐ Paving/general construction ☐ Vertical ☐ Final landscaping/stabilization

Construction activities completed:__On-going -- In Progress__________________________

Weather Information: (SWPPP Projects ONLY)
Was precipitation present during inspection? ☐ Yes ☐ No Rainfall/Rain Gauge (in.)
Beginning time of storm event: ___ Rain Station:________________________
Elapsed time since last rain event:____ Duration of event:_____

Are there any odors, sheens, turbidity, floating or suspended materials, discoloration on any water discharges? ☐ Yes ☐ No ☐ N/A
If yes, describe the source:____

Catch Basin Cleanout Contract? ☐ Yes ☐ No If yes, see only: SS-1, SS-7, SS-10, NS-6, WM-2, WM-4, WM-5, WM-6

1. Temporary Soil Stabilization Practices

A. Included in SWPPP?		BMP Description		B. Deployed on Site?		C. Adequately designed /implemented?			D. Maintained/ effective?			Location/Deficiencies/Corrective Actions/Implementation Dates
Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	SS-1	Scheduling	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-2	Preserve Existing Vegetation	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-3	Hydraulic Mulch	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-4	Hydroseeding	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-5	Soil Binders	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-6	Straw Mulch	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-7	Geotextiles/Plastic/EC Blankets/Mats	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-8	Wood Mulching	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-9	Earth dikes/drainage swales and	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-10	Outlet Protection/Velocity Dissipation	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-11	Slope Drains	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SS-12	Streambank Stabilization	☐	☐	☐	☐	☐	☐	☐	☐	

2. Temporary Sediment Control Practices

Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	SC-1	Silt Fence	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-2	Desilting Basin	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-3	Sediment Trap	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-4	Check Dam	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-5	Fiber Rolls	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-6	Gravel Bag Berm	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-7	Street Sweeping and Vacuuming	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-8	Sandbag Barrier	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-9	Straw Bale Barrier	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	SC-10	Storm Drain Inlet Protection	☐	☐	☐	☐	☐	☐	☐	☐	

3. Wind Erosion Control Practices

A. Included in SWPPP?		BMP Description		B. Deployed on Site?		C. Adequately designed /implemented?			D. Maintained/ effective?			Location/Deficiencies/Corrective Actions/Implementation Dates
Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	WE-1	Wind Erosion Control	☐	☐	☐	☐	☐	☐	☐	☐	

4. Tracking Control Practices

A. Included in SWPPP?		BMP Description		B. Deployed on Site?		C. Adequately designed /implemented?			D. Maintained/ effective?			Location/Deficiencies/Corrective Actions/Implementation Dates
Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	TC-1	Stabilized Construction Entrance/Exit	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	TC-2	Stabilized Construction Roadway	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	TC-3	Entrance/Outlet Tire Wash	☐	☐	☐	☐	☐	☐	☐	☐	

5. Non-Storm Water Management

A. Included in SWPPP?		BMP Description		B. Deployed on Site?		C. Adequately designed /implemented?			D. Maintained/ effective?			Location/Deficiencies/Corrective Actions/Implementation Dates
Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	NS-1	Water Conservation Practices	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-2	Dewatering Operations	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-3	Paving and Grinding Operations	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-4	Temporary Stream Crossing	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-5	Clear Water Diversion	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-6	Illicit Connection/ Illegal Discharge	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-7	Potable Water/ Irrigation	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-8	Vehicle and Equipment Cleaning	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-9	Vehicle and Equipment Fueling	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-10	Vehicle and Equipment Maintenance	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-11	Pile Driving Operations	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-12	Concrete Curing	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-13	Material/Equipment Use Over Water	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-14	Concrete Finishing	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-15	Demo/Removal Over Water	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	NS-16	Temporary Batch Plants	☐	☐	☐	☐	☐	☐	☐	☐	

6. Waste Management and Materials Pollution

A. Included in SWPPP?		BMP Description		B. Deployed on Site?		C. Adequately designed /implemented?			D. Maintained/ effective?			Location/Deficiencies/Corrective Actions/Implementation Dates
Yes	No			Yes	No	Yes	No	N/A	Yes	No	N/A	
☐	☐	WM-1	Material Delivery and Storage	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-2	Material Use	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-3	Stockpile Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-4	Spill Prevention and Control	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-5	Solid Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-6	Hazardous Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-7	Contaminated Soil Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-8	Concrete Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-9	Sanitary/Septic Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	
☐	☐	WM-10	Liquid Waste Management	☐	☐	☐	☐	☐	☐	☐	☐	

Photos

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2 __________
3 __________
4 __________
5 __________

Appendix C

Notice of BMP Noncompliance Form

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LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS

NOTICE OF BMP NONCOMPLIANCE FORM
INSTRUCTIONS

PURPOSE: To document and monitor a Contractor's noncompliance with the proper implementation, effectiveness and maintenance of Best Management Practices (BMPs) on all construction projects.

PROCEDURE: When the Contractor has failed to comply with contract Special Provisions or has failed to complete the recommended corrective action(s) identified on the Best Management Practices (BMP) Checklist, the LACDPW Staff shall complete Part 1 of the form.

PART 1

1.) Complete and sign Part 1:
(A) BMP Description,
(B) Location
(C) Recommended corrective action(s), and
(D) Date Corrective Action to be Completed (specify 2 working days or less).

2.) The form shall be signed by the Area Supervisor or the Environmental Compliance Unit (ECU) and then a copy shall be given to the Contractor. Request Contractor signature and make a copy after Contractor signs as recipient.

3.) When the corrective action is completed by the Contractor, write in the date in Column (E) "Date Corrective Action Completed."

4.) If the corrective action is completed by the specified date, check "Yes" in Column (F) Corrective action completed by time/date required (Column D).

5.) If the corrective action is not complete by the required time/date (Column D), the LACDPW Staff shall check "No" in Column (F) indicating the corrective action was not completed, and immediately notify the ECU.

PART 2

6.) Complete and sign Part 2 of the form if a corrective action was not completed by required time/date. Contractual Sanctions shall be implemented on a daily basis until the recommended corrective action is completed to the satisfaction of the LACDPW Staff and the ECU. Write the date once the corrective action is completed in Column (E).

7.) All completed forms shall be reviewed and signed by the Area Supervisor or ECU prior to forwarding them to the Contractor and the main office.

FREQUENCY: When the Contractor is not in compliance with contract Special Provisions or fails to complete recommended corrective actions on the BMP Checklist.

DISTRIBUTION:
1.) Copy to be given to Contractor.
2.) Original form shall be forwarded to the Office Engineer with each week's project records.
3.) The office Engineer shall forward a copy to the ECU.
4.) Copy to be retained in the field project files.

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LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS
NOTICE OF BMP NONCOMPLIANCE FORM

Project Name: ______________________ PCA No.: ______________________
Contractor Name: ______________________ Contractor Rep.: ______________________
LACDPW Staff Name: ______________________ Noncompliance Notice Date/Time: ______________________
Office Engineer Name: ______________________ BMP Checklist Report No./Date: ______________________
Area Supervisor Name: ______________________

PART 1 BMP Corrective Action

No.	(A) BMP Description	(B) Location (Station, Intersection, etc.)	(C) Recommended Corrective Actions (within 2 working days)	(D) Date Corrective Action to be Completed	(E) Date Corrective Action Completed	(F) Corrective Action completed by required date/ time (Column D)?
						IF NO, GO TO PART 2.
1.						☐ Yes ☐ No
2.						☐ Yes ☐ No
3.						☐ Yes ☐ No
4.						☐ Yes ☐ No

Potential BMP Noncompliance Sanctions

You are advised that failure to comply with or late response to fully implement any of the above required corrective actions for BMP Noncompliance will result in ASSESSIING $1,000.00 per day for each noncompliance described above pursuant to Section 7-8.6 of the contract specifications. Such noncompliance may also be subject to Los Angeles County Code - Section 12.80.630 punishable by a fine of not more than $1,000 or by imprisonment in the county jail for a period of not to exceed six months, or by both such fine and imprisonment. In addition, any noncompliance may also be subject to the Regional Water Quality Control Board assessment of fines up to $10,000 per day for each noncompliance and $10 per gallon of water discharged pursuant to Section 13385 and 13387 of the Porter-Cologne Act.

LADPW Staff Signature: ______________________ Recipient Name: ______________________

Area Supervisor or Environmental Compliance Unit Signature: ______________________ Signature/Date ______________________

(Note: Signing this document is not an admission of guilt.)

PART 2 Contractual Sanctions

CONTRACTUAL SANCTIONS ARE REQUIRED. BEGIN ASSESSING $1,000.00 PER DAY FROM THE CONSTRUCTION PROGRESS PAYMENTS IN ACCORDANCE WITH SECTION 7-8.6 OF THE CONTRACT SPECIFICATIONS.

LACDPW Staff Name: ______________________ Recipient Name: ______________________
LACPDW Staff Signature/Date: ______________________ Signature/Date ______________________
Area Supervisor Signature/Date: ______________________ (Note: Signing this document is not an admission of guilt.)

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HYDROLOGY MANUAL

Los Angeles County Department of Public Works
January 2006

RB-AR33521

Los Angeles County Department of Public Works

HYDROLOGY MANUAL

Water Resources Division
January 2006

Donald L. Wolfe, Director

900 South Fremont Avenue
Alhambra, California 91803

RB-AR33522

HYDROLOGY MANUAL

Prepared By:

Technical Assistant: Chris Conkle
Technical Assistant: Janelle Moyer

Project Manager: Ben Willardson, P.E.
Project Supervisor: Adam Walden, P.E.
Project Director: Iraj Nasseri, P.E., Ph.D.

Review Committee:

Martin Araiza, P.E.
Thuong Do, P.E.
Peter Imaa, P.E.

Los Angeles County Department of Public Works
January 2006

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CHAPTER 1

Introduction

1.1 PURPOSE AND SCOPE

This manual establishes the Los Angeles County Department of Public Works' hydrologic design procedures and serves as a reference and training guide. This manual contains charts, graphs, and tables necessary to conduct a hydrologic study within the County of Los Angeles. Examples provide guidance on using the hydrologic methods.

The primary purpose of this manual is to explain the steps involved in converting rainfall to runoff flow rates and volumes using Public Works' standards. This manual contains procedures and standards developed and revised by the Water Resources Division based on historic rainfall and runoff data collected within the county. The hydrologic techniques in this manual apply to the design of local storm drains, retention and detention basins, pump stations, and major channel projects. The techniques also apply to storm drain deficiency and flood hazard evaluations. Low flow hydrology methods related to water quality standards are also discussed.

This manual compiles information from previous editions of the County of Los Angeles Hydrology Manual, the 2002 Hydrology Manual Addendum, and other reference materials. The standards set forth in this manual govern all hydrology calculations done under Public Works' jurisdiction. Hydrologic procedures in manuals prepared for use by other Divisions within Public Works must be compatible with this manual.

1.2 OVERVIEW OF HYDROLOGIC METHOD

The Los Angeles County Flood Control District initiated its Comprehensive Plan in 1931. Engineers determined that the runoff data within the District was insufficient to create empirical runoff calculations due to limited stream flow data. Lack of stream flow data made it difficult to establish standards

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and a hydrologic method based on runoff observations. Therefore, the engineers decided that computing design flows based on rainfall was necessary. A rainfall based hydrologic method was deemed more acceptable due to the availability of rainfall data. Figure 1.2.1 shows a rain gage used to collect rainfall data for hydrologic analysis.

Figure 1.2.1
Rain Gage #47D Located at Clear Creek School

Using rainfall-runoff relationships, methods are developed to compute flow rates and define hydrographs based on a design storm event. The two rainfall-runoff methods that apply to hydrology studies within the County of Los Angeles are the Rational and Modified Rational Methods. The use of these rainfall-runoff methods depends on the study requirements.

The Rational Method, Q = CIA, is used for simple hydrology studies within the County of Los Angeles. This method produces a peak flow rate and is only applicable to small areas. The Rational Method applies to development of small areas when no storage volume information is required and overland flow is the primary collection method.

The primary method, in use since the 1930's, is the Modified Rational Method (MODRAT). MODRAT is based on the Rational Method, but uses a time of concentration and a design storm to determine intensities throughout the storm period. The intensities are used to determine the soil runoff coefficient. The rational formula then provides a flow rate for a specific time. Plotting the time specific flow rate provides a hydrograph and an associated flow volume. MODRAT is the standard method for hydrologic studies within the county. Computer programs implement MODRAT to compute runoff data from input parameters.

MODRAT relies on a design storm defined by a time-intensity relationship and a spatial precipitation pattern. The temporal and spatial distributions of rainfall used with MODRAT have changed over the years based on analysis of historic rainfall records. A dimensionless design storm represents rainfall events commonly observed during major extratropical storms in the Los Angeles area. The storm duration is four days. The maximum rainfall quantity occurs on the fourth day.

Rainfall isohyets show the spatial distribution of rainfall over the county. The isohyets represent the depth of rainfall for a standard design frequency over a specified period of time. Multiplying the unit hyetograph by the rainfall isohyetal depth produces the design storm for a specific area. Figure 1.2.2 shows rainfall isohyets in the County of Los Angeles. This area-specific design storm and an area-specific time of concentration define the time-intensity relationship for a particular subarea. Each subarea requires an area specific time of concentration and design storm.

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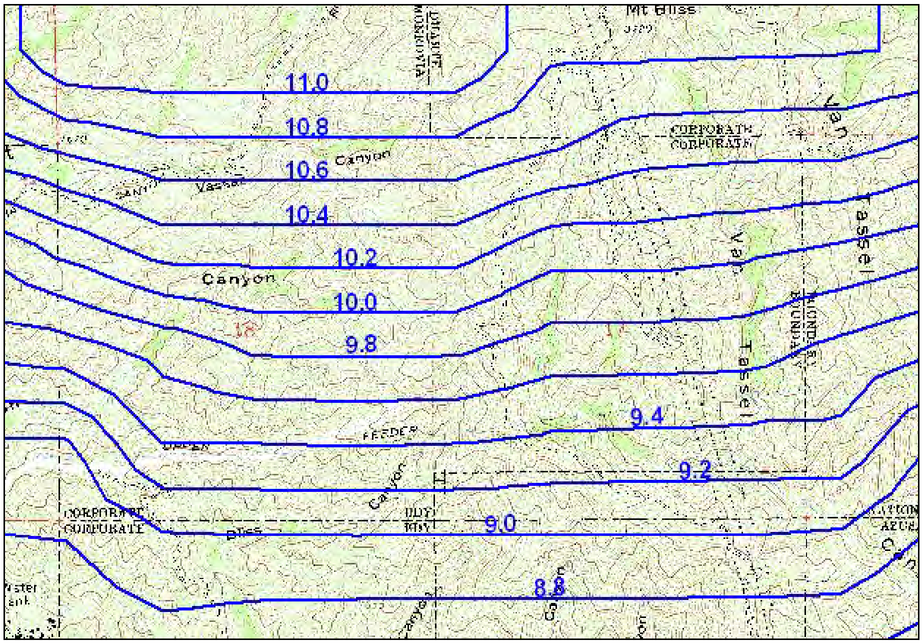

Figure 1.2.2
50-year, 24-hour Rainfall Isohyets in the County of Los Angeles

Calculation of the time of concentration has evolved over time. Currently, time of concentration calculations rely on a regression equation based on the kinematic wave theory.

Reservoir routing of hydrographs for storage uses the Modified Puls method. This method is based on a finite difference approximation of the continuity equation coupled with an empirical representation of the momentum equation.[1] This method is widely used for reservoir routing in hydrologic studies and is the approved method for use within the County of Los Angeles.

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Figure 1.2.3 shows Morris Reservoir located in the San Gabriel Mountains.

Figure 1.2.3
Morris Reservoir

[1] US Army Corps of Engineers. Hydrologic Modeling System HEC-HMS Technical Reference Manual. Washington, D.C. 2002

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CHAPTER

2

Physical Factors Affecting Hydrology

2.1 TOPOGRAPHY

The County of Los Angeles covers 4,083 square miles and measures approximately 66 miles from east to west and 73 miles from north to south. The topography within the county is 25 percent mountains, 10 percent coastal plain, and 65 percent foothills, valley, or desert. Elevations range from sea level to a maximum of 10,064 feet at the summit of Mount San Antonio. The county is divided into five principal drainage systems: Los Angeles River Basin, San Gabriel River Basin, Santa Clara River Basin, Coastal Basin, and Antelope Valley.

The coastal plain slopes mildly and contains relatively few depressions or natural ponding areas. The slopes of the main river systems crossing the coastal plain, such as San Gabriel River, Los Angeles River, and Ballona Creek, range from 4 to 14 feet per mile.

The mountain ranges within the County of Los Angeles are generally aligned in an east-west direction and are part of the Transverse Ranges. The major range in the county is the San Gabriel Mountains. Most of the mountainous areas lie below 5,000 feet with only 210 square miles above this elevation. The mountainous area is rugged. The deep "V"-shaped canyons with steep walls are separated by sharp dividing ridges. The average slope of the canyon floors ranges from 150 to 850 feet/mile in the San Gabriel Mountains.

2.2 GEOLOGY AND SOILS

The geologic setting of the County of Los Angeles is largely the result of the tectonic plate boundary between the North American and Pacific plates that runs along the northern edge of the county. The San Andreas Fault forms the boundary between these plates and bisects the state in a northwest to southeast direction. In the Los Angeles area, the fault bends to an east-west

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orientation before returning to its former course. Crustal forces resulting from this change in geometry are uplifting the San Gabriel Mountains. The San Gabriel Mountains experience a high rate of uplift that is being counteracted by high erosion rates. As a result, the county's valleys contain deep deposits of alluvial sediments.[1]

Igneous, sedimentary, and metamorphic rock groups are present within the county. The San Gabriel Mountains and Verdugo Hills are composed primarily of highly fractured igneous rock, with large formations of granitic rock exposed above coarse and porous alluvial soils. Faulting and deep weathering have produced pervious zones in the rock formations. These rock masses have a comparatively shallow soil mantle caused by accelerated erosion on the steep slopes. Figure 2.2.1 illustrates a weathered igneous rock outcrop along Highway 39 in San Gabriel Canyon.

Figure 2.2.1
Weathered Igneous Rock Outcrop Along Highway 39 in San Gabriel Canyon

Other mountainous and hilly areas within the county are composed primarily of folded and faulted sedimentary rocks, including shale, sandstone, and

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conglomerate. Residual soils in these areas are shallow and are generally less pervious than those of the San Gabriel Mountains.

Valley and desert surface soils are alluvial and grade from coarse sand and gravel near canyon mouths to silty clay and clay in the lower valleys and coastal plain. The alluvium builds up through repeated deposition of debris and reaches depths as great as 2,000 feet. Where there is little clay, this material is quite porous. Impervious lenses and irregularities divide the alluvium into several distinct groundwater basins. Valley soils are generally well drained with relatively few perched water or artesian areas.

2.3 VEGETATIVE COVER AND LAND USE

The principal vegetative cover of upper mountain areas consists of various species of brush and shrubs known as chaparral. Most trees found on mountain slopes are oak. Figure 2.3.1 shows oak trees along a stream in the San Gabriel Mountains. Pine, cedar, and juniper are found in ravines at higher elevations and along high mountain summits. Alder, willow, and sycamore are found along streambeds at lower elevations.

Figure 2.3.1
Oaks Trees Along a Stream in the San Gabriel Mountains

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The chaparral is extremely flammable, and extensive burning of the mountain vegetation frequently occurs during dry, windy weather. Chaparral depends on fire to germinate and has the ability to sprout quickly after fire, reestablishing the watershed cover within a period of five to ten years. Figure 2.3.2 shows the revegetation of chaparral after a fire.

Figure 2.3.2
Revegetation of Chaparral After Fire

Grasses are the principal vegetation on the low elevation hills. Most of the hills and valleys have been converted to urban and suburban use in the portion of the county south of the San Gabriel Mountains. Development of the desert areas north of the San Gabriel Mountains and in the Santa Clarita Valley has increased in recent years and is proceeding at an accelerated rate.

2.4 CLIMATE

The climate within the county varies greatly. The windward side of the San Gabriel Mountain range is subtropical while the leeward side in the Mojave Desert is arid. Seasonal, normal precipitation totals for representative areas are shown in Table 2.4.1.

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Location	Average Annual Precipitation (in)
Coastal Plain	15.5
San Gabriel Mountains	32.9
Desert – Antelope Valley	7.8

Table 2.4.1
Seasonal Normal Precipitation for Various Climate Zones

Most precipitation occurs between December and March. Precipitation during summer months is infrequent, and rainless periods of several months are common.

Snow rarely falls on the coastal plain. Snowfall at elevations above 5,000 feet frequently occurs during winter storms. This snow melts rapidly except on the higher peaks and north facing slopes.

January and July are the coldest and warmest months of the year, respectively. Table 2.4.2 illustrates the seasonal variation of temperature in the mountain and coastal plain areas.

	Los Angeles (Coastal Plain)	Mt Wilson (San Gabriel Mts)
Average January Minimum Temperature	48°	35°
Average July Maximum Temperature	84°	80°
Record High	112°	99°
Record Low	28°	9°

Table 2.4.2
Characteristic Temperatures of the Mountain and Coastal Plain Areas

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2.5 HYDROMETEOROLOGIC CHARACTERISTICS

Hydrometeorological characteristics are greatly influenced by the mountains within the county. Winter storms affect the coastal areas while convective storms affect the desert areas.

Coastal and Mountain Areas

Most precipitation in the Los Angeles area occurs in the winter due to extratropical cyclones from the North Pacific. Major storms consist of one or more frontal systems, extending 500 to 1,000 miles in length. The frontal systems produce rainfall simultaneously throughout the county, occasionally lasting four days or longer.

These storms approach Southern California from the west or southwest with southerly winds that continue until the front passes. The mountain ranges lie directly across the path of the inflowing warm, moist air. The coastal and inland ranges cause the warm air to rise. As it rises, precipitation forms and falls. This orographic effect intensifies rainfall along the mountains and coastal areas. As a result, rainfall intensities and totals in these areas increase. The effect of snow melt on flood runoff is significant only in the few cases where warm spring rains from southerly storms fall on a snow pack. Temperatures throughout the county usually remain above freezing during major storms. Figure 2.5.1 is a view of the coastal area within the County of Los Angeles.

Figure 2.5.1
Coastal Area

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Desert Areas

Orographic precipitation over the mountains produces a rain shadow on the leeward side of the mountains. As a result, the northern San Gabriel Mountains and the Mojave Desert regions experience primarily summer convective rainfall. The most serious floods in many desert areas may result from convective summer storms. Figure 2.5.2 shows a view of the desert area within the County of Los Angeles.

Figure 2.5.2
Desert Area Near Lancaster

2.6 RUNOFF CHARACTERISTICS

Runoff characteristics are influenced by soil type, slope, vegetation, and many other conditions. General regions behave differently based on these factors and runoff varies greatly between mountain and valley areas.

Mountain Areas

Steep canyon walls and channel slopes rapidly concentrate storm runoff in mountainous areas. Depression and detention storage effects are minor in this rugged terrain.

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The moisture content of mountain soils has a pronounced effect on runoff during a storm. Precipitation during periods of low soil moisture is almost entirely absorbed by the porous soils. Soil moisture is lowest at the beginning of the rainy season due to evapotranspiration during the preceding summer months. Significant surface runoff does not occur until soil moisture is near field capacity, except during extremely intense rainfall. Consequently, in certain areas, significant runoff occurs as subsurface flow, or interflow, rather than direct runoff. Most streams in the county are intermittent. Natural year-round perennial discharge is mostly limited to springs in portions of the San Gabriel Mountains.

Hill and Valley Areas

Runoff concentrates rapidly below the generally steep slopes in hilly areas. Runoff rates from undeveloped hilly areas are normally smaller than those from mountain areas of the same size. Development in hilly areas decreases runoff concentration times considerably due to increased channelization. Runoff volumes and rates increase due to increased imperviousness.

Debris production from undeveloped hilly areas is normally less than debris production from mountainous areas of the same size. Increased development reduces erosion and limits debris in storm flow.

Figure 2.6.1 shows a hilly area located in the Santa Clara River Watershed.

Figure 2.6.1
Hills in Santa Clara River Watershed

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Runoff in the valleys and coastal plain is affected by ponding and spreading of flows. Valley areas are affected by development. In highly developed valley areas, local runoff volumes increase as impervious materials replace the soil. Peak runoff rates for valley areas increase due to the elimination of natural ponding areas and improved hydraulic efficiency. Conveyances, such as streets and storm drain systems carry the water to the ocean more rapidly and do not allow infiltration. Figure 2.6.2 shows a view of the Los Angeles basin from the San Gabriel Mountains.

Figure 2.6.2
Los Angeles Basin from the San Gabriel Mountains

[1] *San Gabriel River Corridor Master Plan, March 2004.*

CHAPTER

3

Major Watersheds and Tributaries

There are five major watersheds within the County of Los Angeles. Four of these drain to the ocean and the fifth enters dry lakes in the desert. The watersheds are unique and are developed to different extents. Watershed descriptions and a location map shown in Figure 3.1 are provided to help understand the hydrologic conditions within each watershed.

Figure 3.1
Major Watersheds in the County of Los Angeles

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3.1 LOS ANGELES RIVER[1]

The Los Angeles River Watershed covers over 830 square miles. The watershed includes the western portion of the San Gabriel Mountains, the Santa Susana Mountains, the Verdugo Hills, and the northern slope of the Santa Monica Mountains. The river flows from the headwaters in the western San Fernando Valley and outlets in San Pedro Bay near Long Beach. The river crosses the San Fernando Valley and the central portion of the Los Angeles Basin. The watershed terrain consists of mountains, foothills, valleys, and the coastal plain.

The Los Angeles River and many of its tributaries have been the subject of extensive engineering work to reduce the impacts of flood events. Prior to development, the Los Angeles River system was typical of other streams in the southwest. The river's channel was broad and often shifted location within the flood plain due to the high sediment loads. The stream location within the coastal plain has varied greatly over the years. Between 1815 and 1825, the river changed course completely. Breaking its banks in what is now Downtown Los Angeles, the river followed the course of Ballona Creek, reaching the ocean at a location 20 miles from its current outlet.

Numerous flood control facilities were constructed in the early 20th century, as development began to take place on this wide flood plain. The concrete sections of the Los Angeles River were constructed between the late 1930's and the 1950's. Channel improvements and extensive watershed development decrease times of concentration and increase runoff flow rates and volumes. The Los Angeles County Flood Control district constructed three major dams during this period: Pacoima, Big Tujunga and Devil's Gate. The dams were built to reduce downstream flow rates and conserve water for ground water recharge purposes. In the Rio Hondo drainage area, several dams were constructed including Eaton Wash, Sierra Madre, Santa Anita and Sawpit. Additionally, the U.S. Army Corps of Engineers operates four major dams in the watershed to assist in flood control. The four dams are Hansen, Lopez, Sepulveda and Whittier Narrows. Figure 3.1.1 is a view of Big Tujunga Dam after the January 2005 storms.

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Figure 3.1.1
Big Tujunga Dam
January 11, 2005

The parts of the San Gabriel Mountains tributary to the Los Angeles River contain some of the most prolific sediment producing streams in the world. Intense rainfall, coupled with highly erodible sediment, produces damaging debris discharges. Numerous debris basins have been constructed along the foothills of the San Gabriel Mountains to remove sediment from the flow.

The Los Angeles River Watershed has a diverse land use pattern. The upper portions of the watershed are covered by Angeles National Forest and other rural areas. The remainder of the watershed is highly developed. The watershed has large areas of commercial, residential, and industrial development. Few parks or natural areas exist in the lower watershed.

The major tributaries of the Los Angeles River include Burbank Western Channel, Pacoima Wash, Tujunga Wash, and Verdugo Wash in the San Fernando Valley; and the Arroyo Seco, Compton Creek, and Rio Hondo in the Los Angeles Basin. Much of this tributary network has also been lined with concrete to meet flood control needs. Figure 3.1.2 shows a view of the Los Angeles River at Willow Street.

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Figure 3.1.2
Los Angeles River
At Willow Street

3.2 SAN GABRIEL RIVER

The San Gabriel River Watershed is located in the eastern portion of the county. The river drains the San Gabriel Mountains to the north and is bounded by the Los Angeles River Watershed and Santa Ana River Watersheds. The watershed drains 640 square miles. The watershed outlets into the Pacific Ocean between Long Beach and Seal Beach after passing through the Alamitos Bay estuary. Tributaries to the San Gabriel River include: Walnut Creek, San Jose Creek, and Coyote Creek.

The upper portions of the watershed are contained almost entirely within the Angeles National Forest and are nearly untouched by development. The mountains in this area are extremely rugged with steep V-shaped canyons. The vegetation is dominated by chaparral and coastal sage scrub with patches of oak woodlands. Conifers are dominant at higher elevations. The streambeds in the area contain sycamore and alder woodlands.[2]

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In contrast, the lower part of the watershed is mostly developed below the mouth of the San Gabriel Canyon. The developments include commercial, residential, and industrial use. The developed area in the San Gabriel Valley and Los Angeles Basin comprises 26% of the total watershed area. Figure 3.2.1 shows the upper natural portion of the San Gabriel River.

Figure 3.2.1
Upper Portion of the San Gabriel River

Similar to the Los Angeles River, the San Gabriel River once occupied a wide floodplain and shifted course to accommodate large flows and sediment loads. Development of the floodplain required changing the character of the river dramatically since periodic inundation of the floodplain was not compatible with the new land uses.

Several major dams and debris basins impound floodwaters and prevent debris flows originating in the San Gabriel Mountains. These include Cogswell Dam, San Gabriel Dam, Morris Dam, Big Dalton Dam, San Dimas Dam, Live Oak Dam, and Thompson Creek Dam. Many of these facilities were constructed in the 1930's and have proven their worth by preventing significant damage from large flood events. Major flood events occurred in 1938, 1969, 1978, 1983, 1998, and 2005. Additionally, the U.S. Army Corps of Engineers operates the Santa Fe Dam and Whittier Narrows Dam in the watershed to assist in flood control. Figure 3.2.2 shows the San Gabriel Dam at full capacity.

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Figure 3.2.2
San Gabriel Dam at Full Capacity

The San Gabriel River has been channelized below Santa Fe Dam to aid in flood prevention. However, the channel invert was left unlined for much of its length between Santa Fe Dam and Florence Avenue in Downey. The unlined bottom promotes infiltration of flood waters released from upstream dams. Public Works installed rubber dams to further utilize the river bottom for ground water recharge. Figure 3.2.3 is a rubber dam located in the lower portion of the river.

Figure 3.2.3
Rubber Dam Located in the Lower Portion of the San Gabriel River

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The most significant spreading ground facilities in the county are located in the San Gabriel River watershed. Runoff resulting from storm events is diverted into the spreading facilities and allowed to recharge groundwater. Major spreading grounds are located at the mouth of San Gabriel Canyon and in the Montebello area downstream of the Whittier Narrows Dam.

3.3 SANTA CLARA RIVER

The Santa Clara River originates in the northern slopes of the San Gabriel Mountains at Pacifico Mountain and travels west into Ventura County, discharging into the Pacific Ocean near the City of Ventura. The river runs approximately 100 miles from the headwaters near Acton, California, to the ocean. The river drains an area of approximately 1,600 square miles.

The upper portion of the river, within the County of Los Angeles, has a watershed area of approximately 644 square miles. Ninety percent of this area is mountainous with steep canyons; while the remaining ten percent is alluvial valleys.[3] The area is mostly undeveloped with a large portion in the Angeles National Forest. There are some mixed-use developed areas concentrated in or near the City of Santa Clarita. The watershed is currently experiencing an accelerated rate of development in areas adjacent to the river. Figure 3.3.1 shows the Santa Clara River after the 1978 storms.

Figure 3.3.1
Santa Clara River Downstream of Magic Mountain Parkway
March 4, 1978

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The Santa Clara River and its tributaries are ephemeral streams characterized by alluvial soils. Discharge occurs quickly during rainfall events and diminishes quickly after rainfall has ceased. As in other county watersheds, the mountain and foothill areas are susceptible to debris-laden flows during intense rainfall, especially when a watershed is recovering from fire.[4]

The river remains in a generally natural state with some modifications related to the development of the floodplain. The expected population increase will continue to produce floodplain encroachment, requiring additional bank protection, channelization, and channel crossings. The expected population increase, as well as increased imperviousness, will impact the hydrologic characteristics of the river and the sediment balance.

Some of the major tributaries in the county's portion of the Santa Clara River watershed include: Castaic Creek, San Francisquito Canyon, Bouquet Canyon, Sand Canyon, Mint Canyon, and the South Fork of the Santa Clara River.

3.4 COASTAL[5]

The Coastal watershed is comprised of a number of individual watersheds that outlet into Santa Monica and San Pedro Bays. These include the major watersheds of Malibu Creek, Topanga Creek, Ballona Creek, and the Dominguez Channel. These watersheds have unique topographic and hydrologic characteristics ranging from undeveloped to highly urbanized. For simplicity, these coastal watersheds are grouped together due to their relatively small sizes.

The Malibu Creek Watershed is comprised of 109 square miles at the western end of the County of Los Angeles and extends into Ventura County. Most of the watershed is undeveloped public land. There is sporadic but increasing development throughout the area. The most extensive development is centered along US Highway 101. The northern portion is hilly while the southern portion, near the ocean, is rugged mountain terrain. Malibu Creek drains into the Pacific Ocean near the Malibu Civic Center. A portion of Malibu Creek is shown in Figure 3.4.1.

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Figure 3.4.1
Malibu Creek

Topanga Creek drains 18 square miles in the central Santa Monica Mountains. The watershed is primarily rural with widely scattered residential and commercial development. The creek flows unobstructed along its course and empties into the Santa Monica Bay in an unincorporated portion of the county east of Malibu.

Ballona Creek is a flood control channel that drains the western Los Angeles basin. The watershed area is bounded by the Santa Monica Mountains on the north and the Baldwin Hills on the south. It extends east nearly to downtown Los Angeles. The total watershed area is roughly 130 square miles. The area is primarily developed but includes undeveloped areas on the south slope of the Santa Monica Mountains. The land use is 64%

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residential, 8% commercial, 4% industrial, and 17% open space. The major tributaries to Ballona Creek include: Centinela Creek, Sepulveda Canyon Channel, Benedict Canyon Channel, and numerous storm drains. The watershed drains into Santa Monica Bay at Marina del Rey.

Figure 3.4.2 is a view of the concrete lined portion of Ballona Creek.

Figure 3.4.2
Ballona Creek

The Dominguez Watershed is comprised of approximately 133 square miles in the southern portion of the county. The watershed extends from near the Los Angeles International Airport to the Los Angeles Harbor. The area is almost completely developed with regions of residential, commercial, and industrial land use. The storm drains and flood control channel network, as opposed to natural drainage features, define the watershed.

There are many other smaller watersheds in the Coastal drainage area that drain developed and undeveloped areas directly to the Pacific Ocean.

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3.5 ANTELOPE VALLEY

The Antelope Valley encompasses approximately 1,200 square miles in the northern portion of the County of Los Angeles. The valley is bounded on the north by the Tehachapi Mountains and on the south by the Sierra Pelona and the San Gabriel Mountains. Numerous streams from the mountains and foothills flow across the valley floor. The valley lacks defined drainage channels outside of the foothills and is subject to unpredictable drainage patterns.

Nearly all the surface water runoff from the Los Angeles portion of the Antelope Valley accumulates on Rosamond Dry Lake near the Kern County Line. A small portion is tributary to other dry lakes in the area. This 20 square mile playa is dry during most of the year, but is likely to be flooded during prolonged periods of winter precipitation. Surface runoff, as well as discharges from groundwater, remain on the dry lake until removed by infiltration and evaporation. Anecdotal evidence indicates that at times the playa may be underwater for up to five months at a time, as occurred during the winter of 1965-66.

The valley contains the developed areas of Lancaster and Palmdale. The remainder of the valley is sparsely developed. However, the valley is one of the most rapidly developing areas in the county. Rapid development is likely to continue for some time. This development will significantly alter the hydrologic characteristics of the basin.

A view of Antelope Valley is shown in Figure 3.5.1.

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Figure 3.5.1
Antelope Valley

1 *The Los Angeles River Master Plan.* "Flood Management and Water Conservation". Los Angeles County Department of Public Works. Approved June 13, 1996.

2 *San Gabriel River Corridor Master Plan,* March 2004, pages 2-4.

3 "Hydrologic Model of the Santa Clara River and its Tributaries". David Ford Consulting. December 1999.

4 "Hydrologic Model of the Santa Clara River and its Tributaries". David Ford Consulting. December 1999.

5 See North Santa Monica Bay Watersheds White Paper, November 6, 2003; Dominguez Watershed Management Master Plan, April 2004

6 Dettling, C., R.H. French, J.J. Miller, and J. Carr (2004). An Approach to Estimating the Frequency of Playa Lake Flooding.

RB-AR33555

CHAPTER

4

Policy on Levels of Protection

4.1 DEPARTMENT POLICY MEMORANDUM

A Department of Public Works memorandum dated March 31, 1986, General Files No. 2-15.321, established the policy on levels of flood protection. This policy describes degrees of flooding and which design storms should be used for certain conditions and structures. Chapter 5 defines the design storms for use in the County of Los Angeles.

4.2 CAPITAL FLOOD PROTECTION

The Capital Flood is the runoff produced by a 50-year frequency design storm falling on a saturated watershed (soil moisture at field capacity). A 50-year frequency design storm has a probability of 1/50 of being equaled or exceeded in any year. Capital Flood protection also requires adding the effects of fires and erosion under certain conditions. This section describes specific criteria for applying the burning and bulking requirements for Capital Flood protection.

The following sections describe facilities and structures required to meet the Capital Flood level of protection.

Natural Watercourses

The Capital Flood level of protection applies to all facilities, including open channels, closed conduits, bridges, dams, and debris basins not under State of California jurisdiction. These facilities must also be constructed in or intercept flood waters from natural watercourses. Facilities under the State of California jurisdiction must also meet the state's criteria, which may include the Probable Maximum Flood criteria described in Section 4.4.

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A natural watercourse is a path along which water flows due to natural topographic features. For definition purposes, a natural watercourse drains a watershed greater than 100 acres. Natural watercourses have not been subject to major engineering works such as channel realignment or bank protection. The watercourse must also meet one or more of the following conditions during a Capital Flood:

1. Flow velocities greater than 5 ft/sec.

2. Flow depths greater than 1.5 feet.

Replacement of the natural watercourse with flood control facilities that do not provide the Capital Flood level of protection requires water surface elevation analysis. The water surface elevation must be at least one foot below the base of existing dwellings adjacent to the channel. The construction must also meet the requirement of the National Flood Insurance Program described in Section 4.6. An example of a natural watercourse in Bouquet Canyon is shown in Figure 4.2.1.

Figure 4.2.1
Bouquet Canyon
Natural Watercourse
in June 2005

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Floodways

The Capital Flood applies to all areas mapped as floodways. See Section 4.6 for more information on floodways.

Natural Depressions or Sumps

The Capital Flood level of protection applies to all facilities constructed to drain natural depressions or sumps. These facilities include channels, closed conduits, retention basins, detention basins, pump stations, and highway underpasses. A depression or sump is an area from which there is no surface flow outlet and must meet one or more of the following conditions during a Capital Flood:

1. Ponded depth of 3 feet or greater.

2. Ponded water surface elevations within one foot below the base of adjacent dwellings resulting from construction of facilities with less than the Capital Flood capacity. This condition does not apply if ponded water can escape as surface flow before reaching the base of adjacent dwellings during the Capital Flood.

Figure 4.2.2 shows an example of a flooded sump at the intersection of San Fernando Road and Tuxford Street in Sun Valley.

Figure 4.2.2
Flooded Sump at Intersection of San Fernando Road and Tuxford Street
January 9, 2005

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Sumps with drainage from roadways require special care. If flows reach the sump by following the roadway from upstream, use the Capital Flood on all areas upstream of the sump that drain to the roadway. The roadway must carry the Capital Flood capacity with a water surface elevation below the private property line. Otherwise, drainage facilities must be added beneath the roadway. See the Los Angeles County Highway Design Manual[1], and Chapter 44 of the Land Development Division Guidelines.

Culverts

The Capital Flood level of protection applies to all culverts under major and secondary highways.

Tributary Areas Subject to Burning

Canyons and mountainous areas within the County of Los Angeles are subject to burning. The Capital Flood applies to all areas likely to remain in a natural state, regardless of size. Burned canyons and mountainous areas also add debris to the runoff. Therefore, flow from "burned" areas must be "bulked." Bulking reflects increases in runoff volumes and peak flows related to inclusion and transport of sediment and debris.

Section 6.3 discusses the development of burned watershed hydrology. Section 3.3 of the Public Works' Sedimentation Manual contains information on bulking flows.

4.3 URBAN FLOOD PROTECTION

All drainage facilities in developed areas not covered under the Capital Flood protection conditions must meet the Urban Flood level of protection. The Urban Flood is runoff from a 25-year frequency design storm falling on a saturated watershed. A 25-year frequency design storm has a probability of 1/25 of being equaled or exceeded in any year.

Street flow due to the urban flood may not exceed the private property line elevation. However, runoff can be conveyed in drains under the street and on the street surface. Urban Flood runoff is allowed to flow in the street to the point where the flow reaches the street capacity at the property line. Depth analysis is to be started at the upstream end of the watershed. The flow should be split to allow conveyance in the street and in a drain below the street when flows exceed street capacity. Drains must at least carry flow

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from the 10-year frequency design storm. See the Los Angeles County Highway Design Manual[1] and Chapter 44 of the Land Development Division Guidelines for road design requirements.

The street or highway must carry the balance of the 25-year frequency design storm below the property line. The drain may carry more flow to lower the water surface on the street to below the private property line or meet other requirements for vehicular or pedestrian traffic. See the Los Angeles County Highway Design Manual for the traffic requirements[1]. The maximum allowable pipe diameter for hydrology studies is 96 inches. Beyond this size, choose a rectangular channel conveyance. Figure 4.3.1 provides an example of street flow.

Figure 4.3.1
Street Flow After 1938 Storm

4.4 PROBABLE MAXIMUM FLOOD PROTECTION

The Probable Maximum Flood (PMF) results from the most severe combination of critical meteorological and hydrologic conditions that are reasonably possible in the region[2]. The Probable Maximum Precipitation[3] (PMP) represents the greatest depth of rainfall theoretically possible for a

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given duration over a given drainage basin. The PMF occurs when the PMP falls over watersheds that have reached field capacity (saturated) conditions.

California's Division of Safety of Dams (DSOD) requires a PMF analysis for dams and debris basins that hold at least 1,000 acre-feet, are 50 feet or higher, would require at least 1,000 people to be evacuated, and have a damage potential of $25,000,000 or more. Most dams and debris basins (earth embankment, concrete, or other materials) in the County of Los Angeles must safely pass the PMF[4]. Figure 4.4.1 shows a chart of the State's height and storage parameters that define dam jurisdiction[5]:

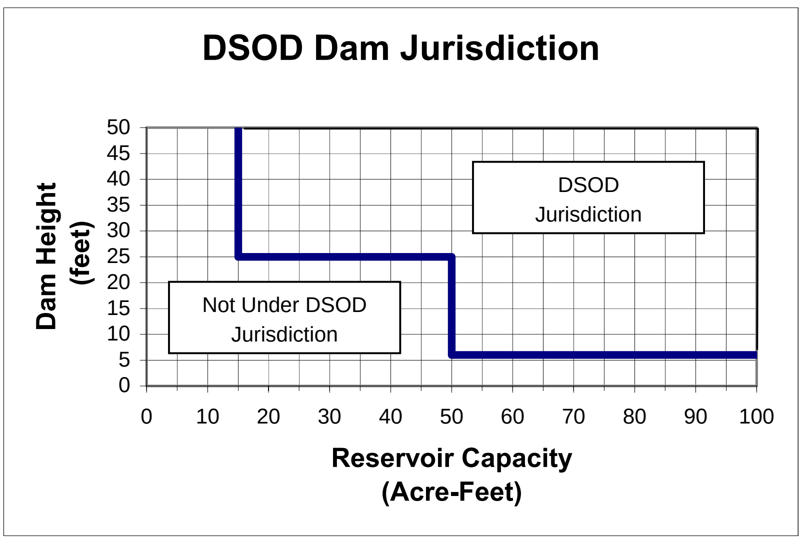

Figure 4.4.1
Dam Jurisdiction Chart

Spillway sizing requirements for dams and debris basins is available through the California Department of Water Resources, Division of Safety of Dams[4]. Figure 4.4.2 is a picture of Morris Dam, constructed in 1932, which falls under DSOD jurisdiction.

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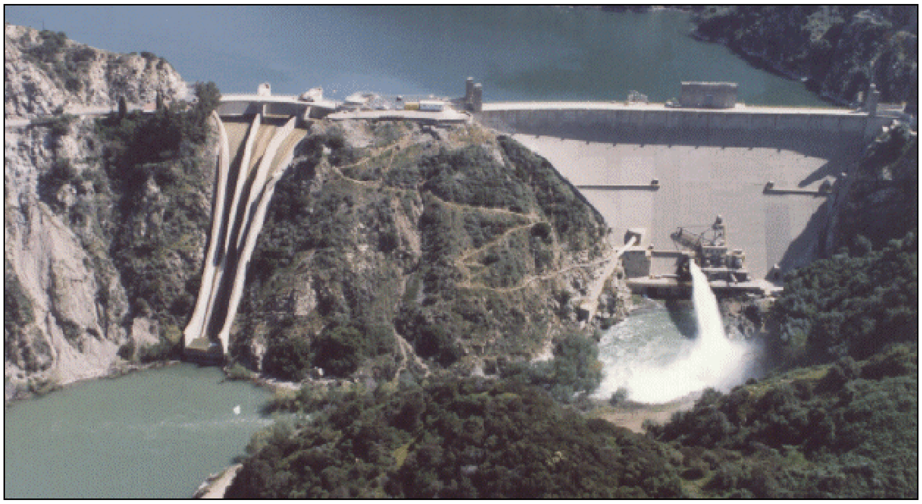

Figure 4.4.2
Morris Dam
1993

4.5 NATIONAL FLOOD INSURANCE PROGRAM

The National Flood Insurance Program (NFIP) set the 100-year flood as the standard for flood insurance protection. The 100-year flood relies on historic runoff records for definition. The standard makes no allowance for future urbanization or the possible inclusion of debris in the flow. In flood hazard areas, the federal standard requires the finished floor elevation of proposed dwellings to be at least 1 foot above the water surface elevation of the 100-year flood[5]. The Base Flood Elevation (BFE) refers to the water surface elevation of the 100-year flood on the pre-developed condition.

Public Works uses the Capital Flood peak flow rate for Los Angeles County floodway mapping standards. FEMA Flood Insurance Rate Maps (FIRM Maps) are available at: http://www.ladpw.org/apps/wmd/floodzone. More information about the NFIP level of protection requirements are available at the www.fema.gov/nfip/ website.

The floodway is determined using the 1-foot rise criterion. Some misinterpret this to mean that development in a floodway is permitted if it does not raise the BFE more than one foot. Floodplain management regulations dictate that any rise in the BFE, as a result of a floodway encroachment, is unacceptable without a Conditional Letter of Map Revision[6]. FEMA provides guidelines and standards for flood hazard mapping and requirements to meet the NFIP level of protection. More information on the FEMA requirements is found at http://www.fema.com/fhm/gs_main.shtm.

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4.6 COMPATIBILITY WITH EXISTING SYSTEMS

The level of protection standards may require modification if the receiving system has limited capacity at the proposed drain's outlet. If the receiving drain will be replaced or relieved in the future, size the proposed drain for the appropriate level of protection. The proposed drain capacity is restricted to match the capacity available in the downstream drain when no future relief is planned.

Solutions to the situations with restricted capacities require project specific decisions. The Design Division of Public Works should review the proposed drainage system and the outlet conditions to determine the compatible level of protection.

4.7 EXISTING LEVEL OF FLOOD PROTECTION

Sub-surface drainage often replaces surface drainage when land is developed. Replacing or modifying surface drainage systems requires maintaining or increasing the original level of flood protection. The total capacity, sub-surface and surface, must equal or exceed the original surface capacity. Adequate surface drainage capacity must be retained if the proposed sub-surface drain provides a lower level of protection than the original surface drainage system.

4.8 MULTIPLE LEVELS OF FLOOD PROTECTION

There are numerous instances where a drainage system must provide more than a single level of flood protection. Drainage systems must meet the criteria described in this chapter of the Hydrology Manual.

For example, there may be a natural canyon area tributary to a proposed drainage system that drains an urban area containing a sump. The proposed drainage system must convey the burned and bulked Capital Flood flow from the canyon area, protect the sump from a Capital Flood, and protect the developed area from the Urban Flood. Refer to Table 4.1.1 of the Sedimentation Manual to determine if a structure, such as a debris basin, is needed for the natural canyon. If a structure is needed, then only the burned flow is carried through the drainage system.

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Figure 4.8.1 is an example of a debris basin.

Figure 4.8.1
Sawpit Debris Basin
January 11, 2005
(Courtesy of Leopoldo A. Herrera)

1 Los Angeles County Highway Design Manual 5th edition. 2001.
2 US Army Corps of Engineers. Flood-Runoff Analysis (EM 1110-2-1417). page 13-7. Washington, D.C. 1994.
3 US Department of Commerce, National Oceanic and Atmospheric Administration, US Army Corps of Engineers. Hydrometeorological Report Number 59. Probable Maximum Precipitation for California. 1999.
4 Calzascia and Fitzpatric. Hydrologic Analysis Within California's Dam Safety Program. California Department of Water Resources, Division of Safety of Dams. http://wwwdsod.water.ca.gov/tech-ref/fitz-paper.pdf
5 National Flood Insurance Program Flood Insurance Manual. Federal Emergency Management Agency. October 2004.
6 Dyhouse, G., J. Hatchett, J. Benn. Floodplain Modeling Using HEC-RAS. Haestad Methods. Connecticut. 2003.

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CHAPTER

5

Rainfall and Design Storm Characteristics

The Department of Public Works' hydrologic method uses a design storm derived from historic rainfall data. Observed major extratropical storms in the Los Angeles region provided a pattern for the design storm. The storm does not represent an actual event but is an idealized series of precipitation data that fits a specific design objective. The design storm is a composite determined by analysis of regional rainfall patterns. Three components define the design storm: an Intensity-Duration-Frequency (IDF) equation, a temporal distribution, and a spatial rainfall distribution.

Public Works developed the rainfall distribution and design storms in 2002. A network of approximately 250 rain gages allowed an accurate definition of the spatial and temporal variability of rainfall over the county. The average historic record length for these gages is 75 years.

Data analysis provided the three components needed for the design storm. Analysis of rainfall data within the county provided the IDF equation, which is a relationship between rainfall intensity, duration, and frequency. Then a 24-hour temporal distribution was established using the IDF relationship. The 24-hour temporal distribution is represented by the unit hyetograph, which plots rainfall intensity versus time. Finally, a set of isohyets was established for the county. The isohyets represent rainfall depths for a specific duration and frequency and are applied to the unit hyetograph. The result is a hyetograph for a given location and recurrence interval, which is the design storm for a specific subarea.

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5.1 RAINFALL INTENSITY-DURATION-FREQUENCY

The fundamental unit of rainfall is depth. Rain gages directly measure depth. Measuring depth and time provides intensity. Intensity is the amount of rain that has fallen per unit of time. The average intensity is calculated by dividing a rainfall depth by the duration, the time over which the rainfall accumulated. The average intensity is:

Equation 5.1.1

$$\text{Intensity} = \frac{\text{Rain Depth}}{\text{Duration}}$$

The peak intensity produces the largest runoff rate. If rainfall were constant throughout a storm, any duration less than the storm duration would produce the same intensity. However, rainfall is rarely constant for the storm duration and intensity varies.

Table 5.1.1 shows the calculated intensity for various durations. Intensities are calculated using the rainfall depth and storm times in the first two rows. Each of the duration rows show intensities calculated based on different durations. For example, I_5 is the intensity calculated over a period of 5 minutes starting at t = 0 and ending at t = 5 minutes, or starting at t = 5 and ending at t = 10 minutes, etc. Bold text denotes the maximum intensity for each intensity duration. The table shows a decrease of maximum intensity as duration increases for a storm with non-uniform precipitation.

Table 5.1.1
Rainfall Intensity Calculations for Various Durations

	Storm Time (minutes)	0	5	10	15	20	25	30	35	40	45	50	55	60
	Cumulative Precipitation (in)	0	0.5	1.5	2.0	2.25	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Durations	I_5 (in/hr)	-	6.0	12.0	6.0	3.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	I_{10} (in/hr)	-	-	9.0	9.0	4.5	3.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0
	I_{30} (in/hr)	-	-	-	-	-	-	5.0	4.0	2.0	1.0	0.5	0.0	0.0
	I_{60} (in/hr)	-	-	-	-	-	-	-	-	-	-	-	-	2.5

Design decisions often require assigning a probability of occurrence to the rainfall event. Statistical analysis of rainfall intensity data yields a probability that such a rainfall will occur in a given year. The reciprocal of this probability is the frequency. The frequency represents the time between two occurrences of a specific rainfall event. The rainfall frequency is inversely proportional to the size of the event. Large rainfall events are much less common than small rainfall events.[1]

A study of rain gage data provided relationships between intensity, duration, and frequency within the County of Los Angeles. The study analyzed historic records for 107 rain gages and determined the maximum intensities for rainfall durations of 5, 10, 15, 30, 60, 120, 180, 240, 300, 720, and 1440 minutes. The analysis looked at the frequencies associated with the various intensities. Each intensity was assigned frequencies of 2-, 5-, 10-, 25-, 50-, 100-, and 500-years based on the Gumbel extreme value distribution of each gage.

The 1440 minute, or 24-hour duration, was a primary focus of this analysis. Sets of factors were developed to relate the rainfall depths of various frequencies to the 50-year rainfall frequency. Section 5.3 details the development of these factors.

The normalized intensity equation relates the intensity, duration, and frequency (IDF). The Hydrologic Method authorization memorandum outlines development of the equation.[2] Equation 5.1.2 provides the normalized IDF relationship:

$$\frac{I_t}{I_{1440}} = \left(\frac{1440}{t}\right)^{0.47}$$ **Equation 5.1.2**

Where: t = Duration in minutes

I_t = Rainfall intensity for the duration in in/hr

I_{1440} = 24-hour rainfall intensity in in/hr

$\frac{I_t}{I_{1440}}$ = Peak normalized intensity, dimensionless

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Equation 5.1.2 allows calculation of the peak-normalized intensity for durations from 5 to 1440 minutes. For durations less than 5 minutes, I_t / I_{1440} = 14.32. Figure 5.1.1 graphically presents the peak-normalized intensity for durations of 5 minutes to 30 minutes.

In addition to its role in defining the design storm, Equation 5.1.2 is used to calculate the peak intensity for time of concentration calculations described in Section 7.3. The equation calculates the intensity for any duration when the 24-hour rainfall intensity is known. Section 5.4 contains an example that illustrates the use of Equation 5.1.2 and Table 5.1.1 to determine the 25-year, 10-minute intensity from the 50-year, 24-hour rainfall isohyetal data.

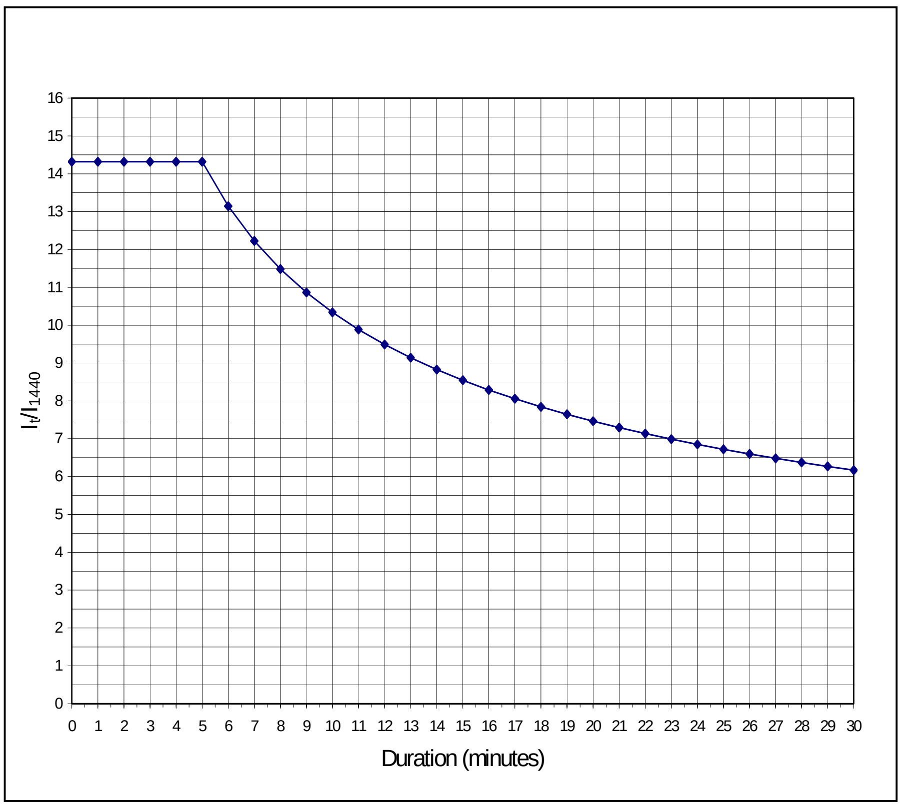

Figure 5.1.1
Normalized Intensity Curve

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5.2 UNIT HYETOGRAPH

The definition of a design storm requires a description of how rainfall occurs over time. Public Works' design storm uses a 24-hour cumulative unit hyetograph to describe the temporal distribution of precipitation. The unit hyetograph provides the temporal distribution of one inch of rainfall occurring over a 24-hour period. Figure 5.2.1 shows an example of a cumulative hyetograph and its accompanying incremental hyetograph.

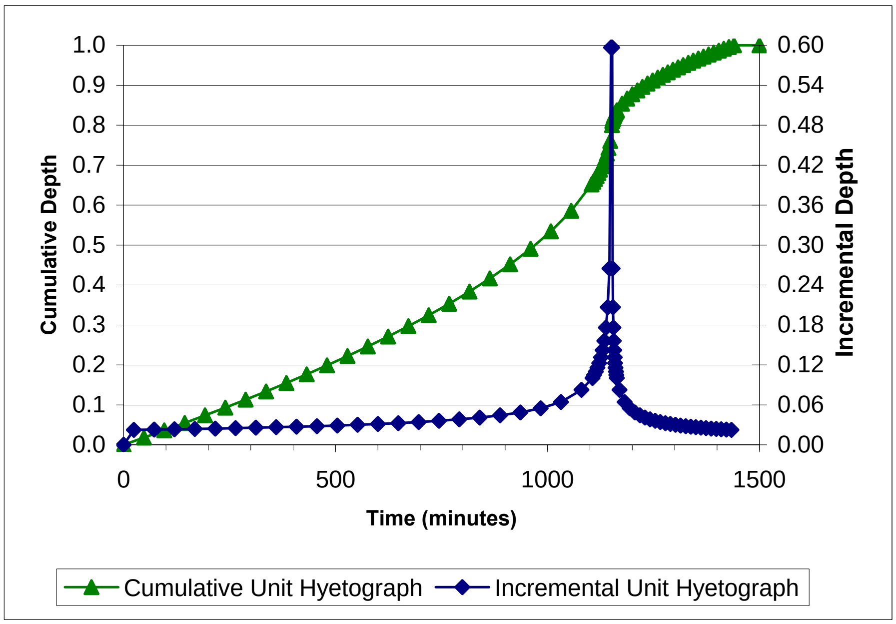

Figure 5.2.1
Relationship Between Cumulative and Incremental Unit Hyetographs

The unit hyetograph is scaled to match design rainfall depths. Design storm rainfall depths are determined from isohyets based on hydrologic design standards. Construction of the hyetograph used the normalized intensity equation solutions with an assumption about where the inflection point of the cumulative hyetograph occurs.

Development of the rainfall hyetograph used a modified alternating block method. See *Applied Hydrology* for a description and example of the alternating block method.[3] Modifications resulted from the use of the normalized intensity curve, instead of a traditional IDF curve, and the regionally specific location of the inflection point. This process produces an

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incremental unit rainfall distribution for a 24-hour period. The cumulative distribution is developed by summing the incremental distribution at each time step.

Developing the unit hyetograph using the IDF equation required an assumption about the timing of the most intense rainfall. The inflection point of the cumulative unit hyetograph represents the highest intensity. An analysis of the hourly distribution of large historical 24-hour events showed rainfall intensities increasing during the first 70 to 90 percent of the period and decreasing for the remaining time. Approximately 80 percent of the total 24-hour rainfall occurs within the same 70 to 90 percent of the period.

The unit hyetograph assumes the rainfall inflection point occurs when 80 percent of the 24-hour rainfall total has fallen and 80 percent of the 24-hour period has elapsed. Ratios of the depth at a given time relative to the total 24-hour depth were derived from the intensity equation. These ratios were then used to define the unit hyetograph curve. The depth ratios shown in Figure 5.2.1 were calculated at 5-minute time steps from 5 to 60 minutes and 60-minute time steps between 60 and 1440 minutes.

The rainfall depth ratios for each intensity were placed on either side of the inflection point. The alternating blocks were placed around the inflection point. However, instead of alternating the blocks on either side with decreasing intensity, the depth ratios for each time step were split with 20 percent of depth for each time step after the inflection point and 80 percent before the inflection point. The distribution of the time steps was similarly divided using 80 percent before the time of inflection and 20 percent after. Table 5.2.1 illustrates the first few intervals in this process:

Table 5.2.1
Rainfall Distribution Around Hyetograph Inflection Point

t	(D_t/D_{1440})	t*20%	$0.8+(D_t/D_{1440})*20\%$	t*80%	$0.8-(D_t/D_{1440})*80\%$
5	0.0497	1	0.8099	4	0.7602
10	0.0717	2	0.8143	8	0.7425
15	0.0890	3	0.8178	12	0.7287

With the inflection point at 80 percent of the time (1152 minutes) and 80 percent of the rainfall depth (0.8), the t = 5 time step contributes a point above the inflection point at 1153 minutes, 0.8099 and below the inflection

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point at 1148 minutes, 0.7602. Continuing this process provides the points that define the entire design unit hyetograph.

As described in Section 2.5.1, most major precipitation events in the county are the result of extratropical winter storms. Significant runoff tends to occur when these storms last several days and are comprised of several individual bands of intense precipitation. In the case of a multiple day storm, the most intense rainfall tends to occur on the last day. These observations form the basis for Public Works' 4-day design storm.

The unit hyetograph is multiplied by the 24-hour rainfall depth to produce a rainfall hyetograph for the fourth day. The first through third days have respectively 10, 40, and 35 percent of the fourth day's rainfall. Appendix A contains the unit hyetograph in tabular form. Multiplying the unit hyetograph by the depth for each day results in the daily hyetograph.

5.3 RAINFALL ISOHYETS

Historical data indicates that spatial distribution of precipitation across the county is not uniform during storm events. To account for this spatial variability of rainfall, Public Works developed rainfall isohyetal maps for the County of Los Angeles.

Isohyetal maps show the 24-hour rainfall depths expected for the 50-year storm frequency. The rainfall pattern depicted on these maps shows the influence of topography on rainfall.

The isohyetal maps incorporate information from Public Works' rain gages and the National Oceanic and Atmospheric Administration's (NOAA) gridded rainfall maps of the area. The process used NOAA's *Atlas 2,* 2-year, 24-hour isohyetal data to provide the spatial rainfall pattern. NOAA is a widely accepted source for meteorological data, and NOAA *Atlas 2* is a recognized standard for spatial rainfall distribution data.

Detailed rain gage analysis was performed to determine the various rainfall depth and frequency relationships. Table 5.3.1 summarizes the relationship between various frequencies as factors of the 50-year frequency depths. The factors are normalized to the 50-year event because this event is used for Capital Flood Hydrology.

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Frequency	Multiplication Factor
2-yr	0.387
5-yr	0.584
10-yr	0.714
25-yr	0.878
50-yr	1.000
100-yr	1.122
500-yr	1.402

Table 5.3.1
Rainfall Frequency Multiplication Factors

Appendix B contains isohyetal maps for the 50-year, 24-hour rainfall depth. The isohyetal contour lines are spaced at intervals of two-tenths of an inch. The spatial rainfall distributions for the county design storms were converted to grid data for use with Geographic Information System (GIS) compatible hydrologic models.

5.4 DESIGN STORM

The three components of the design storm include the IDF equation, the unit hyetograph curve, and the isohyets. These components are used to define the design storm for a particular location and frequency. As an example, consider the 25-year design storm for the Palmer Canyon watershed in Figure 5.4.1. Subarea 1A of this watershed, shown in Figure 5.4.2, will be used for the sample calculations.

1. Compute the area between successive isohyetal lines and multiply by the average of the isohyet values. Table 5.4.1 shows the areas between isohyets for Subarea 1A.

2. The sum of these precipitation-area values divided by the total subarea area provides the area weighted average rainfall depth. The average rainfall should be calculated to the nearest two-tenths of an inch. Table 5.4.1 contains the calculations for the isohyetal values in this subarea.

It may be noted that for small subareas, the isohyet nearest the centroid of the subarea usually equals the design depth. Selecting the isohyets nearest the subarea centroid is an acceptable method for determining the design rainfall for subareas of approximately 40 acres.

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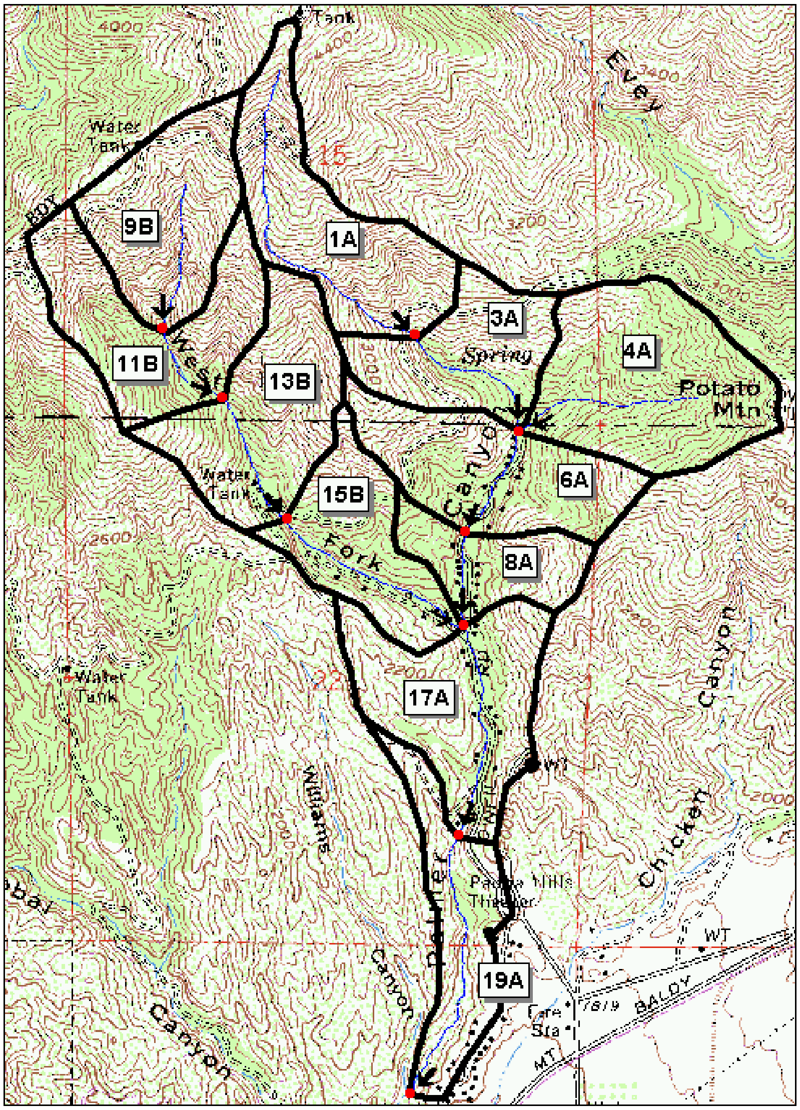

Figure 5.4.1
Palmer Canyon Watershed

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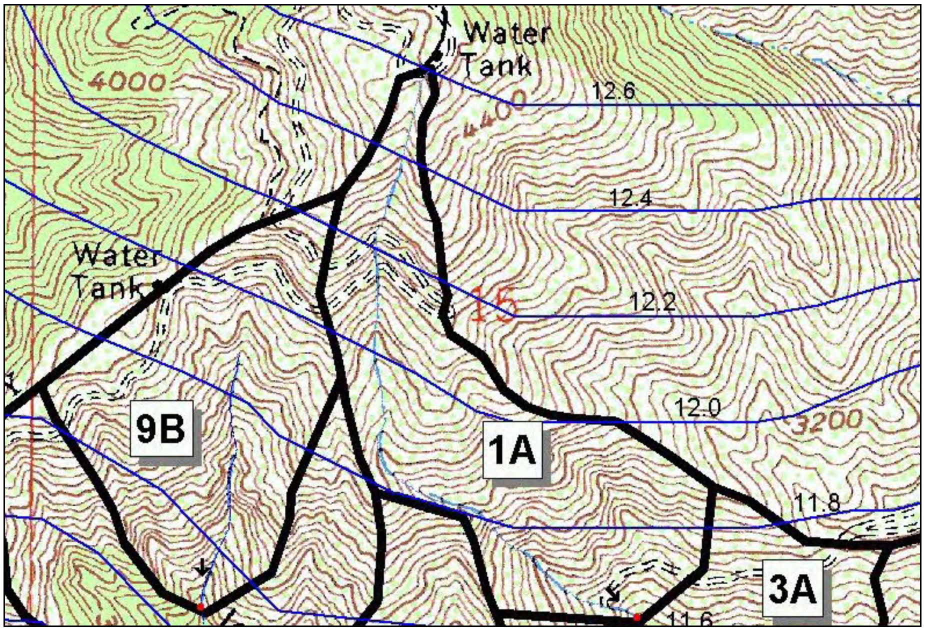

Figure 5.4.2
Subarea 1A with 50-Year, 24-Hour Rainfall Isohyets

Subarea 1A	Isohyet (in)	Area between Isohyets (acres)	Average Depth (in)	Precipitation * Area (in-acres)
	12.6			
	→	2.6 *	12.5 =	32.5
	12.4			
		6.9	12.3	84.9
	12.2			
		13.4	12.1	162.1
	12.0			
		29.7	11.9	353.4
	11.8			
		15.1	11.7	176.7
	11.6			
Total		67.7		809.6
809.6 in-acre / 67.7 acre = 11.96 in → 12.00 in				

Table 5.4.1
Subarea 1A Average Rainfall Depth Calculation

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Table 5.4.2 shows average rainfall values calculated for the other subareas using the method from steps 1 and 2.

Table 5.4.2
Subarea Average Rainfall Depths

Subarea	Isohyetal Depth (in)
3A	11.4
4A	11.2
6A	11.0
8A	10.8
9B	11.4
11B	11.2
13B	11.0
15B	10.8
17A	10.2
19A	9.4

3. Using the rainfall frequency factor, the 50-year, 24-hour depths are scaled to match the required 25-year, 24-hour depths. The 25-year, 24-hour factor from Table 5.3.1 is 0.878.

Table 5.4.3
Scaling Rainfall Depths

Subarea	50-year depth (in)	50-year to 25-year factor	25-year depth (in)
1A	12.0	* 0.878 =	10.5
3A	11.4	* 0.878 =	10.0
4A	11.2	* 0.878 =	9.8
6A	11.0	* 0.878 =	9.7
8A	10.8	* 0.878 =	9.5
9B	11.4	* 0.878 =	10.0
11B	11.2	* 0.878 =	9.8
13B	11.0	* 0.878 =	9.7
15B	10.8	* 0.878 =	9.5
17A	10.2	* 0.878 =	9.0

4. Next, apply this 25-year, 24-hour depth to the unit hyetograph to produce the design storm hyetograph for the subarea. Multiply each depth on the

unit hyetograph by the 25-year, 24-hour rainfall depth. This produces a cumulative hyetograph for the fourth day. Calculate hyetographs for the first three days by multiplying the unit hyetograph by 10, 40, and 35 percent of the fourth day's rainfall depth. Figure 5.4.3 shows Subarea 1A's temporal rainfall distribution for each day of the design storm.

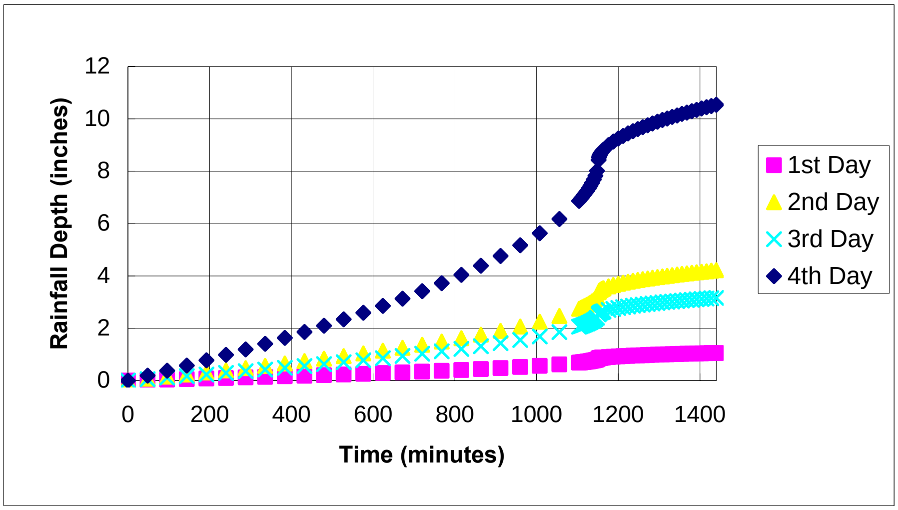

Figure 5.4.3
Hyetographs for Each Storm Day – Subarea 1A

Equation 5.1.2 determines the maximum intensity for the design storm assuming the time of concentration for Subarea 1A is 8 minutes.

$$\frac{I_t}{I_{1440}} = \left(\frac{1440}{t}\right)^{0.47}$$

(Equation 5.1.2)

Where:
- I_t = Rainfall intensity for the duration given in in/hr
- t = 8 minutes
- I_{1440} = 10.5 in / 24 hrs = 0.4375 in/hr

$$I_8 = \left(\frac{1440}{8\,\text{min}}\right)^{0.47} \times 0.4375 = 5.02 \ \text{in}/\text{hr}$$

The peak 8-minute intensity for the 25-year storm is 5.02 in/hr. If the time of concentration is 8 minutes, the peak flow will be Q = CIA, where I = 5.02 in/hr.

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5.5 PROBABLE MAXIMUM PRECIPITATION (PMP)

As noted in Section 4.5, many dam spillways that fall under the State of California jurisdiction must safely pass runoff from the Probable Maximum Precipitation (PMP). The National Weather Service developed PMP design storms for use in the United States.

There are two types of PMP storms: the 3-day general-storm and the 6-hour local-storm. Facilities requiring protection from the Probable Maximum Flood must follow the PMP procedures to develop design storms. The National Weather Service's Hydrometeorological Reports No. 58 and 59 detail procedures for developing the design storm.[4,5] These reports are available at http://www.nws.noaa.gov/oh/hdsc/On-line_reports

Figure 5.5.1
Appian Way in Long Beach
January 21, 1969

1 Applied Hydrology. Chow, Maidment, and Mays. page 466, McGraw-Hill, New York, 1988.
2 Memorandum from Reza Izadi to Brian T. Sasaki, Re: Los Angeles County Hydrologic Method dated March 4, 2002.
3 Applied Hydrology. Chow, Maidment, and Mays. page 466, McGraw-Hill, New York, 1988.
4 Hydrometeorological Report No. 58, Probable Maximum Precipitation for California Calculation Procedures, National Weather Service. October 1998.
5 Hydrometeorological Report No. 59, Probable Maximum Precipitation for California, National Weather Service. February 1999.

CHAPTER

6

Rainfall-Runoff Relationships

Only a portion of the rain that falls on a watershed appears as surface runoff in a stream. This section of the manual describes two methods for estimating the portion of rainfall that becomes runoff. This portion is called the rainfall excess or effective rainfall.

6.1 RAINFALL LOSSES AND RUNOFF PRODUCTION

Rainfall becomes runoff when all loss processes are satisfied. Runoff results from rainfall not lost to infiltration, interception, depression storage, and evaporation.

"Infiltration is the process of water penetrating the ground surface into the soil."[1] Interception loss occurs when water is retained on vegetation and other surfaces. Intercepted water may evaporate or infiltrate. Loss due to depression storage occurs when water accumulates in depressions of all sizes that are not connected to a flow path. Evapotranspiration, a dominant force in the hydrologic cycle, proceeds slowly during a storm.

Different methods have been developed to model rainfall losses. These include runoff coefficients, constant loss parameters, the Horton method, exponential loss calculations, and Green-Ampt losses. The Modified Rational Method uses runoff coefficients. The following sections discuss infiltration and loss methods used within the County of Los Angeles.

6.2 INFILTRATION

Infiltration losses have the greatest effect on surface runoff. The rate of infiltration is a function of the state of the soil and is highly heterogeneous over space and time. Hydraulic conductivity is a measure of the ease with which water can travel through the soil and is a measure of the infiltration

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rate when the soil is saturated. Similar soils generally have similar hydraulic conductivities. However, the infiltration rate is also affected by the degree of soil saturation. Dry soil allows more infiltration than wet soil. Factors such as ground cover or recent fires within the watershed affect the soil surface and infiltration rates.

Public Works' hydrologic standards assume that watersheds subject to design rainfall are at a field capacity soil moisture condition. This condition is also referred to as a saturated condition. At field capacity, the forces due to gravity and the surface tension on a drop of water in the soil column are in balance. At this point, no water is draining from the soil. Adding water to the soil forces downward movement and allows infiltration to begin.

6.3 MODIFIED RATIONAL LOSS CALCULATIONS

The modified rational method (MODRAT) uses a runoff coefficient that is a function of the rainfall intensity. The runoff coefficient reflects the fraction of rainfall that does not infiltrate and is based on the rainfall intensity for a given time period.

The Modified Rational Method uses the following equation at each time step:

$$Q = C*I*A$$ **Equation 6.3.1**

Where: Q = Volumetric flow rate in cfs
C = Runoff coefficient, dimensionless
I = Rainfall intensity at a given point in time in in/hr
A = Watershed area in acres

The following sections describe development of the unburned soil runoff coefficient, C_u, the developed soil runoff coefficient, C_D, and the burned soil runoff coefficient, C_{ba}. The appropriate coefficient represents runoff for different watershed conditions.

Undeveloped Runoff Coefficient (C_u)

MODRAT uses runoff coefficient curves to model the runoff response of the soil to changing intensity. The 179 undeveloped runoff coefficient curves, plotted in Appendix C, correspond to different soil types within the County of Los Angeles. Figure 6.3.1 shows the shape of a typical runoff coefficient curve.

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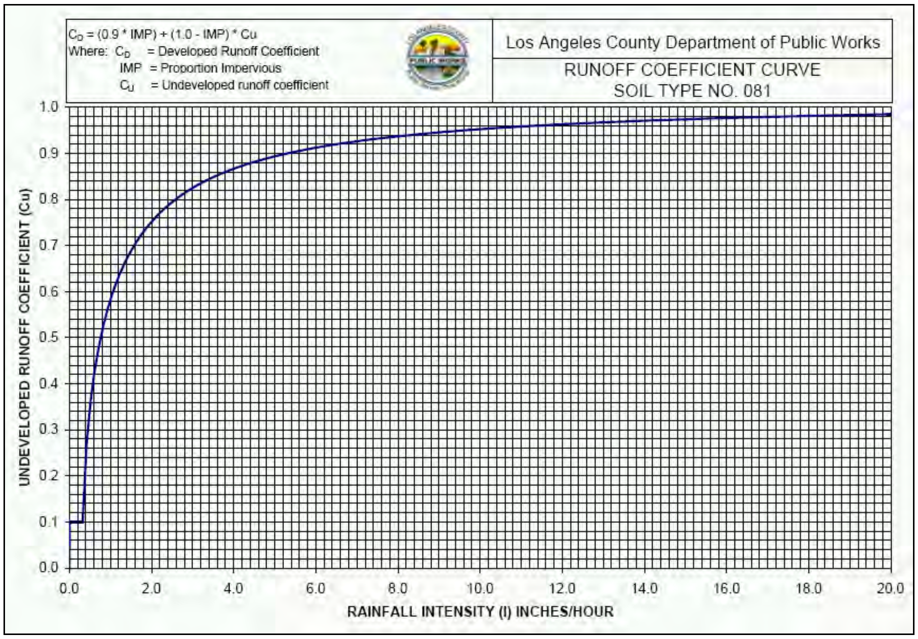

Figure 6.3.1
Runoff Coefficient Curve for Soil 081

Double ring infiltrometer tests provided data for the runoff coefficient curves. The infiltrometer tests used a department-designed, sprinkling–type infiltrometer. Before performing infiltrometer testing, the county was divided into regions of likely hydrologic homogeneity. Areas of homogenous runoff characteristics in the valley and desert areas were based on soil classifications published by the United States Department of Agriculture, Natural Resources Conservation Service. Criteria for homogeneity included topography, rock type, soil type, vegetative cover, and litter. Results from the infiltrometer tests within the homogenous areas determined the infiltration rate.

A series of runoff coefficient-intensity pairs compose each runoff coefficient curve. Each of the curves has a minimum coefficient (C_u) of 0.1 indicating that there is some runoff even at the smallest rainfall intensities. Appendix C contains the runoff coefficient curves for all the soils within the County of Los Angeles.

MODRAT requires assigning a single soil type for each subarea modeled. If a subarea contains more than one soil type, the predominant soil type in the subarea is used.

Developed Soil Runoff Coefficient Curves (C_D)

Each undeveloped runoff coefficient curve represents natural soil conditions. When precipitation occurs over a developed watershed, the rain falls on directly connected impervious areas and pervious areas. Runoff from pervious areas only occurs during heavy rainfall. Directly connected impervious area always produces direct runoff. As impervious area increases, the amount of direct runoff increases. The runoff coefficient curve must be modified to match the developed condition. Equation 6.3.2 accounts for the effects of development based on the undeveloped runoff coefficient and the amount of impervious area.

$$C_d = (0.9 * IMP) + (1 - IMP) * C_u$$

Equation 6.3.2

Where: C_d = Developed area runoff coefficient
IMP = Percent impervious
C_u = Undeveloped area runoff coefficient

The 0.9 in the equation represents the general assumption that no development is completely impervious. This assumption also accounts for initial abstraction losses in developed areas.

Imperviousness is assigned based on the land use types present in a subarea. Land use information requires existing and/or planned development patterns. If more than one type of development is present within a subarea, a composite impervious value must be determined using an area-weighted average. For example, consider a subarea with the characteristics in Table 6.3.1.

Table 6.3.1
Composite Impervious Values

	Percent Impervious	Area (acres)	Impervious*Area
	91%	20	1820
	42%	5	210
	21%	10	210
	1%	5	5
Total	-	40	2245

To determine the composite impervious value for this subarea, calculate the area weighted average of imperviousness. First, multiply each impervious

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value by the area it represents. Then sum these products and divide by the total area. The composite area weighted imperviousness for the example subarea is:

$$\text{Composite imperviousness} = {}^{2245}\!/_{40} = 56\%$$

The Southern California Association of Governments (SCAG) land use studies establish the land use patterns within the county. SCAG creates land use maps based on development type. Public Works assigns imperviousness values to each development type and then verifies these values using previous studies and aerial photos. The current land use map is based on SCAG data from 2000.

Representative proportion impervious values have been developed by measuring sample areas for each land use type. Appendix D has a table of these values. For undeveloped rural areas, 1% of the area is assumed impervious. Table 6.3.2 shows the standard range of percent impervious values for different development types.

Table 6.3.2
Standard Range of Percent Impervious

Type of Development	Percent Impervious
Single-Family	21% to 45%
Multi-Family	40% to 80%
Commercial	48% to 92%
Industrial	60% to 92%
Institutional	70% to 90%

Burned Soil Runoff Coefficient Curves (C_{ba})

Wildfires frequently burn undeveloped watersheds within the County of Los Angeles. Infiltrometer tests conducted in burned chaparral-covered mountain watersheds indicate that these watersheds suffer from a decreased infiltration rate after a fire. The decrease results from calcification caused by intense heat, plugging of the soil pores by ash or other fines, and other chemical reactions that produce a hydrophobic condition. A lack of surface cover also promotes the formation of a crust of fine soil due to the impact of raindrops. This crust further impedes infiltration.[2]

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Collection of field infiltrometer data in recently burned areas quantified the infiltration rate decrease for all soil types. Tests were done in burned and unburned portions of an area with previously homogenous infiltration.

Figure 6.3.2 is a picture of the 2002 Williams Fire in the San Gabriel Mountains viewed from Santa Fe Dam.

Figure 6.3.2
Williams Fire in the San Gabriel Mountains Viewed From Santa Fe Dam 2002

Burned area runoff calculations use a runoff coefficient curve adjusted for the burned watershed condition. For burned watersheds, the rational equation becomes $Q_{ba} = C_{ba}IA$, in which Q_{ba} and C_{ba} are respectively the peak runoff from a burned area and the statistically adjusted burned soil runoff coefficient. The burned runoff coefficient is adjusted using a fire factor. The fire factor is an index between the natural and completely burned watershed conditions, which ranges from 0 to 1 respectively. An analysis of historic fires in the major watersheds within the County of Los Angeles provided design fire factors for undeveloped watersheds.[3,4] Table 6.3.3 contains the design fire factors.

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Table 6.3.3
Design Fire Factors for Use with Burned Watershed Hydrology

Watershed	Fire Factor
Santa Clara River Watershed & Antelope Valley	0.34
Los Angeles River Watershed	0.71
San Gabriel River Watershed	0.71
Coastal Watershed	0.83

Only undeveloped subareas with 15% or less imperviousness require burn calculations. Equation 6.3.3 calculates the burned runoff coefficient.

$$C_{ba} = FF \times [(1 - K) \times (1 - C_u)] + C_u$$

Equation 6.3.3

Where:
- C_{ba} = Adjusted burned soil runoff coefficient, dimensionless
- FF = Fire Factor, the effectively burned percentage of watershed area, dimensionless
- K = Ratio of burned to unburned infiltration rates for I, $0.677 \times I^{-0.102}$, dimensionless
- I = Rainfall intensity in in/hr
- C_u = Undeveloped runoff coefficient, dimensionless

The K factor represents the ratio of burned to unburned infiltration rates. The ratio varies with the rainfall intensity. Equation 6.3.4 is useful for determining the burned peak flow when an unburned flow and intensity are known.

$$Q_{ba} = FF \times [(0.677 \times I^{-0.102} - 1) \times (Q_u - A \times I)] + Q_u$$

Equation 6.3.4

Where:
- Q_{ba} = Peak runoff from a burned area in cfs
- FF = Fire Factor, the effectively burned percentage of watershed area
- I = Rainfall intensity in in/hr
- A = Watershed area in acres
- Q_u = Peak runoff from an unburned area in cfs

Fires increase runoff and debris production. Higher runoff rates entrain more debris and burned watersheds have more debris available for entrainment. Debris production yields as much as 120,000 cubic yards/square mile of watershed for major storms. Boulders up to eight feet in diameter have been deposited in valley areas at considerable distances from their source. Debris quantities equal in volume to the storm runoff (100 percent bulking) have been recorded in major storms. The Flood Control District and the

RB-AR33584

Department of Public Works have built many debris control and storage structures in the foothills to minimize the chance of channels clogging with debris.

Peak flows from burned watersheds are “bulked” to account for volume changes caused by debris entrainment. Debris basins remove the sediment so that downstream flows are equal to flows from burned watershed. For more information on debris production, bulking flows, sediment transport, and design of debris retaining structures and basins, see the Department of Public Works Sedimentation Manual.

6.4 CONSTANT LOSS METHOD

The constant loss method is a frequently used and generally accepted rainfall loss method for flood hydrology. The constant loss method models infiltration by allowing all rainfall to infiltrate when the rainfall intensity is below a certain rate. All rainfall exceeding this infiltration rate will run off. Table 6.4.1 contains example calculations of direct runoff using the constant loss method. A constant loss rate of 0.1 in/hr is applied to an incremental rainfall series. Rainfall exceeding the loss rate becomes runoff.

Table 6.4.1
Application of Constant Loss Method

Time (hours)	Incremental Rainfall (in)	Loss (CL=0.10 in/hr)	Runoff (in)
1	0.00	0.00	0.00
2	0.05	0.05	0.00
3	0.08	0.08	0.00
4	0.10	0.10	0.00
5	0.20	0.10	0.10
6	0.12	0.10	0.02
7	0.05	0.05	0.00

Figure 6.4.1 illustrates the relationship between the constant loss rate and the total rainfall. In this example, a total of 0.60 inches of rain fell in 7 hours. Of this rain, a total of 0.48 inches was lost to infiltration while 0.12 inches became runoff. The runoff coefficient for this entire period is 0.2, representing that 20 percent of rainfall becomes runoff.

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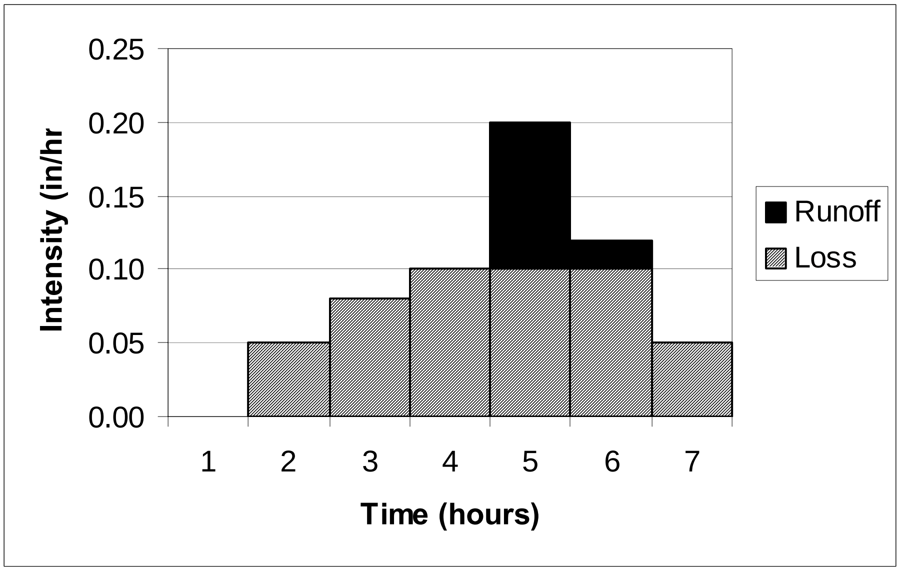

Figure 6.4.1
Rainfall Hyetograph and resulting Constant Loss Runoff

In general, application of a constant loss rate requires model calibration to estimate the loss rate parameters. Constant loss rates are highly variable and depend on the degree of saturation, soil type, storm duration, and rainfall intensity.

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1 *Applied Hydrology*. Chow, Ven Te; David R. Maidment; and Larry W. Mays. page 188. McGraw-Hill, Inc. New York, 1988.

2 *Handbook of Hydrology*. Ed. Maidment, David R. page 5.42. McGraw-Hill. New York, 1993.

3 "Development of Burn Policy Fire Factors." Los Angeles County Department of Public Works. August 5, 2004.

4 "Development of Burn Policy Methodology (Santa Clara River Pilot Project)." Los Angeles County Department of Public Works. June 2003.

CHAPTER

7

Runoff Calculation Methods

The design of drainage systems for stormwater conveyance within the County of Los Angeles requires converting rainfall into runoff volumes and flow rates. There are many methods available for converting the rainfall to runoff.

The Department of Public Works uses two basic methods for converting rainfall to runoff, depending on the conditions. The methods are facilitated by software for use on a personal computer. The sections in this chapter explain how to select the proper method for hydrologic studies and the theory and application of the two methods.

7.1 SELECTING THE PROPER METHOD

Table 7.1.1 provides a brief description of the uses and limitations of each method.

Table 7.1.1
County of Los Angeles Hydrologic Methods

Method	Use / Limitations	
Rational Method	Use:	For drainage areas 40 acres or less; finds the peak flow rate for any frequency design storm
	Limitations:	Does not create hydrographs or determine runoff volumes. Area limited to approximately 40 acres.
Modified Rational (MODRAT)	Use:	For any size watershed; for any combination of laterals; for any combination of developed and undeveloped drainage areas; to create hydrographs and runoff volumes at specified locations; to find peak subarea and mainline flow rates; recommended method for systems incorporating pumping or water impoundment.
	Limitations:	Underestimates volumes in rural areas when interflow and baseflow add to the runoff volume.

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7.2 RATIONAL METHOD

Mulvaney first outlined the rational method[1], which assumes that a steady, uniform rainfall rate will produce maximum runoff when all parts of the watershed are contributing to outflow[2]. This occurs when the storm event lasts longer than the time of concentration. The time of concentration is the time it takes for rain in the most hydrologically remote part of the watershed to reach the outlet. The method assumes that the runoff coefficient remains constant during a storm. The rational method formula is Q = CIA, previously mentioned in Chapter 6 as Equation 6.3.1. The direct runoff volume is calculated using the following equation:

$$V = C * \left(\frac{P}{12}\right) * A$$ **Equation 7.2.1**

Where: V = Volume in ac-ft
C = Runoff coefficient, proportion of rainfall that runs off the surface
P = Rainfall depth in inches
A = Drainage area in acres

Use of the rational method for drainage system design in small urban areas is appropriate. Use within the County of Los Angeles requires subarea division when[3]:

- Subareas are larger than approximately 40 acres
- There is more than one drainage channel
- Hydrologic properties are different within the area
- The time of concentration is greater than 30 minutes

The following are disadvantages of the classic rational method:

- Does not produce a hydrograph
- Runoff coefficient, C, is usually the same regardless of rainfall intensity
- Results are unreliable for areas greater than 200 acres[8]

The rational method applies to small watersheds where storage routing is not necessary. The method is useful for determining peak flows from small subdivisions and development projects or to determine flows to catch basins.

RB-AR33588

Section 7.5 describes catch basin hydrology in detail. Section 12.2 contains an example using the rational method to compute runoff.

7.3 MODIFIED RATIONAL METHOD

The modified rational method (MODRAT) uses a design storm and a time of concentration to calculate runoff at different times throughout the storm. Section 5.2 describes the temporal distribution of the design storm. Section 5.3 describes the spatial distribution of design storm rainfall within the County of Los Angeles.

Calculating flows based on the rainfall distribution results in a runoff hydrograph. The volume of runoff equals the area under the hydrograph curve. MODRAT allows users to route hydrographs generated in each subarea through conveyances and combine hydrographs based on time. MODRAT produces peak flows equal to or lower than flows calculated using the rational method. The reduction in peak results from attenuation, channel storage, and combining flows that peak at different times. Figure 7.3.1 shows an example of channel flow and storage.

Figure 7.3.1
Water storage occurring in Bradbury Channel May 28, 1981

RB-AR33589

Time of Concentration

The time of concentration (T_C) is the time it takes for rain in the most hydrologically remote part of the watershed to reach the outlet. Using a rainfall duration equal to the T_C ensures that the runoff from the entire subarea is contributing flow at the outlet. MODRAT requires a time of concentration in order to calculate intensities for use with the rational equation.

There are several methods for calculating the T_C. Simple relationships use the length of flow multiplied by an assumed flow velocity based on the type of conveyance (overland flow, sheet flow, pipe flow, etc.) Other methods include empirical equations derived through research and the use of the kinematic wave theory. The T_C calculation method for hydrology studies within the County of Los Angeles relies on a regression equation derived from hundreds of studies using the kinematic wave theory.

Time of Concentration - Kinematic Wave Theory[4]

The kinematic wave theory is a method accepted by Public Works, to calculate the time of concentration, T_C. Use of the kinematic wave theory to calculate the T_C requires separating the longest flow path into two parts: overland flow and conveyance flow. Equation 7.3.1 demonstrates this:

$$T_C = t_o + t_c$$

Equation 7.3.1

Where:
- T_C = Time of concentration in minutes
- t_o = Overland flow travel time in minutes
- t_c = Sum of all conveyance travel times in minutes

RB-AR33590

Conservation of mass and the momentum equation are used to determine the time associated with overland flow. Equations 7.3.2 and 7.3.3 are used to calculate overland flow time, t_o:

$$t_o = \frac{0.94 * L_o^{0.6} * n_o^{0.6}}{I_x^{0.4} * S_o^{0.3}}$$

Equation 7.3.2

$$I_x = C * I$$

Equation 7.3.3

Where:
- t_o = Overland flow travel time in minutes
- L_o = Overland flow length in feet
- n_o = Roughness for overland flow surface, dimensionless
- I_x = Rainfall excess in in/hr
- S_o = Slope of overland flow in ft/ft
- C = Runoff coefficient, ratio of runoff rate to rainfall intensity in in/in
- I = Rainfall intensity in in/hr

Values for the roughness coefficient of overland flow surfaces are found in Table 7.3.1.

Table 7.3.1
Roughness Coefficients for Overland Flow Computation

Surface Cover[5]	n_o
Smooth Asphalt	0.012
Concrete Paving	0.014
Packed Clay	0.030
Light Turf	0.250
Dense Turf	0.350
Industrial/Commercial	0.014
Residential	0.040
Rural	0.060

Table 7.3.2 shows standard values for different types of lots. The kinematic wave method requires evaluation of each subarea to determine the overland flow length and slope.

Table 7.3.2
Standard Values for Overland Flow Computation

Surface Cover[6]	Lot Length (ft)	Range of Lot Slope
Industrial/Commercial	200	0.005 - 0.020
Residential	100	0.010 - 0.050
Rural	200	0.050 - 1.000

Figure 7.3.2 illustrates the different types of lots where overland flow occurs.

INDUSTRIAL/ COMMERCIAL | **RESIDENTIAL** | **RURAL**

Figure 7.3.2
Different Types of Lots Where Overland Flow Occurs

The kinematic wave approach is applicable to channel flow as well as overland flow. The Manning equation is a form of kinematic wave theory for channels. The Manning equation is used to determine the average velocity in the channel. This velocity is used to determine travel times as shown in equation 7.3.4:

$$t_c = \left(\frac{1}{60}\right)\left(\frac{L_c}{V_{ave}}\right)$$

Equation 7.3.4

Where: t_c = Conveyance flow travel time in minutes
L_c = Conveyance flow length in feet
V_{ave} = Average conveyance velocity based on Manning equation in ft/sec

Comparison of results from Equation 7.3.1 with Izzard's overland flow experimental results and the results of Yu and McNown showed good correlation[6].

Use of the equations in this section requires an iterative approach since the rainfall excess and T_C are related to each other. An example problem illustrates application of the kinematic wave method for calculating T_C. Figure 7.3.3 shows the subarea that will be analyzed to determine the T_C using the kinematic wave method.

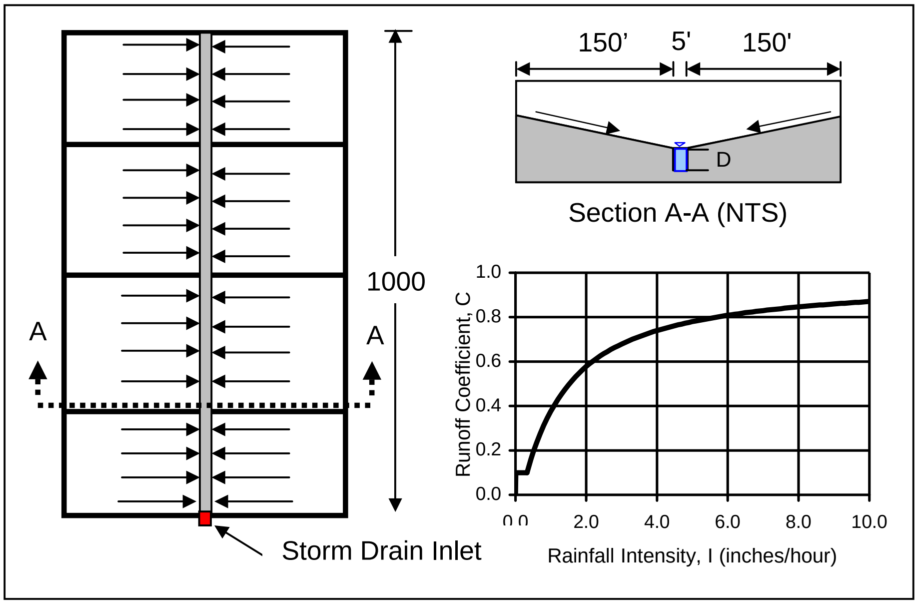

Figure 7.3.3
Example Subarea Demonstrating Kinematic Wave Method

This example shows eight residential lots that drain to a small grassy channel that eventually flows into a storm drain. Table 7.3.3 provides the lot and channel characteristics. The 50-year 24-hour rainfall for this area is 5 inches.

Table 7.3.3
Kinematic Wave Conveyance Data

Flow Path	Length (ft)	Slope (ft/ft)	Manning n	Width (ft)	Max. Depth (ft)
Overland Flow - Lot	150	0.020	0.040	-	-
Concrete Channel	1000	0.005	0.013	5	1

The steps involved in calculating a time of concentration using the kinematic wave method and example calculations are provided:

1. Assume an initial time of concentration

Assume a T_C of 12 minutes for the subarea in Figure 7.3.3

2. Calculate the intensity using Equation 5.1.2 and runoff coefficient using Equation 6.3.2 for overland flow using the time of concentration as the duration

$$I_t = I_{1440} * \left(\frac{1440}{t}\right)^{0.47} \Rightarrow I_{12} = \frac{5\text{ in}}{24\text{ hr}} * \left(\frac{1440}{12\text{ min}}\right)^{0.47} = 1.98 \text{ in/hr}$$

With the 2.0 in/hr intensity, the runoff coefficient is determined from the runoff coefficient curve in Figure 7.3.3. The undeveloped runoff coefficient is 0.58. Assuming a percent impervious of 0.42 for residential land use, the developed runoff coefficient is:

$$\begin{aligned} C_d &= (0.9 * IMP) + (1.0 - IMP) * C_u \\ &= (0.9 * 0.42) + (1.0 - 0.42) * 0.58 = 0.71 \end{aligned}$$

3. Calculate the time required for overland flow to reach the channel using Equation 7.3.2

$$t_o = \frac{0.94 * L_o^{0.6} n_o^{0.6}}{i_x^{0.4} S_o^{0.3}} = \frac{0.94 * (150)^{0.6} (0.040)^{0.6}}{(1.98 * 0.71)^{0.4} (0.020)^{0.3}} = 7.78 \text{ minutes}$$

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4. Calculate the average flow in the channel using the rational method

$$\frac{Q}{2} = \frac{C * I * A}{2} = \frac{0.71}{2} * 1.98\,\frac{in}{hr} * \left(\frac{1000\text{ ft} * 305\text{ ft}}{43560\text{ ft}^2/\text{ac}}\right) = 4.92\text{ cfs}$$

5. Determine the velocity for the average channel flow

Solving Manning's Equation for V = 3.39 ft/s

6. Calculate the conveyance flow travel time using Equation 7.3.4

$$t_c = \left(\frac{1}{60}\right)\left(\frac{L_c}{V_{ave}}\right) = \left(\frac{1}{60}\right)\left(\frac{1000}{3.39}\right) = 4.92\text{ minutes}$$

7. Add the overland flow time and the conveyance flow time to determine the time of concentration using Equation 7.3.1

$$T_C = t_o + t_c = 7.78 + 4.92 = 12.7\text{ minutes}$$

8. If the value is within 0.5 minutes of the original estimate, use the estimate. If the value is not within 0.5 minutes, round the value from step 7 to the nearest minute and use the value as the new estimate to start the calculations again.

Round the value to 13 minutes and start at step 2. The second iteration provided the values used to find the final T_C:

I = 1.90 in/hr
t_o = 7.94 minutes
Q_{ave} = 4.66 cfs
V_{ave} = 3.33 ft/s
t_c = 5.00 minutes
T_C = 7.94 + 5.00 = 12.94 minutes

Public Works developed a computer program to calculate T_C for hydrologic study subareas. Public Works used the computer program from 1986 until 2001.

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Time of Concentration - Regression Equation[7]

Determining the overland flow length and roughness was time consuming and determining the T_C for the conveyance often required solving the Manning equation many times. A 1999 study resulted in the creation of a regression equation for T_C calculations. The regression equation relied on T_C computations from a large number of subareas. The subareas were taken from diverse hydrology studies that used the kinematic wave theory equations to calculate T_C. This representative sample of subarea T_C's came from hydrologic studies performed between 1986 and 1999.

Equation 7.3.5 correlates the T_C to independent hydrologic parameters: flow path length and slope, land use, rainfall intensity, and the soil runoff coefficient. Equation 5.1.2 from Chapter 5 provides the relationship between the 24-hour intensity and the intensity related to the T_C. Equation 6.3.2 from Chapter 6 provides a relationship between the developed and undeveloped soil runoff coefficients.

$$T_C = \frac{0.31 * L^{0.483}}{(C_d * I_t)^{0.519} * S^{0.135}}$$

Equation 7.3.5

$$I_t = I_{1440} * \left(\frac{1440}{t}\right)^{0.47}$$

(Equation 5.1.2)

$$C_d = (0.9 * IMP) + (1.0 - IMP) * C_u$$

(Equation 6.3.2)

Where:

	T_C	= Time of concentration in minutes
	L	= Longest flow path length from watershed boundary to outlet in feet
	C_d	= Developed runoff coefficient, ratio of runoff rate to rainfall intensity in in/in
	I_t	= Intensity at time t in in/hr
	S	= Slope of longest flow path in ft/ft
	IMP	= Percent Impervious, percent expressed as 0.0 to 1.0
	C_u	= Undeveloped runoff coefficient, ratio of runoff rate to rainfall intensity in in/in

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The regression method still uses an iterative process to calculate the time of concentration. See Section 11.1 for sample time of concentration calculations using the regression equation.

Reviewing the example in Section 11.1 shows that the regression equation calculation is approximately one minute longer than the kinematic wave method calculation for the same example. This difference is explained by the fact that many studies and calculations were used to create the regression equation. The regression equation provides the best fit for all of the studies, but may not match kinematic wave calculations exactly.

Chapter 10 describes the data necessary for watershed modeling and calculation of the time of concentration. Spreadsheet applications and computer programs listed in Chapter 11 automate the iterative process.

Hydrograph Generation

MODRAT relies on the dimensionless temporal rainfall distribution, an isohyetal depth, and the T_C to generate hydrographs. The steps for calculating the runoff are:

1. Determine the rainfall intensity for a time period equal to the T_C
2. Determine the undeveloped soil runoff coefficient for the time period using the intensity
3. Adjust the soil runoff coefficient using Equation 6.3.2 or 6.3.3 to determine C_d or C_{ba}, depending on the subarea conditions
4. Use the rational equation, Equation 7.2.1, to determine the runoff for the time period
5. Repeat steps 1 through 4 for each time period

Figures 7.3.4, 7.3.5, and Table 7.3.4 illustrate how to determine three flow rates based on the design storm for a specific subarea. The following subarea information is needed:

Area:	40 acres
T_C:	30 minutes
Soil:	068
IMP:	20%
Rain:	10 inches

Figure 7.3.4 shows the steepest portion of the rainfall mass curve related to the 50-year 24-hour rainfall depth of 10 inches. The three time segments

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represent the intensity at the end of each time period. Figure 7.3.5 shows the soil runoff coefficients for soil 068. Table 7.3.4 shows the intensity, undeveloped runoff coefficient, developed runoff coefficient, the area, and the runoff for each time period. Three time periods are shown to demonstrate the changes in intensity that occur around the inflection point on the mass curve.

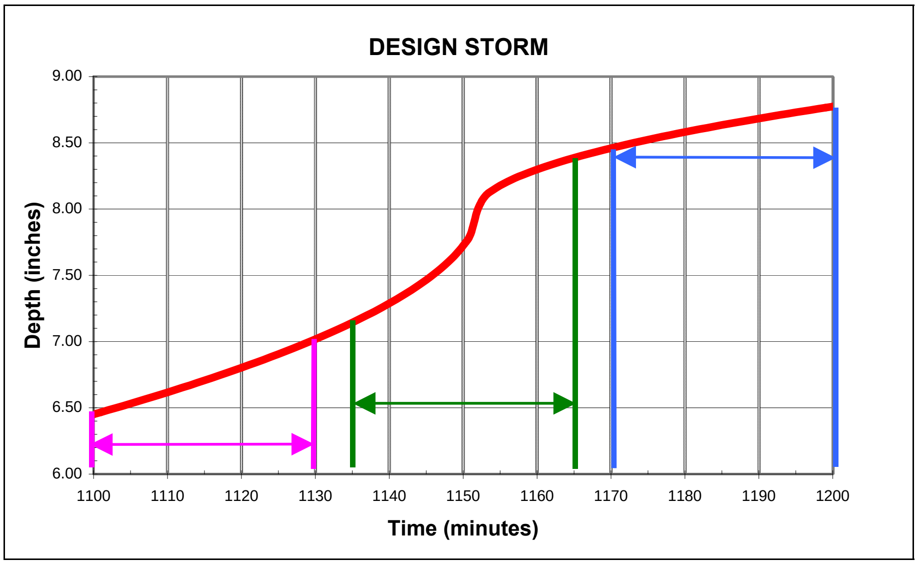

Figure 7.3.4
Three Time Steps for Modified Rational Runoff Calculations

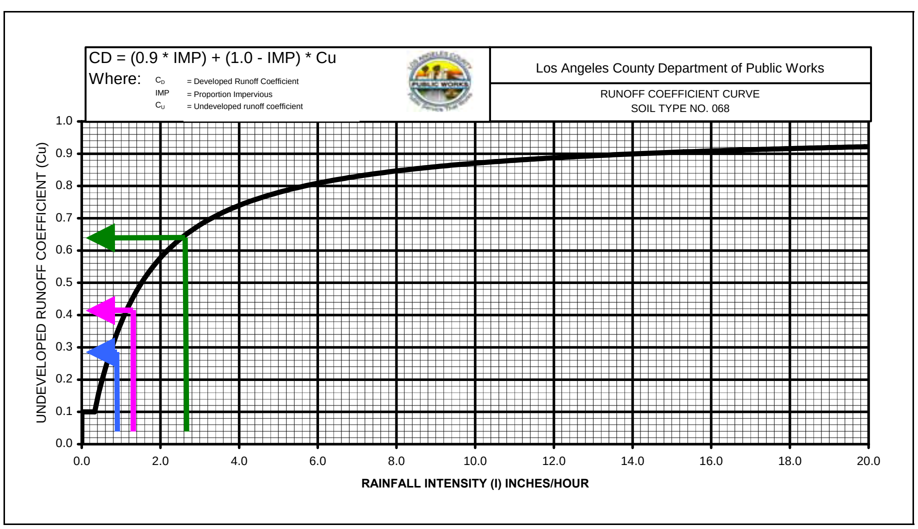

Figure 7.3.5
Undeveloped Runoff Coefficients for 3 Time Steps

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Using Figures 7.3.4, 7.3.5 and Equation 6.3.2, Table 7.3.4 shows the runoff calculations for three time steps.

Time (minutes) To	Time (minutes) From	Rainfall (in)	Intensity, I (in/hr)	Undeveloped Runoff Coefficient, C_u Fig. 7.3.3	Developed Runoff Coefficient, C_d Eq. 6.3.2	Area (acres)	Q = C_d*I*A (cfs)
1100	1130	0.567	1.134	0.39	0.492	40	22.3
1135	1165	1.243	2.487	0.62	0.676	40	69.6
1170	1200	0.314	0.627	0.26	0.388	40	9.7

Table 7.3.4
Table of Runoff Calculations

Using the rainfall mass curve, the rainfall depth, and the time of concentration, the runoff value can be calculated for each one-minute increment. This is done by moving the time window forward one step and completing the process shown above. Computer programs or spreadsheets automate this time consuming process. Calculating the runoff at different time increments allows the user to create a hydrograph. Figure 7.3.6 shows the hydrograph for the three points calculated in Table 7.3.4. The figure assumes that at t = 0 and t = 1440 minutes, the flow rate is zero.

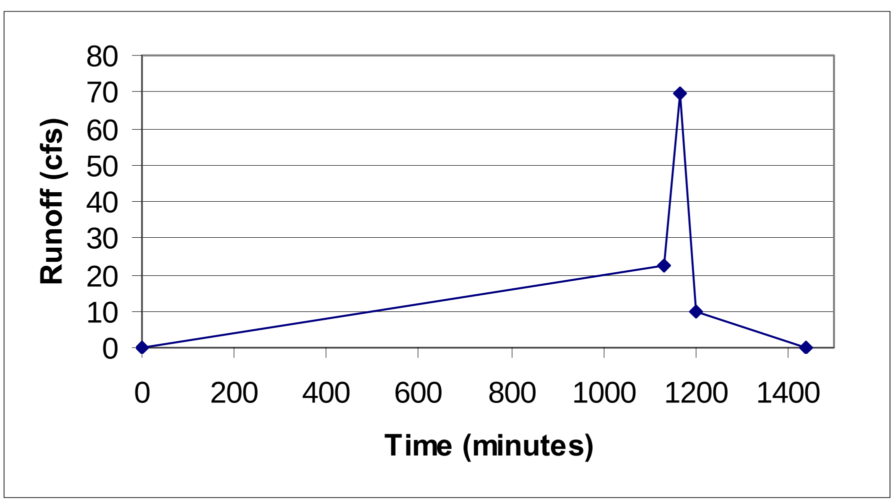

Figure 7.3.6
Hydrograph Generate Using MODRAT Method

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The volume of runoff is calculated by summing up the area under the curve. For example, the volume for the first 1130 minutes is equal to the area under the curve. Finding the area of this triangle:

$$\text{Vol} = \frac{1}{2} * b * h = \frac{1}{2} * 1130\,\text{minutes} * 22.3\frac{\text{ft}^3}{\text{sec}} * 60\frac{\text{sec}}{\text{min}} = 755{,}970\,\text{ft}^3 = 17.35\,\text{ac - ft}$$

Defining the hydrograph with smaller time steps increases the accuracy of the flow rate and volume calculations. Hydrograph routing shows the affects of attenuation and allows superposition of hydrographs. This provides a more realistic evaluation of runoff than adding the peak flow rates calculated using the rational equation.

Channel Routing of Flows

Two types of channel routing exist: hydrologic and hydraulic. Hydrology studies within the County of Los Angeles use hydrologic routing to approximate unsteady flow through channels. Hydrologic routing balances inflow, outflow, and storage volume using the continuity equation. Routing the hydrographs results in outflow hydrographs that are smaller due to peak attenuation and occur later than the inflow due to flood wave translation.

Peak flow attenuation occurs when flows are stored in a channel reach. Figure 7.3.7 shows a graphical representation of peak attenuation. The volume of water stored increases as water fills the channel. Storage continues until the channel depth reaches the maximum water surface elevation. Storage then decreases as the peak flow passes and the water stored in the channel drains.

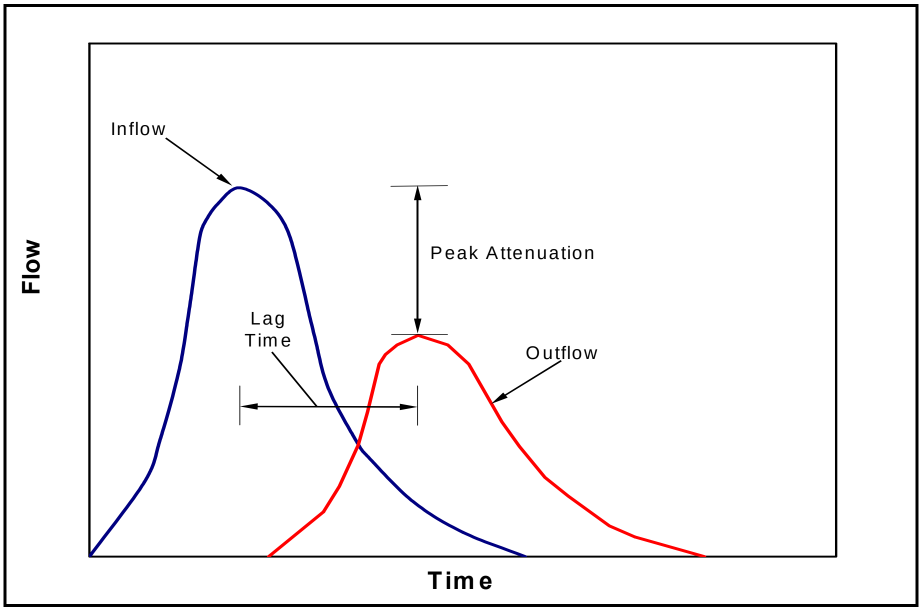

Figure 7.3.7
Peak Attenuation Related to Channel Storage

The water entering the channel must also travel from the upstream end of the section to the downstream end. Hydrologic routing considers this process by shifting the hydrograph in time. The shifting is related to the wave velocity for the specific channel.

There are many methods available for hydrologic routing[8]. The MODRAT method uses the Modified Puls, or level pool, routing method to determine channel storage effects. The method relies on a finite difference approximation of the continuity equation and an empirical representation of the momentum equation. Equation 7.3.8 is the basic equation for the Modified Puls method. The equation allows calculation of the outflow for each time step except the first. Chapter 8 shows another way to write the equation for the Modified Puls method that removes the need to calculate the storage for each time step.

$$\frac{1}{2}\left(I_i + I_{i-1}\right) - \frac{\left(S_i - S_{i-1}\right)}{t_i - t_{i-1}} = \frac{1}{2}\left(O_{i-1} + O_i\right)$$

Equation 7.3.8

Where:

Where:	I_{i-1}	= Inflow at t_{i-1}
	I_i	= Inflow at t_i
	t_i	= Time at step i
	t_{i-1}	= Time at step i-1
	S_{i-1}	= Storage at t_{i-1}
	S_i	= Storage at t_i
	O_{i-1}	= Outflow at t_{i-1}
	O_i	= Outflow at t_i

The method ignores wedge storage within the channel reach and assumes that lateral inflow effects are insignificant. A storage-discharge relationship is also required between the inflow rate and storage in the system[9]. The method requires a defined channel storage versus inflow relationship. The relationship is established using the Manning equation to determine depth of flow. Multiplying channel length, water depth, and cross sectional area provides the channel storage for a specific flow value. Using different flow values produces a storage curve. Figure 7.3.8 presents the channel storage relationship for a triangular channel with the following characteristics: slope = 0.001 ft/ft, length = 1000 ft, Manning n = 0.03, side slope = 1:1 ft:ft, and max depth = 6.8 ft.

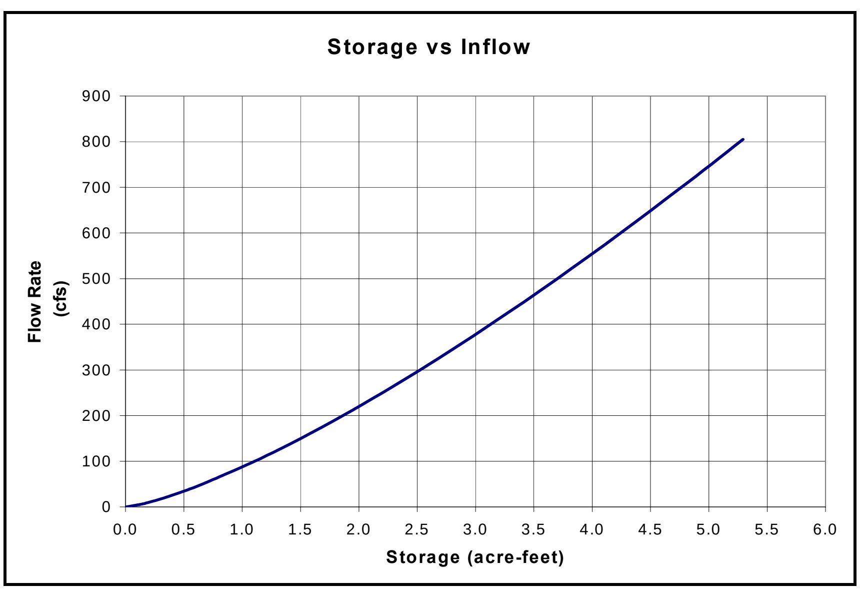

Figure 7.3.8
Storage-Inflow Relationship for a Triangular Channel

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Calculation of translation time, the time it takes for the flood wave to travel from one end of the reach to another, requires using wave velocities. Table 7.3.5, Figure 7.3.9, and Figure 7.3.10 located at the end of the section provide more detail on velocity equations used for translation. Table 7.3.5 contains the equations used for translation time calculations. Figure 7.3.9 shows a typical street cross section. Figure 7.3.10 contains information for determining effective slopes of mountain and valley channels. The figure relates map slopes to slopes that match measured flow rates more accurately. The end of the section also contains a list of variables for the equations.

Correct hydrologic routing allows superposition of hydrographs at different locations within the study area. MODRAT starts at the upstream end of the watershed and calculates a runoff hydrograph. The hydrograph is then translated through the downstream channel. The Modified Puls routing then occurs to determine the effects of channel storage and the modified outflow hydrograph is computed. This hydrograph is then combined with the hydrographs from other subareas or is routed through another channel reach.

Computer programs implement this approach to reduce the amount of work required to define these relationships and route flows through the channels. Chapter 8 contains a detailed example of the Modified Puls routing method.

Table 7.3.5
Hydrograph Translation Equations

$T = \frac{L}{60 * V_W}$	Travel Time (minutes)
$V = \frac{Q}{A}$	Average Channel Velocity (ft/s)
$V = 5.6 * Q^{0.333} S_{eff}^{0.500}$	Velocity for Natural Mountain Channels (ft/s)
$V = (7.0 + 8.0 * Q^{0.352}) S_{eff}^{0.500}$	Velocity for Natural Valley Channels (ft/s)
$V_W = 1.5 * V$	Wave Velocity for Natural Mountain and Valley Channels (ft/s)
$D = \frac{B}{2 * \left(\left(Z^2 + 1 \right)^{0.500} - Z \right)}$	Most Efficient Rectangular or Trapezoidal Open Channel Section
$V = \frac{1.486}{n} * R^{0.667} S^{0.500}$	Pipe, Streets, Rectangular, or Trapezoidal Channels (ft/s)
$V_W = V * \left[\frac{\theta * (3 - 5\cos\theta) + \sin\theta}{3 * \theta(1 - \cos\theta)} \right]$	Wave Velocity for Partially Full Pipes (ft/s)
$V_W = V * \left[\frac{5}{3} - \frac{4 * (B + ZD)}{3 * (2 + B) * (B + 2ZD)} \right]$	Wave Velocity for Rectangular and Trapezoidal Channels (ft/s)
$\theta = 4 * \sin^{-1} \left(\frac{D}{d} \right)^{0.500}$	Angle Measurement to Determine Flow Depths in Pipes
$R = \frac{A}{P}$	Hydraulic Radius (ft)
$n = \frac{n_1 B + 2 * n_2 L_w}{B + 2 * L_w}$	Composite Manning's n for Trapezoidal Channels

Variables:

Variables:	A	= Cross Sectional Area in ft^2
	B	= Channel Bottom Width in feet
	C	= Curb Height in feet
	D	= Flow Depth in feet
	d	= Pipe Diameter in feet
	L	= Length of Channel Reach in feet
	L_w	= Length of Wetted Channel Wall in feet
	n	= Channel Roughness Coefficient
	n_1	= Length of Wetted Channel Wall in feet
	n_2	= Length of Wetted Channel Wall in feet
	P	= Wetted Perimeter in feet
	Q	= Flow Rate in cfs
	R	= Hydraulic Radius in feet
	S	= Slope of channel reach (ft/ft)
	S_{eff}	= Effective channel slope, natural valley and mountain conveyances
	T	= Travel Time in minutes
	V	= Mean Velocity in ft/sec
	V_w	= Wave Velocity in ft/sec
	W_R	= Road Width From Curb to Curb in feet
	Z	= Channel Side Slope Computed as Horizontal Projection of Wall Divided by Depth in ft/ft

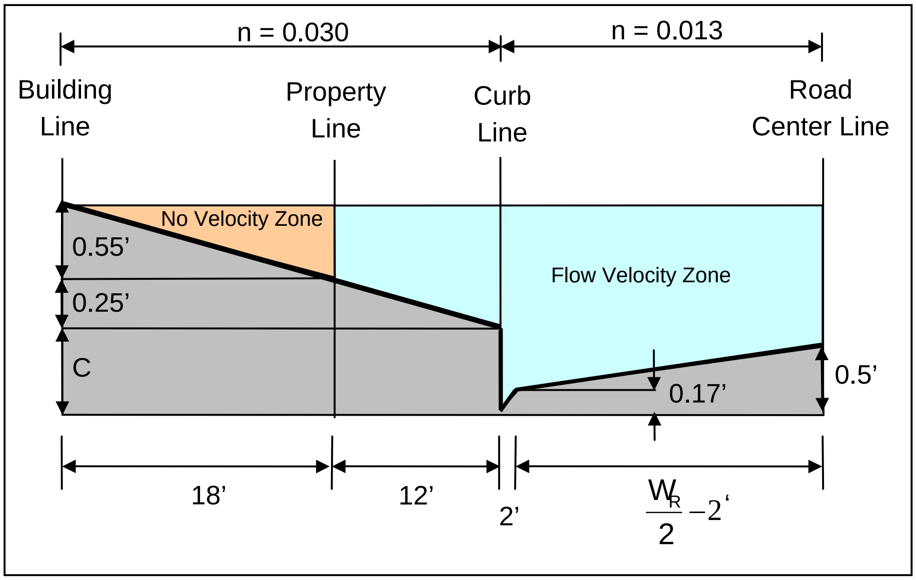

Figure 7.3.9
Typical Street Cross Section

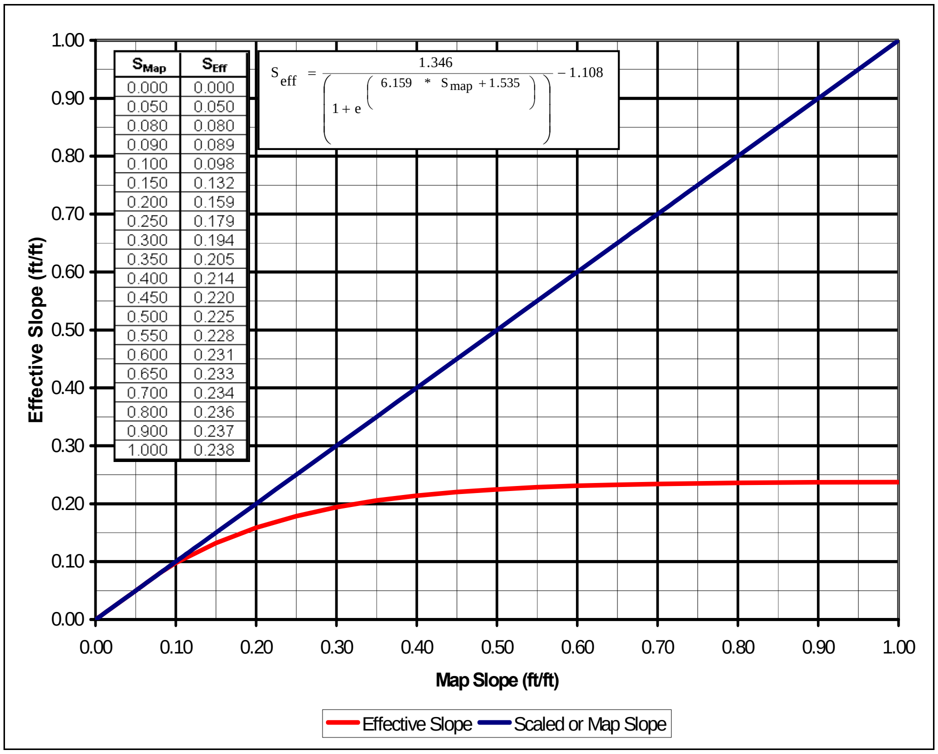

Figure 7.3.10
Effective Slope to Map Slope Relationship

7.4 CATCH BASIN FLOW CALCULATIONS

Flows that drain to catch basins usually come from areas smaller than the 40-acre subareas recommended in the hydrology manual. Determining flow to the catch basins is done by apportioning flow rates from the subarea based on the area draining to individual catch basins. Figure 7.4.1 shows a residential subarea of 35.5 acres that contains nine catch basins.

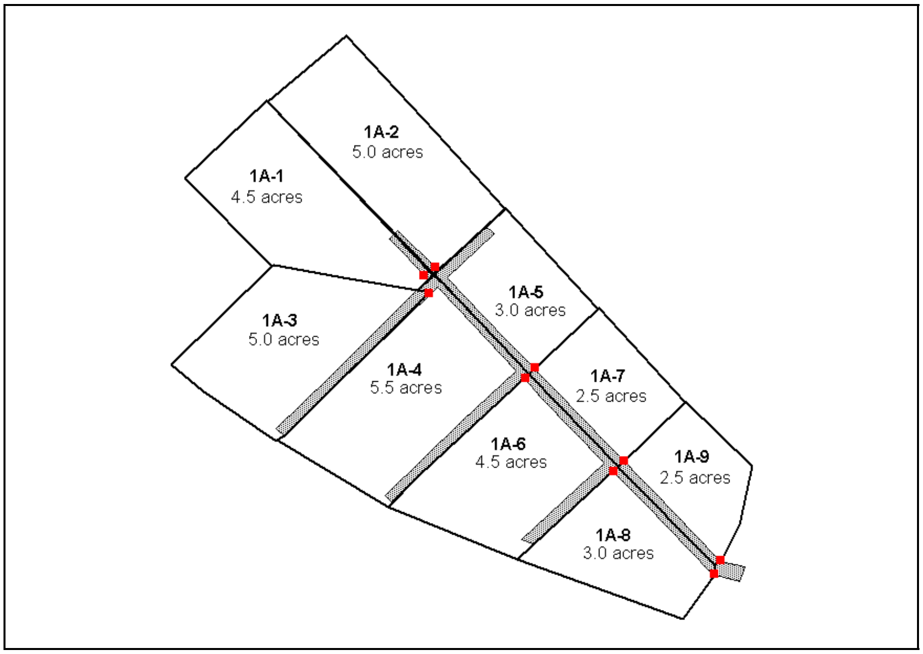

Figure 7.4.1
Catch Basin Flow Allotment

Catch basin allotment relates the peak subarea flow calculated using the MODRAT method to the subareas contributing flow. The steps for determining catch basin flow rates are:

1. Determine the area contributing flow to each proposed catch basin
2. Sum up the subarea areas to determine the total area
3. Divide each catch basin drainage area by the total area to get a weighting factor
4. Multiply the weighting factor by the MODRAT subarea watershed peak flow to get the catch basin peak flow rate for each basin

Table 7.4.1 contains the peak flow calculation for each catch basin in Figure 7.4.1. The total area for the MODRAT subarea 1A is 35.5 acres with a peak flow of 100 cfs.

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Catch Basin Drainage Name	Area (A_i) (acres)	Weighting Factor (A_i/A_T)	Subarea Peak Flow (cfs)	Catch Basin Flows (cfs)
1A-1	4.5	0.13	100	13
1A-2	5.0	0.14	100	14
1A-3	5.0	0.14	100	14
1A-4	5.5	0.15	100	15
1A-5	3.0	0.08	100	8
1A-6	4.5	0.13	100	13
1A-7	2.5	0.07	100	7
1A-8	3.0	0.08	100	8
1A-9	2.5	0.07	100	7
Total Area (A_T)	35.5			

Table 7.4.1
Peak Flow Allotment for Catch Basins within Subarea 1A

7.5 REPORTING RUNOFF VALUES

Reporting official peak flow rates on maps and data sheets requires a standard method. This section describes two methods for flow reporting. The first method is used when reporting flow rates from each subarea and is consistent with the United States Geologic Survey (USGS) flow reporting procedures. The second method is for reporting burned and bulked flow rates using the reach grouping method.

Peak Flow Reporting - USGS Method

The USGS is recognized for expertise in flow measurement and reporting. Flow rates reported for subareas and reaches within The County of Los Angeles must use the USGS rounding rules. Table 7.5.1 shows the rules for reporting flow rates using the USGS standard.

Flow Rate (cfs)	Round Flow To Nearest
$0 \leq Q < 1$	0.01 cfs
$1 \leq Q < 10$	0.1 cfs
$10 \leq Q < 100$	1 cfs
$100 \leq Q < 10,000$	10 cfs
$10,000 \leq Q < 100,000$	100 cfs
$Q \geq 100,000$	1,000 cfs

Table 7.5.1
USGS Flow Reporting Rounding Rules

Peak Flow Reporting - Reach Grouping

Reporting flow rates for burned and bulked runoff requires grouping flow rates by reach. A reach is a segment of a watercourse between specified collection points. A grouped reach is a collection of reaches grouped together based on rounding rules listed below. Reach grouping reduces the number of calculations required when bulking flow rates.

Reach grouping involves dividing a watercourse into grouped reaches and then bulking each grouped reach individually. This eliminates the need to bulk flow rates at every collection point along a watercourse. Reach grouping must be used to report burned and bulked flow rates for debris-producing watersheds. The following is the procedure for determining grouped reaches used for bulking.

1. List the burned flow rates (Q_{burn}) for all collection points along the desired watercourse
2. Round the burned flow rates according to the rules in Table 7.5.2
3. Group reaches based on rounded burned flow rates of the same value
4. Determine the Debris Production Area (DPA) zone breakup using the most downstream collection point of the grouped reach to account for all DPA zone areas
5. Bulk the largest non-rounded burned flow rate value from the grouped reach
6. When reporting clear flow rates for the grouped reach, use the largest rounded clear flow rate value from the reaches within the grouped reach

When reporting final grouped reach flow rates, if the flow rate decreases downstream along a watercourse, use the flow rate from the immediate upstream grouped reach.

Table 7.5.2
Rounding Rules for Reach Grouping

Flow Rate (cfs)	Round Flow To Nearest
$0 \leq Q_{burn} < 20$	0.1 cfs
$20 \leq Q_{burn} < 100$	5 cfs
$100 \leq Q_{burn} < 1{,}000$	10 cfs
$1{,}000 \leq Q_{burn} < 100{,}000$	100 cfs
$Q_{burn} \geq 100{,}000$	1,000 cfs

EXAMPLE – Reach Grouping for Reporting Bulked Flow Rates

Figure 7.5.1 shows a portion of a watercourse that contains three reaches. Table 7.5.3 shows the burned flow rates for these reaches. Each of the burned flow rates is rounded using the rules in Table 7.5.2. Following the reach grouping steps, the burned flow rates for each collection point are listed and rounded. The flow rate at 6A is the largest unrounded burned flow rate and is used in the bulk flow calculations. The DPA zones are calculated from collection point 8A upstream to include the area tributary to the entire grouped reach and the bulked flow is calculated. The burned and bulked flow is then rounded for reporting based on Table 7.5.2. Chapter 3 of the Sedimentation Manual contains more information on bulking flows.

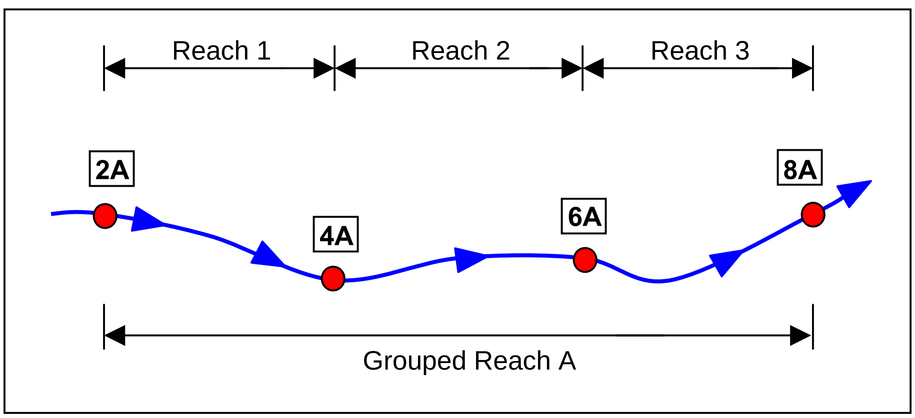

Figure 7.5.1
Grouped Channel Reach Based on Reach Flows

Table 7.5.3
Grouped Reach Flow Rates

Reach	Grouped Reach	Collection Point	50-Year Q_{burn} (cfs)	50-Year Q_{burn} *Rounded* (cfs)	50-Year $Q_{burn\ \&\ bulk}$ (cfs)	50-Year $Q_{burn\ \&\ bulk}$ *Rounded* (cfs)
1	A	4A	6,714.7	6,700	8,939.4	8,900
2		6A	6,724.6	6,700		
3		8A	6,667.8	6,700		

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Figure 7.5.2 shows the aftermath of a bulked flow, downstream of Hook Canyon in Glendora after the January 1969 storm.

Figure 7.5.2
Downstream of Hook Canyon in Glendora
January 26, 1969

1 Mulvaney, T.J. "On the Use of Self-Registering Rain and Flood Gauges. Inst. Civ. Eng. (Ireland) Trans. Vol. 4. pages 1-8. 1851.

2 Bedient, P.B. and W.C. Huber. Hydrology and Floodplain Analysis, 3rd Ed. Prentice-Hall, Inc. NJ. page 84. 2002.

3 US Army Corps of Engineers. Hydraulic Design of Stream Restoration (ERDC/CHL TR-01-28). page 24, Washington, D.C. 2001.

4 Nasseri, I. Use of Kinematic Wave Theory With the Rational Method. ASCE Engineering Workshop on Peak Reduction for Drainage and Flood Control Projects. Proceedings May 9, 1987.

5 Bedient, P.B. and W.C. Huber. Hydrology and Floodplain Analysis, 3rd Ed. Prentice-Hall, Inc. NJ. page 246. 2002.

6 Nasseri, I. Use of Kinematic Wave Theory With the Rational Method. ASCE Engineering Workshop on Peak Reduction for Drainage and Flood Control Projects. Proceedings May 9, 1987. page 132.

7 Los Angeles County Hydrologic Method Approval Memorandum. Los Angeles County Department of Public Works. March 4, 2002.

8 US Army Corps of Engineers. Hydrologic Modeling System HEC-HMS Technical Reference Manual. CPD-74B. March 2000.

9 Bedient, P.B. and W.C. Huber. Hydrology and Floodplain Analysis, 3rd Ed. Prentice-Hall, Inc. NJ. page 246. 2002.

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CHAPTER

8

Reservoir and Basin Routing

Reservoirs and detention ponds are an important aspect of water resources management. Reservoirs and detention ponds change runoff timing and peak runoff rates while storing flows. Hydrologic studies must consider these effects when evaluating existing conditions or planning for future changes within the watershed. Figure 8.1 shows the San Gabriel Reservoir on April 28, 1975.

Figure 8.1
San Gabriel Reservoir
April 28, 1975

Reservoir routing for hydrologic studies within the County of Los Angeles uses the Modified Puls or Level Pool routing method. The method is similar to the method for channel routing, except that no translation is considered. Section 7.3, Channel Routing of Flows discusses the concepts of the

Modified Puls method in more detail. Equation 8.1 is the finite difference form of the continuity equation used for reservoir routing[1]. Equation 8.2 provides a relationship that is used to calculate outflow without actually calculating storage for a given time step. The example problem illustrates use of the equations.

$$(I_n + I_{n+1}) + \left(\frac{2S_n}{\Delta t} - O_n\right) = \left(\frac{2S_{n+1}}{\Delta t} + O_{n+1}\right)$$

Equation 8.1
Form of the Continuity Equation Used for Reservoir Routing

$$\left(\frac{2S_n}{\Delta t} - O_n\right) = \left(\frac{2S_n}{\Delta t} + O_n\right) - 2O_n$$

Equation 8.2
Relationship Used to Calculate Outflow Without Calculating Storage

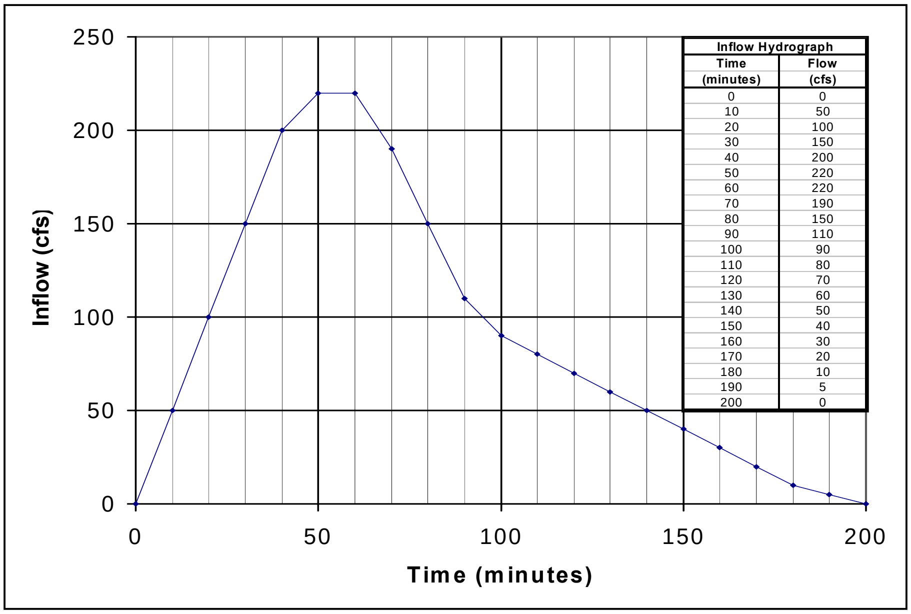
Where:
- I_n = Inflow at $time_n$
- I_{n+1} = Inflow at $time_{n+1}$
- Δt = Difference in time, $time_{n+1}$ - $time_n$
- S_n = Storage at $time_n$
- S_{n+1} = Storage at $time_{n+1}$
- O_n = Outflow at $time_n$
- O_{n+1} = Outflow at $time_{n+1}$

Reservoir routing using the Modified Puls method requires a storage-elevation relationship, an outflow-elevation relationship, and an inflow hydrograph. The relationships, the inflow hydrograph, and a known initial storage condition provide the information necessary to calculate outflow. The following example illustrates the use of the Modified Puls reservoir routing method.

EXAMPLE – Modified Puls Routing Through a Reservoir

This example routes an inflow hydrograph through a simple detention basin. Figure 8.2 defines the inflow hydrograph to be routed through the detention basin in this example.

The detention basin has the storage capacity shown in Table 8.1. Outflow from the basin occurs through an 24-inch drain when the water surface elevation is below 6 feet. When the water surface elevation is above 6 feet, outflow occurs through the drainpipe and over a weir. The weir is 20 feet long and has a weir coefficient of 3.5. Equations 8.3 and 8.4 provide the outflow relationships for the weir and drainpipe based on elevation as shown in Table 8.1.



Inflow Hydrograph	
Time (minutes)	Flow (cfs)
0	0
10	50
20	100
30	150
40	200
50	220
60	220
70	190
80	150
90	110
100	90
110	80
120	70
130	60
140	50
150	40
160	30
170	20
180	10
190	5
200	0

Figure 8.2
Inflow Hydrograph

Table 8.1 contains the storage-elevation and outflow-elevation relationships for this example. When outflow is based only on storage and no inflow is entering the reservoir, these relationships provide enough information to calculate outflow for a specified water surface. If there is inflow occurring at the same time as outflow, the Modified Puls method can be used to calculate outflow. The method requires building a storage indication curve using a specific time interval. The time interval must equal the time interval for the inflow hydrograph. This example uses a 10-minute time interval.

$$Q = CLH^{1.5}$$

Equation 8.3
Weir Flow Equation

$$Q = KA\sqrt{2gH}$$

Equation 8.4
Orifice Flow Equation

Where:
- Q = Outflow in cfs
- C = Weir Coefficient, 3.5
- L = Length of weir crest in feet
- H = Water surface elevation above weir in feet
- K = Orifice flow coefficient, 0.65
- A = Cross sectional area of orifice in ft^2
- g = Gravitational acceleration in ft/sec^2

Table 8.1
Storage-Elevation and Outflow-Elevation Relationships

Water Surface Elevation (ft)	Storage (ft^3)	Orifice Outflow (cfs)	Weir Outflow (cfs)	Total Outflow (cfs)	2S/Δt+O (cfs)	2S/Δt-O (cfs)
0.0	0	0.0	0.0	0.0	0.0	0.0
0.5	30,000	11.6	0.0	11.6	111.6	88.4
1.0	60,000	16.4	0.0	16.4	216.4	183.6
1.5	80,000	20.1	0.0	20.1	286.7	246.6
2.0	100,000	23.2	0.0	23.2	356.5	310.2
2.5	120,000	25.9	0.0	25.9	425.9	374.1
3.0	140,000	28.4	0.0	28.4	495.1	438.3
3.5	160,000	30.7	0.0	30.7	564.0	502.7
4.0	180,000	32.8	0.0	32.8	632.8	567.2
4.5	200,000	34.8	0.0	34.8	701.4	631.9
5.0	220,000	36.6	0.0	36.6	770.0	696.7
5.5	230,000	38.4	0.0	38.4	805.1	728.2
6.0	240,000	40.1	0.0	40.1	840.1	759.9
6.5	250,000	41.8	24.7	66.5	899.9	766.8
7.0	260,000	43.4	70.0	113.4	980.0	753.3
7.5	300,000	44.9	128.6	173.5	1173.5	826.5
8.0	340,000	46.4	198.0	244.3	1377.7	889.0

Figure 8.3 plots the storage indication curves for this detention pond using the 10-minute time increment. The storage indication curve relates storage to outflow and provides a graphical method for calculating outflow based on the Modified Puls Method. Without the graph, solving for outflow requires interpolation of Table 8.1.

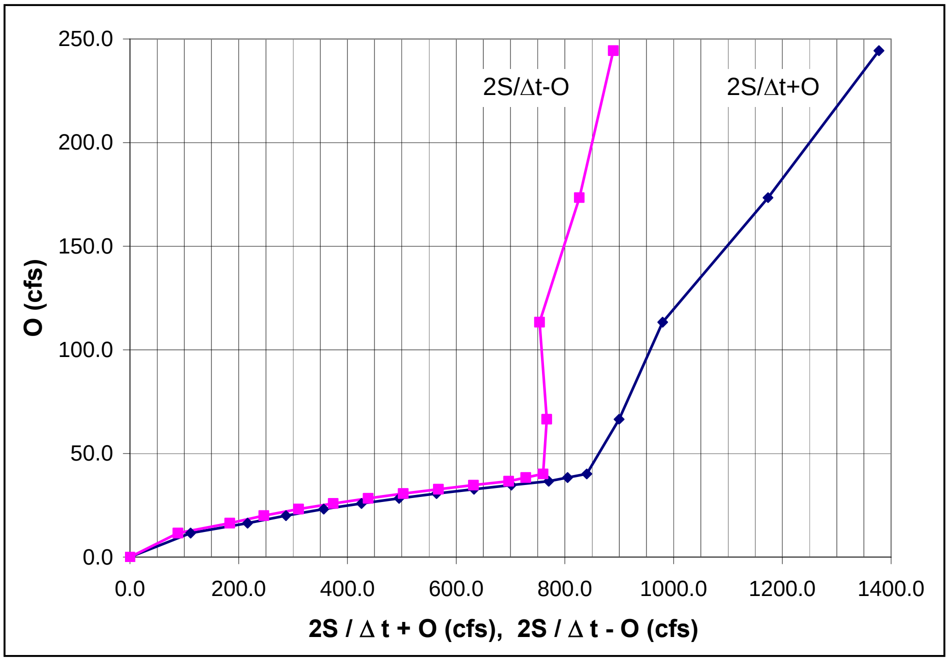


Figure 8.3
Storage-Indication Curve Based on 10-minute Time Interval

The storage-indication curve relates outflow to storage. Routing the flow through a reservoir requires solving graphically, or setting up a spreadsheet or computer program to perform the following steps:

1. Determine the initial storage, inflow, and outflow conditions and the inflow at the first time step (S_n, I_n, O_n, and I_{n+1}). The inflow cannot be greater than the outflow for the first time step.

2. Use the storage-indication curve to determine the storage and outflow for the second time step (S_{n+1} and O_{n+1}).

3. Repeat the steps 1 and 2 until the outflow hydrograph is completed.

The initial values for this example are:

S_1 = 0 ft^3
I_1 = 0 cfs
O_1 = 0 cfs
I_2 = 50 cfs
Δt = (10 minutes)*(60 sec/minute) = 600 sec

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The initial values provide a solution to determine the first value on the storage indication curve. This value is calculated as follows:

$$(I_1 + I_2) + \left(\frac{2S_1}{\Delta t} - O_1\right) = \left(\frac{2S_2}{\Delta t} + O_2\right) \Rightarrow$$
$$(0 + 50) + (0) = \left(\frac{2S_2}{\Delta t} + O_2\right) = 50$$

The outflow value for the second time step is found by reading the storage indication curve for 50 cfs along the X-axis and finding the Y-axis value, or by interpolating between the values shown in the last two columns of Table 8.1.

O_2 = 5.2 cfs (from storage indication curve)

The outflow at 10 minutes is 5.2 cfs. This value then provides the information for the next time step.

Equation 8.2 provides the values for $2S_n/\Delta t\text{-}O_n$ at time steps after the initial time step:

$$\left(\frac{2S_2}{\Delta t} - O_2\right) = \left(\frac{2S_2}{\Delta t} + O_2\right) - 2O_2$$

The calculation for the second time step value of $2S_n/\Delta t\text{-}O_n$ is:

$$\left(\frac{2S_2}{\Delta t} - O_2\right) = (50) - 2(5.2) = 39.6 \text{ cfs}$$

The values for the second iteration are:

I_2 = 50 cfs
O_2 = 5.2 cfs
I_3 = 100 cfs
Δt = (10 minutes)*(60 sec/minute) = 600 sec

$$(I_2 + I_3) + \left(\frac{2S_2}{\Delta t} - O_2\right) = \left(\frac{2S_3}{\Delta t} + O_3\right) \Rightarrow$$
$$(50 + 100) + (39.6) = \left(\frac{2S_3}{\Delta t} + O_3\right) \Rightarrow 189.6$$

O_3 = 15.2 cfs (from storage indication curve)

Spreadsheets facilitate the Modified Puls calculations for reservoir routing. Table 8.2 provides the rest of the calculations for the detention basin routing problem. Many computer programs use this method to calculate outflow from reservoirs and detention basins.

Table 8.2
Outflow Hydrograph Calculation Using Modified Puls Method

Inflow Hydrograph			Outflow Hydrograph Calculations			
Time Index	Time (min)	Inflow (I_n) (cfs)	I_n+I_{n+1} (cfs)	$2S/\Delta t$-O (cfs)	$2S/\Delta t$+O (cfs)	Outflow O_{n+1} (cfs)
1	0	0.0	0.0	0.0	0.0	0.0
2	10	50.0	50.0	0.0	50.0	5.2
3	20	100.0	150.0	39.6	189.6	15.2
4	30	150.0	250.0	159.3	409.3	25.3
5	40	200.0	350.0	358.8	708.8	35.0
6	50	220.0	420.0	638.9	1058.9	137.9
7	60	220.0	440.0	783.1	1223.1	190.7
8	70	190.0	410.0	841.7	1251.7	200.6
9	80	150.0	340.0	850.5	1190.5	179.4
10	90	110.0	260.0	831.7	1091.7	148.1
11	100	90.0	200.0	795.6	995.6	118.2
12	110	80.0	170.0	759.2	929.2	83.7
13	120	70.0	150.0	761.9	911.9	73.5
14	130	60.0	130.0	764.8	894.8	64.3
15	140	50.0	110.0	766.2	876.2	56.1
16	150	40.0	90.0	764.1	854.1	46.3
17	160	30.0	70.0	761.5	831.5	39.7
18	170	20.0	50.0	752.0	802.0	38.3
19	180	10.0	30.0	725.5	755.5	36.2
20	190	5.0	15.0	683.0	698.0	34.7
21	200	0.0	5.0	628.7	633.7	32.8
22	210	0.0	0.0	568.1	568.1	30.8
23	220	0.0	0.0	506.5	506.5	28.8
24	230	0.0	0.0	449.0	449.0	26.7
25	240	0.0	0.0	395.5	395.5	24.7
26	250	0.0	0.0	346.1	346.1	22.7
27	260	0.0	0.0	300.7	300.7	20.7
28	270	0.0	0.0	259.3	259.3	18.6
29	280	0.0	0.0	222.0	222.0	16.7
30	290	0.0	0.0	188.7	188.7	15.1
31	300	0.0	0.0	158.4	158.4	13.7
32	310	0.0	0.0	131.0	131.0	12.5
33	320	0.0	0.0	106.0	106.0	11.0
34	330	0.0	0.0	84.0	84.0	8.7
35	340	0.0	0.0	66.5	66.5	6.9
36	350	0.0	0.0	52.7	52.7	5.5
37	360	0.0	0.0	41.8	41.8	4.3
38	370	0.0	0.0	33.1	33.1	3.4
39	380	0.0	0.0	26.2	26.2	2.7
40	390	0.0	0.0	20.8	20.8	2.2
41	400	0.0	0.0	16.5	16.5	1.7
42	410	0.0	0.0	13.0	13.0	1.4
43	420	0.0	0.0	10.3	10.3	1.1

[1] Bedient, P.B. and W.C. Huber. Hydrology and Floodplain Analysis, 3rd Ed. Prentice-Hall, Inc. NJ. page 256. 2002.

CHAPTER

9

Water Quality Hydrology

Water quality has been an important aspect of water resources planning and use for many years in Southern California[1]. Regulations protect water quality and seek to limit pollution in part by requiring that new developments meet certain criteria for pollution prevention. Other regulations sometimes result in the retrofitting of existing storm water conveyances to reduce pollution of impaired receiving water bodies. Since problems with the quality of runoff can be associated with common rainfall events, smaller, more frequent storms must be addressed. This section discusses several of the issues that relate hydrology to water quality issues.

9.1 STANDARD URBAN STORMWATER MITIGATION PLANS (SUSMP)[2]

The Standard Urban Stormwater Mitigation Plan (SUSMP) is part of the Development Planning Program of the National Pollution Discharge Elimination System, Phase I, Stormwater Permit for the County of Los Angeles. SUSMP applies to development and redevelopment projects within the County that fall within specific categories. The County of Los Angeles has developed a SUSMP manual that includes the permitting and inspection process for projects required to meet SUSMP regulations. Table 9.1.1 provides a summary of the types of development and activities that fall under SUSMP regulation. The SUSMP manual provides more specific information.

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Table 9.1.1
Development or Redevelopment Activities Regulated by SUSMP

Development Type and Activities
• Single-family hillside homes
• Residential development of ten or more units
• Industrial/commercial developments with 1 acre or more of impervious surface area
• Automotive service facilities
• Retail gasoline outlets
• Restaurants
• Parking lots 5,000 ft^2 or more of surface area or with 25 or more parking spaces
• Redevelopment projects in these categories that meet redevelopment thresholds
• Locations within or directly adjacent to or discharging directly to an environmentally sensitive area
• Fueling Areas
• Equipment maintenance, washing and repair areas
• Commercial/Industrial waste handling or storage
• Outdoor hazardous material handling or storage
• Outdoor manufacturing areas
• Outdoor food handling or processing
• Outdoor animal care, confinement, or slaughter
• Outdoor horticultural activities

The objective of SUSMP is to effectively prohibit non-storm water discharges and reduce the discharge of pollutants from storm water conveyance systems to the Maximum Extent Practicable (MEP) statutory standard. SUSMP defines hydrology standards for designing volumetric and flow rate based Best Management Practices (BMPs).

Design of BMPs to meet hydrologic standards for SUSMP must follow the methods outlined in the SUSMP manual. The design must mitigate flows or volumes using one of the required runoff calculations.

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SUSMP regulations allow four methods of runoff volume calculation for BMPs that treat stormwater on a volumetric basis. The four methods allowed to calculate flow volume are:

1. The 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ ASCE Manual of Practice No. 87, (1998).

2. The volume of annual runoff based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in California Stormwater Best Management Practices Handbook – Industrial/Commercial, (1993).

3. The volume of runoff produced from a 0.75-inch storm event, prior to its discharge to a storm water conveyance system.

4. The volume of runoff produced from a historical-record based reference 24-hour rainfall criterion for “treatment” (0.75 inch average for the county area) that achieves approximately the same reduction in pollutant loads as the 85th percentile 24-hour runoff event.

SUSMP regulations also allow three methods to calculate flow rates for BMPs that treat stormwater on a flow through basis. The three methods allowed to calculate flow rates are:

1. The flow of runoff produced from a rain event equal to at least 0.2 in/hr intensity.

2. The flow of runoff produced from a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the County of Los Angeles.

3. The flow of runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

SUSMP also requires controlling peak flow discharges to provide stream channel and overbank flood protection. This requirement relies on hydrology based on flow design criteria selected by the local regulatory agency. Chapter 4 specifies the peak flow discharge criteria.

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Many of the references for the SUSMP manual are available online. The following web addresses are links to the SUSMP Manual and a few of the references.

SUSMP Manual:
http://ladpw.org/WMD/npdes/SUSMP_MANUAL.pdf

CalTrans Storm Water Quality Manual:
http://www.dot.ca.gov/hq/oppd/stormwtr/PPDG-stormwater-2002.pdf

California Storm Water Best Management Practices Handbooks (2003) for Construction Activity, Municipal, Industrial/Commercial, and new development:
http://www.cabmphandbooks.com/

Start at the Source (1999) by Bay Area Stormwater Management Agencies Association:
www.mcstoppp.org/acrobat/StartattheSourceManual.pdf

9.2 TOTAL MAXIMUM DAILY LOADS (TMDL)

Total Maximum Daily Loads fall under Section 303 of the Federal Clean Water Act, which is a different section than the NPDES permit section. Impaired water bodies require reducing the pollutant discharge to a level that the water body can assimilate. The reduction could decrease the pollutant discharges to levels lower than required by an NPDES permit in order to meet the TMDL. TMDLs apply to both wastewater and stormwater discharges. Control of stormwater pollutant concentrations and loads requires implementing Best Management Practices (BMPs). TMDL requirements can relate to storms greater than storms required by SUSMP[3].

Understanding and implementing the TMDL program mandated by the Clean Water Act (Section 303(d)) presents significant challenges for the responsible State Environmental Agencies. States develop TMDLs to determine how to reduce pollution from point sources and non-point sources so that the pollutant loads stay below the maximum specified in the TMDL. Point sources include industrial and municipal facilities that discharge to water bodies. Non-point sources of pollution include urban runoff, agriculture, forestry, septic systems, and air deposition[4].

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States are required to prioritize waters/watersheds for TMDL development. States compile this information in a list and submit the list to the United States Environmental Protection Agency for review and approval. The list is known as the 303(d) list of impaired waters. TMDLs are documents that describe a specific water quality attainment strategy for a water body and the related impairment identified on the 303(d) list. TMDLs may include more than one water body and more than one pollutant.

The TMDL defines specific measurable features that describe attainment of the relevant water quality standards. TMDLs include a description of the total allowable level of the pollutant(s) in question and allocation of allowable loads to individual sources or groups of sources of the pollutant(s) of concern[5].

Each TMDL is for a specific water body and runoff mitigation can be represented by various hydrologic methods. For example, current trash TMDL regulations require that no man-made trash enter the water body at any time. However, hydrology studies for the trash TMDL use the 1-year, 1-hour storm to determine the flow rate that certain treatment systems must accommodate. The Santa Monica Bay Bacteria TMDL does not specify a design storm, but requires that bacteria levels remain below a certain concentration within the wave-wash of the bay. Figure 9.2.1 shows an example of low flow in a channel.

Figure 9.2.1
San Gabriel River
Low Flow Channel

Establishing TMDL hydrology requires data for rainfall, runoff, and water quality. Several agencies recognize the need to collect more water quality data, standardize collection methods, and create reporting methods that make this data more available[6,7]. Defining hydrology methods used to design systems to meet TMDL standards requires understanding of the TMDL and water quality issues. As more data is collected and more TMDLs are established, standard TMDL hydrology procedures must be established.

9.3 BEST MANAGEMENT PRACTICES (BMPS)

Best Management Practices (BMPs) are actions and devices that improve or prevent the pollution of urban runoff and stormwater. The 2001 Los Angeles Municipal Stormwater Permit defines BMPs as "…methods, or practices, designed and selected to reduce or eliminate the discharge of pollutants to surface waters from point and non-point source discharges including storm water. BMPs include, but are not limited to, structural and nonstructural controls, and operation and maintenance procedures. BMPs can be applied before, during, and after pollution-producing activities."

BMPs can be proprietary or nonproprietary. Proprietary BMPs include patented and/or manufactured devices. Nonproprietary BMP designs are public domain and include detention basins, grassy drainage swales, catch basin stenciling, and public education.

Under the stormwater requirements of the federal Clean Water Act, stormwater quality must be improved to the "Maximum Extent Practical." The installation of BMPs is considered to meet that requirement.

In Phase II of the Federal Stormwater Permit process, the EPA breaks BMPs into six categories that deal with prevention and treatment of stormwater. The list is:

1. Public education and outreach on stormwater impacts
2. Public involvement/participation
3. Illicit discharge detection and elimination
4. Construction site stormwater runoff control
5. Post-construction stormwater management in new development and redevelopment
6. Pollution prevention/good housekeeping for municipal operations

Each of the six categories contains specific BMPs targeted to improve water quality. More information on the categories and BMPs is available through the EPA[8]. Figure 9.3.1 shows an example of a coastal wetland.

Figure 9.3.1
Coastal Wetland

1 California Environmental Protection Agency. State Water Resources Board History. www.calepa.ca.gov/About/History01/

2 Los Angeles County Department of Public Works. Development Planning for Stormwater Management:
A Manual for the Standard Urban Stormwater Mitigation Plan. September 2002.

3 Los Angeles County Department of Public Works. TMDL Information on Webpage. www.ladpw.org/general/faq/index.cfm?Action=searchResults

4 America's Clean Water Foundation and the Association of State and Interstate Water Pollution Control
Administrators. www.tmdls.net

5 California Environmental Protection Agency, State Water Resources Control Board. http://www.swrcb.ca.gov/tmdl/

6 Committee on Assessment of Water Resources Research, National Research Council. Confronting the
Nation's Water Problems: The Role of Research. The National Academies Press. Washington, D.C. 2001. http://books.nap.edu/catalog/11031.html

7 United States Government Accountability Office. Watershed Management: Better Coordination of Data

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Collection Efforts Needed to Support Key Decisions. GAO-04-382. www.gao.gov/cgi-bin/getrpt?GAO-04-382

8 National Menu of Best Management Practices for Stormwater Phase II. United States Environmental Protection Agency. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/menu.cfm

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CHAPTER

10

Hydrologic Data Requirements and Sources

Hydrologic studies require the use of mathematical models. A model is a representation of physical systems using equations. The parameters in these equations change to represent different hydrologic conditions. Hydrologic models have many forms and attempt to represent many different physical processes. The models used by the County of Los Angeles are lumped parameter models. This means that they consider the spatial variation of parameters only down to a certain level. Below this level, parameters are aggregated using an average.

Whether using hand or computer automated calculations, an important task of model preparation is gathering the input data. Section 10 provides information on obtaining various types of data required for hydrologic modeling.

10.1 REQUIRED DATA

Creating watershed models commonly requires the data types shown in Table 10.1.1. The following sections and chapters present the procedures for obtaining and using data for hydrologic modeling.

Table 10.1.1
Required Watershed Data

Required data	**Description**
Subarea Size	The surface area inside the subarea boundaries
Flow Path Length	Length of the conveyance between subarea collection points
Flow Path Slope	Slope of the flow path used for calculating the T_C
Conveyance Data	A description of the flow conveyance between subarea collection points (length, slope, width, roughness, etc.)
Soil Types	A soil classification identifying the hydrologic characteristics of the area's surface soils
Land Use / Imperviousness	A classification of impervious surface area based on development types within the subarea
Design Storm Definition	Each subarea has a unique design storm based on the location and the rainfall recurrence interval being modeled
Time of Concentration	The time required for runoff from the most hydrologically remote point in a subarea to reach the subarea collection point

10.2 DATA SOURCES

The Hydrology Manual is the official reference for developing design hydrology. There are several other resources available to provide data for hydrologic studies within the County of Los Angeles.

Hydrology Manual Appendices

The Hydrology Manual and Appendices contain the maps and charts necessary to create the hydrologic models.

Appendix A includes a chart and a table representing the unit hyetograph used to develop design storms for the County of Los Angeles. Section 5.2 discusses the development and application of this temporal rainfall distribution.

Appendix B contains USGS Quadrangle maps overlaid with spatial data for the entire county. These include overlays of the 50-year, 24-hour rainfall isohyets, soil type, and debris production area (DPA) zones. Soil type boundaries assist in determining the predominate soil type within a subarea and the appropriate runoff coefficient curve. DPA zones are provided for use in the bulking process and to determine sediment production rates (see the Sedimentation Manual).

Appendix C contains soil names and characteristic information for the 179 soils defined for use with the Modified Rational Method. A soil identification table relates the soil numbers used by Public Works to the Natural Resources Conservation Service (NRCS) or Public Works assigned soil names. Graphs of the soil runoff coefficient curves represent the relationship between undeveloped runoff coefficients and rainfall intensity.

Appendix D contains a table of proportion impervious values for each of the SCAG land use types. While not shown in Appendix B, the land use patterns for the entire county are available as Geographic Information System (GIS) shapefiles.

Geographic Information System (GIS) and Electronic Data

Geographic Information Systems have an important role in current Public Works hydrologic studies. Most watershed characteristics vary by location. These spatial distributions lend themselves to GIS uses. The use of GIS allows the modeler to collect data quickly and accurately. Some computer programs integrate GIS and hydrologic modeling. These programs import and extract GIS data and provide this data to the hydrologic model for use in calculations.

Table 10.2.1 contains information on the principle GIS data available for hydrologic studies within the County of Los Angeles.

Georeferenced USGS Quadrangle map images are used as topographic maps for developing county design hydrology. These images can be opened in the GIS. These maps serve as the basis for delineation of watershed subareas and flow paths. These maps also serve as the basis for delineating the location of hydrologically important structures. Since the image is georeferenced, the resulting lines and subarea polygons have an associated length and area.

Aerial photographs can serve a similar function to map images. Photographs are useful because they can be used to identify various features such as roads, structures, land use, vegetative cover, and bodies of water. Aerial photos are also georeferenced images.

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Digital Elevation Models (DEMs) and Triangular Irregular Networks (TINs) are used to find slopes for each subarea. Some programs automatically delineate watershed boundaries and stream channels using these data sources. DEMs are grids with an elevation assigned to each grid block. USGS DEMs are available in 10 meter and 30 meter resolutions for most of the county. The resolution refers to the size of each block in the grid. TINs replicate the ground surface using triangles formed by irregularly spaced points with known X, Y, and Z coordinates. DEMs and TINs are created from topographic survey data.

Table 10.2.1
GIS Data Types

GIS Data Types	**File Type**
USGS Topographic "Quad" Maps	Image, typically "quad name".tif
Aerial Photographs	Image, typically *.jpg, *.tif
Digital Elevation Models (DEMs)	*.asc,
Triangulated Irregular Networks (TINs)	*.tin
LA County soil shapefile	soils_2004.shp
LA County land use shapefile	ladpw_landuse_2005.shp
LA County rainfall grid	lac50year24hr.asc, for the 50-year frequency

The soil type is another attribute represented spatially as GIS data. A soil shapefile indicates the areas covered by each soil type. GIS models then assist in determining which soil type is predominate in a given subarea.

Land use data is available only as a GIS file. Each of the land use polygons represent a different development type and have an imperviousness value assigned. GIS based models can calculate and assign an area weighted composite imperviousness value to each subarea based on the land use data in the GIS files.

10.3 FIELD RECONNAISSANCE

A field investigation is necessary for all design hydrology projects. The purpose is to gather information that might not be apparent from the data sources discussed in Section 10.2, and to confirm that the data gathered is

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correct. The field investigation is also an opportunity to resolve any discrepancies present in other data collected. Assumptions such as land use and roughness of conveyances should also be verified.

In urban areas, a field investigation is required. Watershed boundaries in these areas are influenced greatly by man-made drainage features. Many of these features are not significant enough to be represented in elevation data or topographic maps and are not visible on aerial photos. The only way to determine the flow pattern in these cases is by field investigation.

While no standard procedure suits all projects, listed below are some basic field check guidelines as a starting point for urban studies.

1. Take a base map overlaid with the existing and proposed flow paths and conveyances identified in the initial research. Take an enlarged street map to use as your field check map.

2. Start your field check at the outlet of the drainage area. Crisscross the watershed heading upstream while preparing the map.

3. Note the following on the field check map:

   - Surface flow directions at every street intersection for both sides of the street; note the flow direction with an arrow pointing downhill. Show gutters, cross gutters, catch basins, burpers, sumps and grade breaks. Also, note any streets without curbs. Use the field check symbols in Figure 10.3.1.

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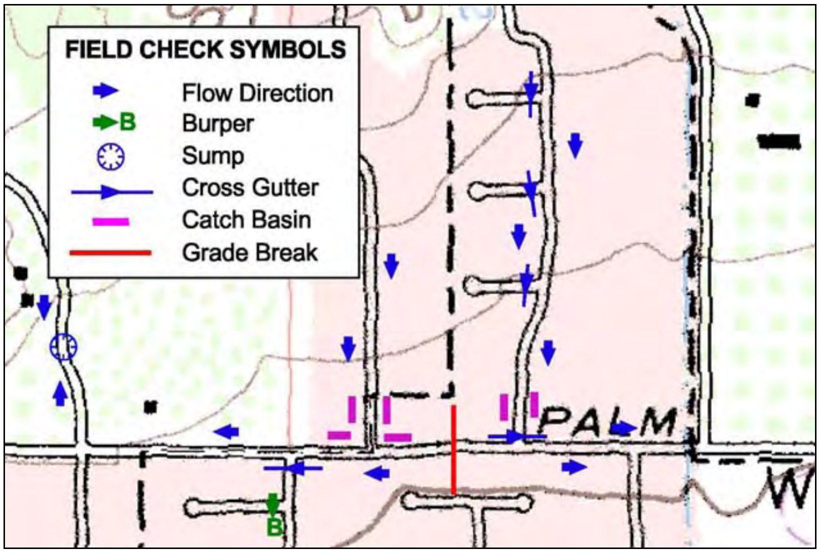

Figure 10.3.1
Field Check Symbols Map

- Check the types of development, such as single family or industrial, in order to verify the percent impervious.

- Check surface flow directions off property so that "frontage" along streets can be accounted for.

4. Get out of the car to investigate when there is uncertainty about flow directions.

5. Take a carpenter's level and place it in the gutter to determine the direction of flow on streets that are flat. Slopes are sometimes deceiving; use the level when in doubt.

6. Before leaving the area, check the map and note any flow contradictions. Now is the time to go back and resolve them. After the field check, research any new issues that may have come up such as unexpected drain locations or flow patterns.

10.4 WATERSHED DELINEATION

A watershed is an area of land that drains to a given location. The process of delineating the watershed for a given point is an important part of creating a hydrologic model.

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Watershed delineation requires a source of elevation data such as a topographic map. For the purposes of delineation, there are several important things to remember about topographic maps.

The contour lines are of equal elevation.

Water will follow a path perpendicular to the contour lines. All streams are perpendicular to the contour lines. Contour lines will generally form a "V" or an arrow pointing upstream where they cross streams.

Ridgelines are lines of high ground separating one watershed from another. Ridges may also appear as "V"s or arrows pointing down hill. A watershed boundary follows ridgelines. A drainage boundary will not intersect a stream or flow path except at the drainage area outlet.

See Figure 10.4.1 for examples of typical topographic forms.

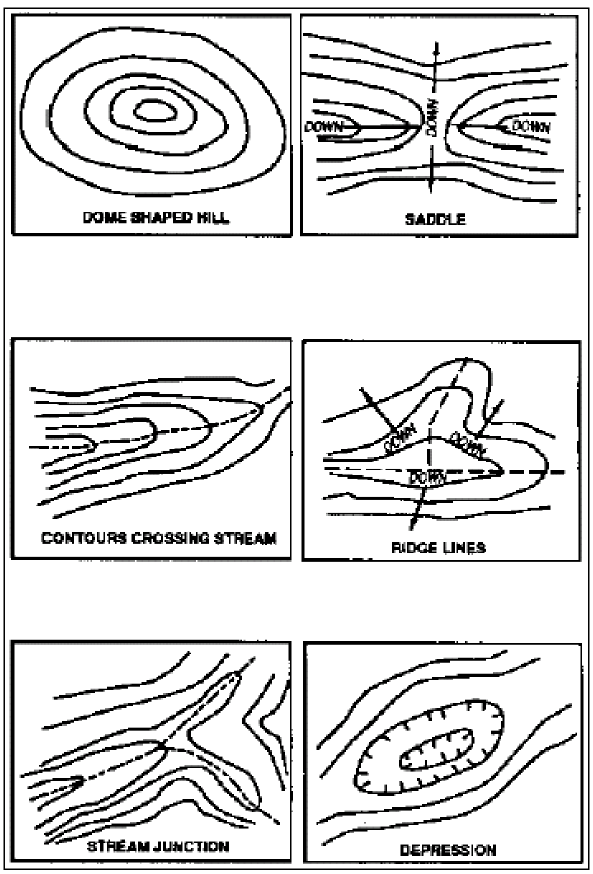

Figure 10.4.1
Typical Topographic Forms
Courtesy of Army Corps[1]

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As an example, consider the watershed delineation of Webber Canyon. Figure 10.4.2 shows the topographic map in the area surrounding Webber Canyon.

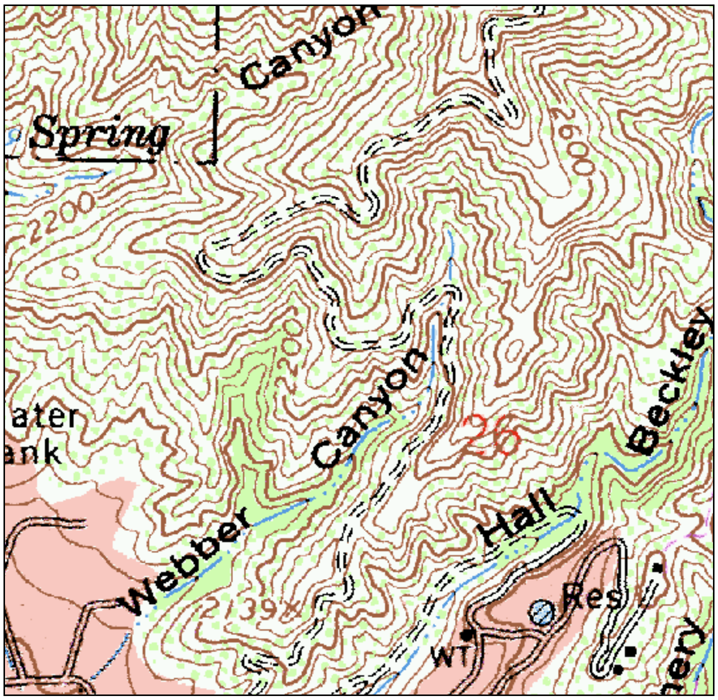

Figure 10.4.2
Topographic Map of Webber Canyon

Consider a point at the mouth of Webber Canyon, just below the "W" in the word "Webber". Webber Canyon and its tributaries upstream of this point comprise the watershed for the hydrology study.

Start by determining the outlet location where a flow rate value is needed, which for this example is location 1 in Figure 10.4.3. From this location, draw a line separating areas that contribute water to this location from areas that do not. Draw a line from the outlet point to the point on the adjacent contour. The line must be perpendicular to the contour line at the point where it crosses location 2.

Continue following and crossing the contours lines. Note that where the watershed boundary coincides with a sharp ridge, the line will be following the "V"s. Where ridgelines meet, it is important to make sure that the areas enclosed within the boundary are part of the same stream network.

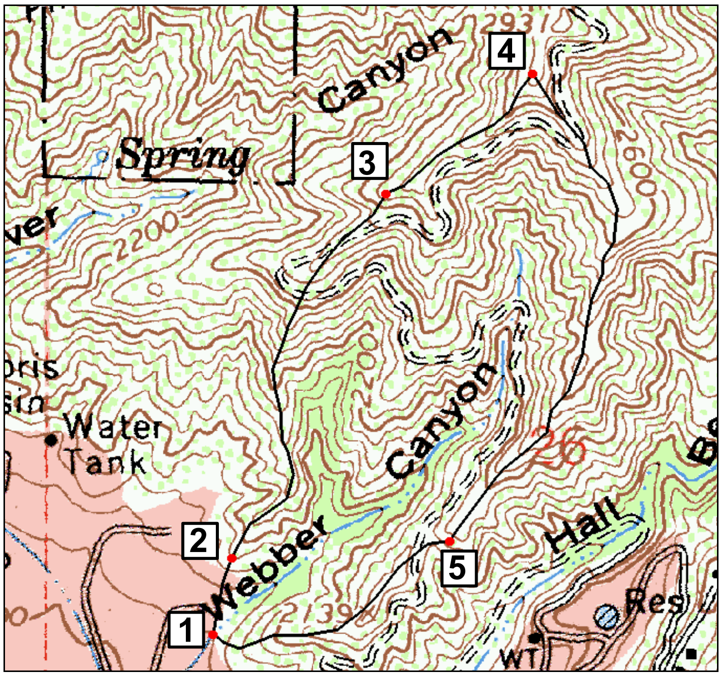

Figure 10.4.3
Webber Canyon Watershed Delineation

At location 3, continue connecting "V"s past the intersection of ridgelines because the intersecting ridge separates Webber Canyon from a tributary. However, location 4 shows the ridgeline intersection that separates Webber Canyon from other watersheds. Stop at a point on the nose of the ridge and then continue back downhill following the intersecting ridge along the arc between locations 4 and 5. Continue down this ridge until you reach the watershed outlet once again at location 1. The area inside the boundary you have drawn is the watershed tributary to the chosen outlet point.

For modeling purposes, it is sometimes necessary to break a watershed up into smaller pieces called subareas. This is done by adding additional outlets upstream of the final outlet and following the same procedure. Outlets should be added at break points on the flow path. These points might include changes in slope, changes in conveyance, entry of laterals or external flows, or points where catch basins are needed. Subarea definition often depends on the purpose of the hydrologic study.

This simple example shows watershed delineation using only a topographic map. As discussed in Section 10.2, topographic maps are insufficient to define the drainage pattern in flat areas and urban areas where man-made drainage features must be considered. In these cases, watershed delineation must account for the actual drainage patterns and collection systems.

Determine the drainage area boundaries for the entire project watershed first. Then draw in the flow paths. The flow paths should include existing and proposed drains. Divide the drainage area into subareas by locating significant collection points in the watershed and delineating the subareas. Subarea delineation follows the same steps as watershed delineation.

10.5 COLLECTING SUBAREA DATA

A primary task in any hydrology study is gathering site specific data that will dictate the way runoff is produced. After delineating the watershed and subareas as described in Section 10.4, it is now possible to collect subarea data. Studies commonly require the lengths and slopes of flow paths and time of concentration paths, characteristic soil types, and percent imperviousness. Data collection is described in the following list.

1. Determine the subarea size using a planimeter or GIS.

2. Determine the length and average slope of conveyances. Draw a path that follows the main watercourse between the outlet of the upstream subarea and the next downstream subarea outlet. Measure the conveyance length using a scale or GIS. Determine the top and bottom elevation and calculate the slope of each conveyance length.

3. Determine the length and average slope of time of concentration paths. The procedure for T_C paths is the same as for conveyances. However, T_C paths are drawn from the furthest or most hydrologically remote point in a watershed subarea to the outlet. This is not necessarily the longest path distance but the one that would take the longest time for water to travel to the outlet.

4. Locate the soil type boundaries on the maps in Appendix B or using GIS, and determine the predominate soil type in the subarea. For the Modified Rational Method, the selected soil's runoff coefficient curve will be used to carry out all the necessary runoff calculations in the subarea.

5. Determine the type and extent of development in each subarea. Land use helps determine the amount of directly connected impervious area and hence the amount of rain that will runoff directly. The land use types have been assigned a percent imperviousness as shown in Appendix D. Each subarea requires an area-weighted average of percent imperviousness.

10.6 COLLECTING RAINFALL DATA

For simulation of a single event, rather than using the rainfall data from a real storm, a design storm is used. The design storm is described in Chapter 5. In order to account for the spatial variability of rainfall, the design storm assumes different magnitudes based on its location. Each subarea has a distinct, 50-year, 24-hour rainfall depth based on its position within the rainfall grid. The procedure for determining the average design rainfall is called the Isohyetal Method.

1. Locate the isohyetal lines on the quad maps from Appendix B and use the methods from Section 5.4 to assign each subarea an isohyetal depth for the 50-year, 24-hour event.

2. If the modeled event will be other than the 50-year, use the Rainfall Frequency Factors in Table 5.3.1 to convert this isohyetal depth for the desired frequency.

3. Produce the design hyetograph by multiplying each point on the unit hyetograph by the isohyetal depth.

For some dams it is necessary to evaluate runoff from standard design storms and the Probable Maximum Flood (PMF). Development of the design storm for the PMF must follow the procedures of Hydrometerological Report (HMR) No. 59. In this case, other specific data about the watershed may need to be collected.

Chapter 5 describes the derivation of the design storm and the isohyetal maps from rain gage data collected in the county. Public Works' operates and maintains over 250 rain gages. These rain gages record rainfall amounts for durations from 5 minutes to 24 hours. Many of these rain gages have records that are greater than 50 years in length. Daily and annual rainfall amounts are available in the annual Public Works' Hydrologic Report

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and at http://www.ladpw.org/wrd/report/. Intensities for other durations are available by contacting the Hydrologic Records Section.

Public Works collects rainfall data using non-recording and automatic recording rain gages. Non-recording gages collect rain and hold it in a container until it can be measured using a dipstick or graduated marking on the side of the collector. Volunteer observers typically read these gages daily at a specified time.

The automatic recording gages record the rainfall amounts for shorter time intervals. All of the Public Works' recording gages use tipping buckets to measure rainfall. The gages have a set of buckets that are alternately filled. When one of the buckets fills to a predefined amount, it tips. The other bucket then moves into the filling position. The frequency of the tipping allows the corresponding rainfall intensity to be calculated. This type of recording gage allows for very precise definition of a hyetograph. Most of the recording rain gages are connected to a central computer system using radio and satellite links so that rainfall amounts can be monitored in real-time. These gages are part of the Automatic Local Evaluation in Real-Time (ALERT) network. This network provides information for decision making during storm events.

10.7 CONVEYANCES

Conveyances are the links within a hydrologic model that simulate the flow of water through channel reaches. A hydrograph is specified at the top of a reach and a resulting outflow hydrograph is calculated at the bottom. Conveyance modeling is necessary due to the reduction of peak flow rates by attenuation and travel time. These processes affect the hydrograph at the downstream end of the conveyances.

The Modified Rational method uses six conveyance types: mountain, valley, street, circular pipe, rectangular channel, and trapezoidal channel. The types of conveyances between subarea collection points must be determined. The type of conveyance is important because water will flow much faster in a pipe than through a valley. Select the type that best characterizes the existing or planned conveyance. Several of the types require additional information about the dimensions and characteristics of the conveyance. The various conveyance types are described in detail in Section 7.3.

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The length and slope of the conveyance between collection points are also important in determining the effects of hydrologic routing. The conveyance lengths are determined by measuring the flow path length using a scale or GIS. This length information is combined with the elevation data from a DEM or topographic map to determine the slope. For natural mountain and valley conveyances, the slope must be corrected using the slope correction curve, Figure 7.3.10.

Figure 10.7.1 shows water being conveyed on the streets of Lakewood after the 1950 storm season.

Figure 10.7.1
Streets of Lakewood Flooding After 1950 Storm

[1] US Army Corps of Engineers, "Topographic Surveying", Manual 1111-1-1005. Washington D.C. August 31, 1994.

CHAPTER

11

Time of Concentration Calculation

The time of concentration is the time required for runoff from the most hydrologically remote point in the subarea to reach the subarea outlet. The Modified Rational Method requires a time of concentration calculation for each subarea.

In the past, Public Works used kinematic wave theory to calculate the time of concentration (Section 7.3). To simplify these calculations, Public Works developed a regression equation based on hundreds of studies using kinematic wave theory. The regression equation replaces the original kinematic wave calculations.

Time of concentration calculations can either be done by hand (Section 11.1) or using the T_C calculator program (Section 11.2). Watershed Modeling System (WMS) and XP-SWMM software also incorporate these calculations.

11.1 TIME OF CONCENTRATION – HAND CALCULATIONS

The following provides a step-by-step approach for using the regression equation to calculate the time of concentration. The steps show the calculations for the example in Chapter 7 shown in Figure 7.3.3.

1. **Determine subarea boundaries and then calculate flow path length and flow path slope**

   L = 1,150 feet
   S = (150*0.02+1,000*0.005) / 1,150 = 0.007 ft/ft

2. **Assume an initial value for T_C**

   Assume T_C = 12 minutes

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3. Use Equation 5.1.2 to calculate intensity at time t, I_t

$$I_t = I_{1440} * \left(\frac{1440}{t}\right)^{0.47} \Rightarrow I_{12} = \frac{5\,\text{in}}{24\,\text{hr}} * \left(\frac{1440}{12}\right)^{0.47}$$
$$= 1.98 \text{ in/hr}$$

4. Determine the developed soil runoff coefficient using the soil curve data and Equation 6.3.2.

$$C_d = (0.9 * IMP) + (1.0 - IMP) * C_u$$
$$= (0.9 * 0.42) + (1.0 - 0.42) * 0.58 = 0.71$$

5. Use Equation 7.3.5 to determine a new T_C value

$$T_C = \frac{0.31 * L^{0.483}}{(C_d * I_t)^{0.519} * S^{0.135}}$$

$$= \frac{0.31 * 1150^{0.483}}{(0.71 * 1.98)^{0.519} * 0.007^{0.135}} = 15.27 \text{ minutes}$$

6. Compare initial assumption with new T_C value

15.27 minutes > 12.0 minutes

7. If the value is not within 0.5 minutes of the assumed, use the new T_C value and begin at Step 3 to complete another iteration

Use T_C = 15 minutes for the next assumption

8. Iterate until initial and final T_C values are with 0.5 minutes

The new values using T_C = 15 minutes are:

I_t = 1.78 in/hr
C_u = 0.54
C_d = 0.69
T_C = 16.37 minutes

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The difference between 15 and 16.37 is greater than 0.5 minutes
Use T_C = 17 minutes and recalculate

I_t = 1.68 in/hr
C_u = 0.53
C_d = 0.69
T_C = 16.87 minutes

The difference between 17 and 16.87 is less than 0.5 minutes, use T_C = 17 minutes for subarea.

The acceptable T_C range is from 5 to 30 minutes. If a T_C of less than 5 minutes is calculated, use 5 minutes. If a T_C greater than 30 minutes is calculated for the 50-year 24-hour design storm, the subarea must be divided into two subareas.

11.2 TIME OF CONCENTRATION - T_C CALCULATOR

Public Works developed a time of concentration calculator to automate time of concentration calculations. In addition to carrying out the T_C calculation process, the T_C Calculator completes the full modified rational runoff calculation process yielding peak runoff rates and volumes. Routing is not a feature in the calculator.

The T_C Calculator spreadsheet, “TC_calc_vol.xls”, has been included on the CD with the Hydrology Manual.

1. The inputs to the calculator are the same as for the hand calculation method and are summarized in Table 11.2.1:

Table 11.2.1
T_C Calculator Inputs

Subarea size	7 acres
Soil type	068
Land use	42% impervious
Flow path length	1150 feet
Flow path slope	0.007
Rainfall depth	5 inches

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2. If burned flow rates are desired, the appropriate fire factor should be determined from Table 6.3.3. In this case, no burned flow rate was necessary. A fire factor of 0 was used.

3. Figure 11.2.1 shows the interface for the T_C calculator with the data for Subarea 1A entered. For calculating the runoff from a single subarea, fill out the boxes in the upper left hand corner of the calculator under "Subarea Parameters Manual Input." Depressing the "Calculate T_C" button in the lower right will display the results shown in the figure.

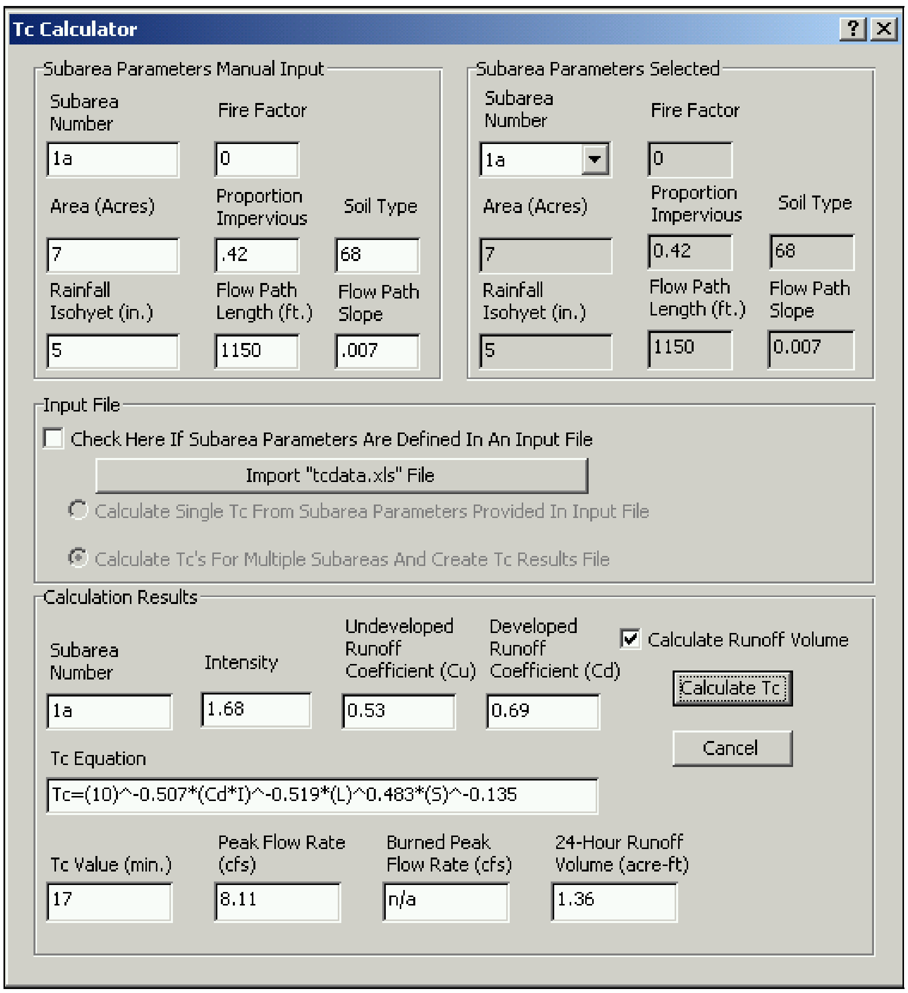

Figure 11.2.1
T_C Calculator Interface with Subarea 1A Results

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The calculated T_C value, intensity, runoff coefficients, and peak flow rate are all the same as the values reached by hand calculation. Round off error and the uncertainties of reading table values cause the minor differences. The 24-hour runoff volume is also calculated if the "Calculate Runoff Volume" box is checked. By checking this box, the number of calculations increases and may take more time to display the results.

4. To calculate multiple subareas simultaneously, the T_C calculator can also accept Excel spreadsheets as input files containing a number of subareas. This file must be in the format specified in the “datasamp” sheet of the T_C calculator and in Figure 11.2.2

	A	B	C	D	E	F	G	H	I	J
1	Project	Subarea	Area	%imp	Frequency	Soil Type	Length	Slope	Isohyet	Fire Factor
2	Example	1a	7	0.42	standard	68	1150	0.007	5	0
3	Herondo Drainage	32j	30	0.92	standard	10	2525	0.008	4.52	0
4	Herondo Drainage	24g	19	0.92	standard	10	1950	0.006	4.38	0
5	Herondo Drainage	6a	11	0.92	standard	10	1600	0.017	4.24	0
6	Herondo Drainage	32j	30	0.92	standard	10	2525	0.008	4.1	0
7	Herondo Drainage	24g	19	0.92	standard	10	1950	0.006	3.96	0

Figure 11.2.2

T_C Calculator Input File Format

Name the Excel spreadsheet “tcdata.xls”. To use an input file with the program, first check the box on the input dialog that says, “Check Here If Subarea Parameters Are Defined In An Input File”. Then select the button labeled, “Calculate T_C’s for Multiple Subareas and Create a T_C Results File.”

Import the data by clicking “Import ‘tcdata.xls’ File” button. Once the data is imported, the box in the upper right corner of the calculator window displays data for individual subareas. You can select a subarea of interest by scrolling through the pull down box called “Subarea Number” at the right.

5. After pressing the “Calculate Tc” button, you will be prompted to name the results file. The results can then be viewed using Excel or individually using the pull down box. The results file shown in Figure 11.2.3 contains all the input and output information.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Project	Subarea	Area (acres)	%imp	Frequency	Soil Type	Length (ft)	Slope (ft/ft)	Isohyet (in.)	Tc-calculated (min.)	Intensity (in./hr)	Cu	Cd	Flow rate (cfs)
2	Example	1a	7	0.42	standard	68	1150	0.007	5	17	1.68	0.53	0.69	8.11
3	Herondo Drainage	32j	30	0.92	standard	10	2525	0.008	4.52	25	1.27	0.23	0.85	32.39
4	Herondo Drainage	24g	19	0.92	standard	10	1950	0.006	4.38	23	1.28	0.23	0.85	20.67
5	Herondo Drainage	6a	11	0.92	standard	10	1600	0.017	4.24	17	1.42	0.27	0.85	13.28
6	Herondo Drainage	32j	30	0.92	standard	10	2525	0.008	4.1	27	1.11	0.18	0.84	27.97
7	Herondo Drainage	24g	19	0.92	standard	10	1950	0.006	3.96	25	1.11	0.18	0.84	17.72

Figure 11.2.3
T_C Calculator Results File for Multiple Subareas

Peak Flow Rate and Volume Calculations

Runoff volumes are calculated by calculating runoff rates for multiple time steps. Section 7.3.2 explains the calculations needed to define a hydrograph. The volume of flow equals the total area under the hydrograph.

Calculating flow volume by hand is impractical for all but the simplest cases. The T_C Calculator program has an option that allows the user to calculate the total runoff volume. After indicating this intention by checking the box marked "Calculate Runoff Volume," the user can produce the 4th day runoff volume by pressing the "Calculate Tc" button and naming the output file as before.

Substituting the rainfall depths for the first through third days into the calculator produces daily runoff volumes for the other days of the design storm. Rainfall depths for these days are a specified percentage of the fourth day as Table 11.2.2 indicates.

Day of Storm	Percentage
1st day	10%
2nd day	40%
3rd day	35%

Table 11.2.2
Percentage of Fourth Day Depth

The T_C calculator also produces a hydrograph plot when calculating runoff volumes. The hydrographs are accessed by pressing cancel in the calculator. This takes you to the workbook that contains the sheets that store the data behind the calculator interface. One of these sheets is labeled "hydrograph chart". The hydrograph shown is from the last subarea selected for analysis. Figure 11.2.4 shows the runoff hydrograph for the previous example.

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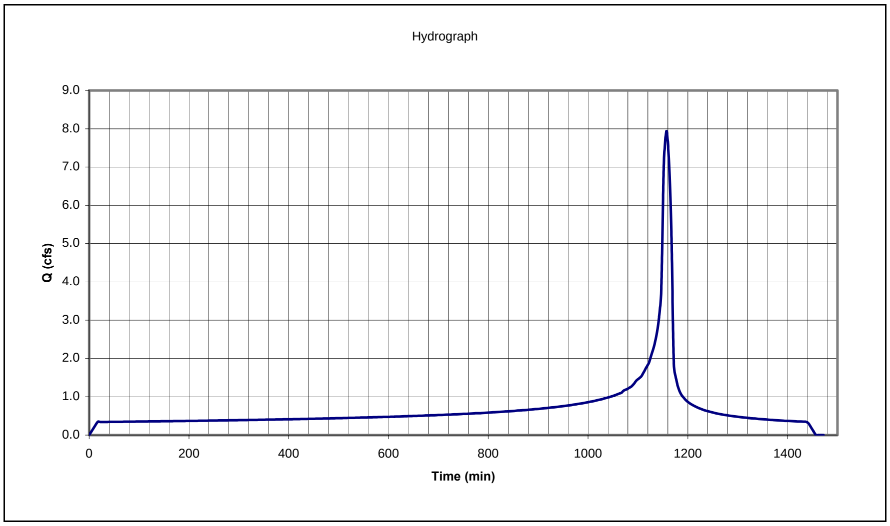

Figure 11.2.4
Runoff Hydrograph From the T_C Calculator

Storage Volume Requirements

Regional Basins

Regional Basins must be able to handle the 4-day design storm runoff volume. This may be accomplished by passing the first 3 days of storm flow through the basin, if the flow rate increase does not exceed pre-development flow rate levels. The regional basins must be able to store the post-development 4-day runoff volume, excluding the outflow during the storm. The basins must also meet other requirements determined by Land Development Division and Building and Safety Division.

ΔQ Basins – Antelope Valley

ΔQ Basins must store the change between pre- and post-development flow volumes, from all 4 days, for a 25-year event for percolation.

CHAPTER

12

Rational & Modified Rational Modeling

12.1 WATERSHED MODEL CREATION

The County of Los Angeles uses two related methods, the Rational and Modified Rational Method to calculate runoff rates. This section describes the necessary steps for creating a watershed model using both methods.

The first step in creating a model is to delineate the watershed using the methods described in Section 10.2. For countywide uniformity, subarea sizes should be approximately 40 acres. Smaller subarea sizes are acceptable.

Once the watershed and subareas are delineated, subareas and outlets must be numbered. The County of Los Angeles uses a subarea numbering system for hydrologic modeling that indicates the spatial relationships without the need for a diagram. A number and letter are assigned to each subarea and collection point.

Figure 12.1.1 shows an example of watershed numbering. Subarea IDs are indicated with a box and outlets are indicated with a leader. Numbers are assigned starting along the “mainline”. This is typically the longest stream channel in a watershed.

The upper most subarea on the mainline is assigned the label 1A. The watershed outlet of Subarea 1A is labeled 2A. The next watershed downstream from 1A is labeled 3A. In the example, Subarea 3A shares its outlet with another subarea, so instead of assigning the ID 4A to this outlet, 4A is assigned to the connecting subarea. The outlet downstream of 3A and 4A is labeled 5A. The numbering continues sequentially downstream.

When a confluence point with another stream or tributary is reached, numbering continues at the upstream end of the second stream or tributary. In the example, the A-line subarea upstream of the confluence is numbered

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8A. The most upstream subarea in the confluencing stream is numbered 9B. The B-line is numbered the same way as the A-line. When the B-line reaches the confluence with the A-line, the confluence ID requires two suffix letters. One represents the mainline and the other represents the lateral. In this case, the confluence is labeled 16AB. This ends the B-line numbering. Continue the numbering in sequence using the suffix A. This numbering system can be extended to accommodate any number of confluencing laterals.

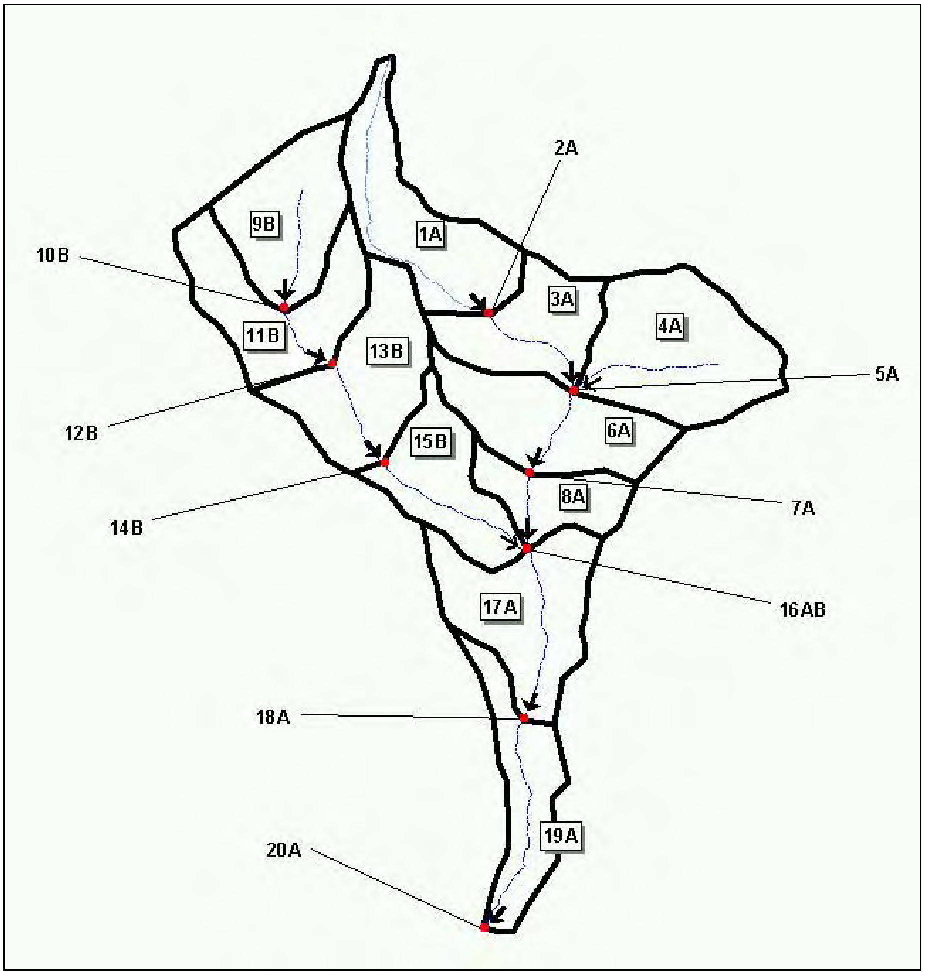

Figure 12.1.1
Watershed Numbering Example

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Diversions are numbered as reverse confluences and begin at a collection point numbered with two suffix letters. The first letter represents the line where the diversion occurs. The second represents the letter for the diversion line. The diversion can be collected further downstream at a confluence or be allowed to divert water out of the watershed being studied. Figure 12.1.2 shows the same example of watershed numbering except with a diversion just upstream of the watershed outlet.

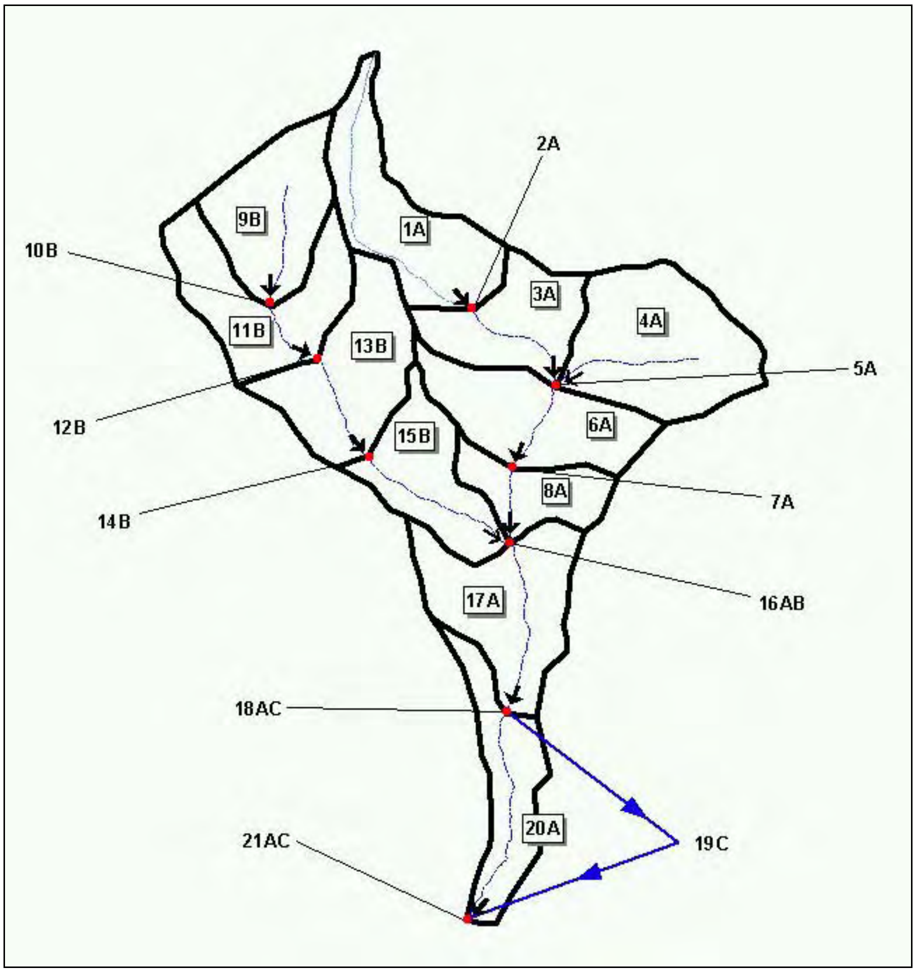

Figure 12.1.2
Watershed Numbering Example With a Diversion

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After labeling the subareas and collection points, subarea characteristics must be determined. Table 12.1.1 contains a description of each of these characteristics and the procedure for calculating them. These steps are illustrated in examples in the following two sections. Also, see Section 10.5.

Table 12.1.1
Required Parameters for Rational and Modified Rational Modeling

Parameter	Units	Symbol	Procedure	Related Section
Basin Area	Acres	A	Measure the drainage area from a scaled topographic map.	-
Conveyance Length	Feet	L	Measure the length of the conveyances between subarea collection points.	-
Conveyance Slope	Feet/Feet	S	Slope is the change in elevation between collection points divided by the conveyance length. If mountain or valley slopes exceed 0.1 see Figure 7.3.8.	-
Soil Type	-	-	Use the maps in Appendix B or the GIS shapefile to determine the predominate soil type.	Section 6.3
Percent Impervious	%	IMP	Assign each subarea a percent impervious based on land use. When more than one land use exists, assign an area-weighted imperviousness average.	Section 6.3
Rainfall Depth	Inches	-	Use the isohyetal method to determine the average rainfall depth for a subarea.	Section 5.4
Time of Concentration	Minutes	T_C	Use Regression Method Equation.	Sections 7.3, 11.1, 11.2

12.2 RATIONAL METHOD

The Los Angeles County Hydrology Method allows use of the rational method for runoff calculation in small watersheds. The Rational Method is the basis of the Modified Rational Method and allows calculation of the peak runoff rate for a single subarea.

Since the rational method generates only peak flow rates and not hydrographs, the only way to combine the flows from two subareas is to add the peak flow rates together. This method of combination neglects the effects of channel routing, peak flow attenuation, and variable times of concentration. These factors reduce the peak flow rate in larger watersheds.

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The peak-to-peak method is overly conservative in watersheds larger than a few subareas.

Subarea 1A, a typical rural watershed from the example in Section 5.4, will be used to illustrate the rational method. Figure 12.1.1 shows the entire watershed. Figure 12.2.1 shows an enlarged view of Subarea 1A.

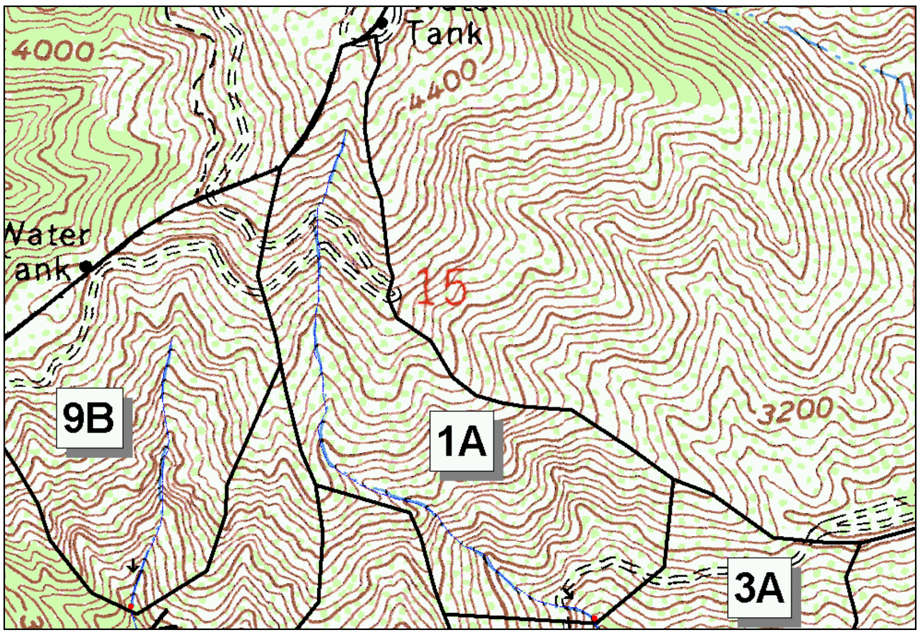

Figure 12.2.1
Subarea 1A

1. Section 5.4 contains the following data for Subarea 1A.

   Subarea size: 67.7 acres
   Rainfall Depth (50-year, 24-hour): 12.0 inches

2. Appendix B contains maps with hydrologic data. Figure 12.2.2 shows the Mount Baldy Quad, 1-H1-31, with soil types delineated. Subarea 1A contains soil types 081 and 088. However, the majority of the area is soil type 081. The characteristics of soil type 081 are used in the runoff calculation.

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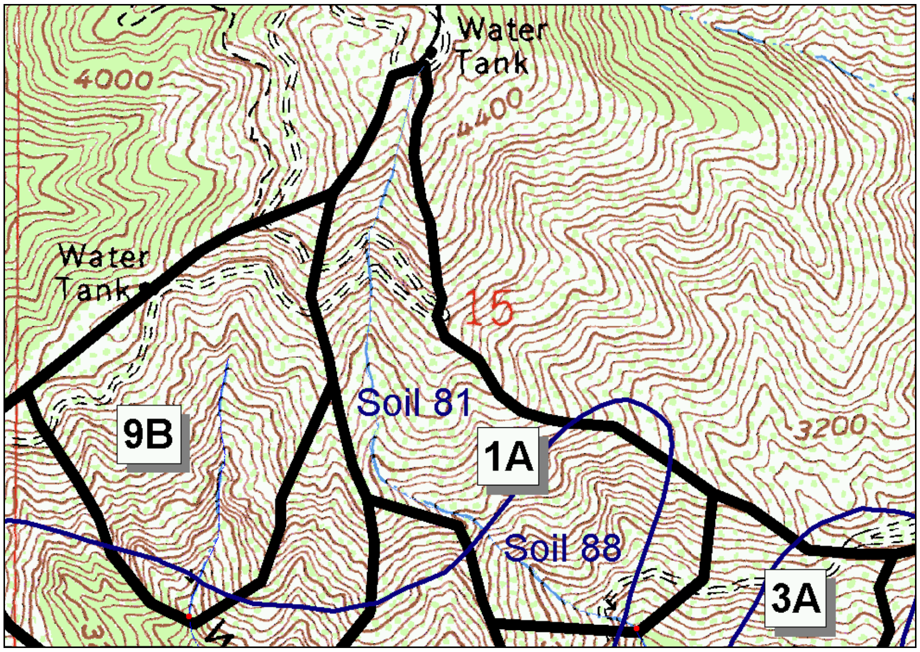

Figure 12.2.2

Appendix B Hydrologic Data Map – Mt. Baldy Quad with Subarea 1A and Soil Types Delineated

3. Appendix D contains information on imperviousness values based on land use. Subarea 1A is mountainous and undeveloped. Undeveloped rural areas are given an imperviousness of 1% in the Los Angeles County Method. For developed areas, the area-weighted imperviousness value is needed for each subarea. Section 6.3 illustrates area-weighted imperviousness calculations.

4. A time of concentration flow path is drawn from the most hydraulically remote location to the subarea outlet. The length and slope of this path needs to be determined. For Subarea 1A, the upper end of the T_C path is at an elevation of 4,612 feet and the collection point elevation is 2,739 feet. The flow path length measured using a planimeter is 4,109 feet.

   The slope is:

$$\text{Slope} = (4{,}612 \text{ ft} - 2{,}739 \text{ ft}) / 4{,}109 \text{ ft} = 0.456$$

5. Find the time of concentration by iteration:

- Convert the 24-hour rainfall depth into intensity, I_{1440}.

  I_{1440} = 12.0 in / 24 hrs = 0.5 in/hr

- Assume an initial T_C value of 12 minutes.

- Use the rainfall intensity-duration-frequency relationship, Equation 5.1.2, to determine the ratio of the 12-minute intensity to the 24-hour intensity.

$$\left(\frac{I_{12}}{I_{1440}}\right) = \left(\frac{1440}{12}\right)^{0.47} = 9.49$$

- Calculate the 12-minute intensity in in/hr;

$$I_{12\ min} = I_{1440} * \left(\frac{I_{12}}{I_{1440}}\right)$$

$$I_{12\,min} = 0.5 * 9.49 = 4.75 \text{ in/hr}$$

- Figure 12.2.3 is the soil runoff coefficient curve for soil type 081 from Appendix C. Using the intensity, I_{12min}, determine the undeveloped runoff coefficient: $C_u = 0.89$.

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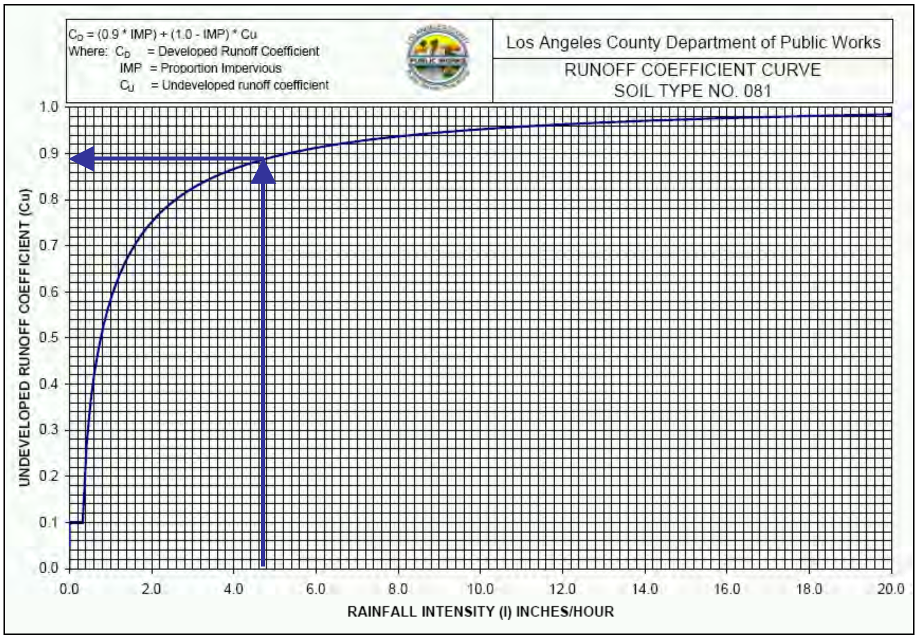

Figure 12.2.3
Soil Type No. 081, Runoff Coefficient Curve from Appendix C

- Calculate the developed runoff coefficient using Equation 6.3.2;

$$C_d = (0.9 * IMP) + (1.0 - IMP) * C_u$$

$$C_d = (0.9 * 0.01) + (1.0 - 0.01) * 0.89 = 0.89$$

- Calculate the value for rainfall excess;

$$\text{Excess rainfall} = C_d * I_{12min}$$
$$= 0.89 * 4.75 = 4.23 \text{ in/hr}$$

- Calculate the time of concentration using Equation 7.3.5;

$$T_C = \frac{0.31 * L^{0.483}}{(C_d * I_t)^{0.519} * S^{0.135}}$$
$$= 0.31 * 4.23^{-0.519} * 4{,}109^{0.483} * 0.456^{-0.135} = 9.1 \text{ minutes}$$

- Since the resulting T_C, 9.1 minutes, is not within half a minute of the assumed T_C, 12.0 minutes, assume another T_C and repeat the calculations. Use the calculated T_C as the guess for the next iteration.

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- Table 12.2.1 contains data for each iteration of the T_C calculations

Table 12.2.1
Iterative T_C Calculations for Subarea 1A

Iteration Number	I_{1440} (in/hr)	Initial T_C (min)	I_t/I1440	I_t (in/hr)	C_u	C_d	C_d*I (in/hr)	Calculated T_C (min)	Difference (min)
1	0.5	12.00	9.49	4.75	0.89	0.89	4.23	9.1	2.9
2	0.5	9.1	10.8	5.4	0.90	0.90	4.86	8.4	.7
3	0.5	8.4	11.2	5.6	0.90	0.90	5.0	8.3	.1
Final	0.5	8.0	11.5	5.75	0.90	0.90	5.18		

- When the T_C is within half a minute of the assumed T_C, round to the nearest minute to get the final T_C and calculate the I_t, C_u and C_d.

- The subarea peak flow rate in cfs is calculated using the rational method. Multiply the rainfall excess (in/hr) by the area of the catchment (acres) to get peak flow.

$$Q_{peak} = (C_d * I_t) * Area$$
$$= (0.90 * 5.75 \text{ in/hr}) * (67.7 \text{ ac}) = 350.3 \text{ cfs}$$

Using the rational method for multiple subareas requires adding peak flow rates. For example, Subarea 3A has a peak flow rate of 146.9 cfs. The total flow rate at outlet 4A is 497.2 cfs using the rational method.

12.3 MODIFIED RATIONAL METHOD

The Modified Rational Method is an extension of the rational method used to create runoff hydrographs from a watershed of any size over a specific time period. The Rational method is limited to considering storms with a duration equal to the time of concentration and provides only a peak flow. The Modified Rational Method can consider single event storms with changing intensities and longer durations. The Modified Rational Method was developed as a means to produce hydrographs for storage design based on the rational method.

In the Modified Rational Method, the rational method is applied to each subarea's hyetograph to produce a hydrograph for each subarea in the watershed. The hydrograph for Subarea 1A of the Palmer Canyon watershed will be generated to show how calculations are performed. Computational implementations of the modified rational method use 1-minute timesteps to define the hyetograph. For illustration, only a few timesteps around the peak runoff at 1152 minutes will be used to define the hydrograph. The following information is needed:

Area:	67.7 acres
T_C:	8 minutes
Soil type:	088
Percent Impervious:	1%
4th day rainfall:	12.0 inches

The steps for hydrograph generation from Section 7.3 are as follows:

1. Determine the rainfall intensity for a time period equal to the T_C.
2. Determine the undeveloped soil runoff coefficient for the time period using the intensity.
3. Adjust the soil runoff coefficient using Equation 6.3.2 to determine C_d.
4. Use the rational equation, Equation 7.2.1, to determine the runoff for the time period.
5. Repeat steps 1 through 4 for each time period.

Illustration of hydrograph calculations will use time steps ending at 1128, 1153, and 1178 minutes. Figure 12.3.1 shows the three time periods used from the portion of the hyetograph near the peak rainfall intensity. Start with the time step ending at 1128. The 8 minute T_C calculated in Table 12.2.1 is used to define the time increment.

The first time interval of interest becomes minutes 1120 to 1128. The slope of the subarea hyetograph in Figure 12.3.1 changes during this period. The average intensity is used for the calculation. To calculate the average intensity, determine the total rainfall during this time and divide by the T_C in hours. The total rainfall from 1120 to 1128 is 0.203 inches in 8 minutes. This is equivalent to an intensity of 1.52 in/hr.

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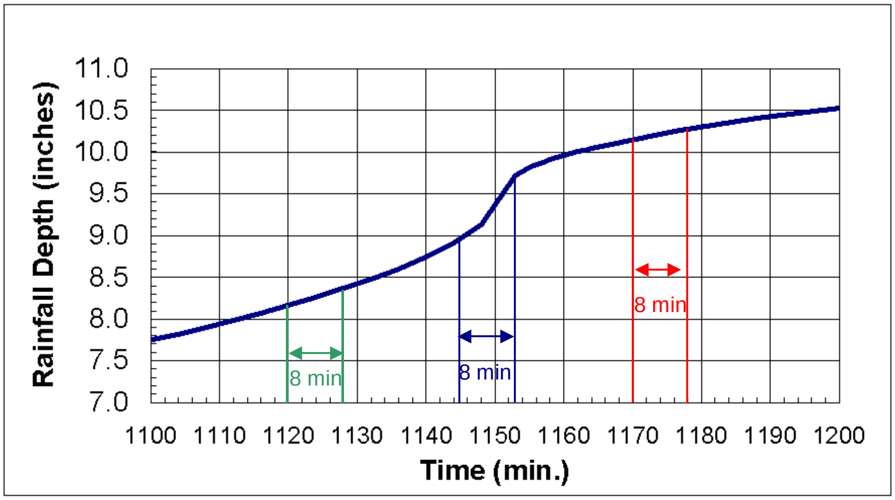

Figure 12.3.1
Subarea 1A Hyetograph With Calculation Points and T_C's Indicated

Figure 12.3.2 provides the C_u values for the three time steps of interest. From Figure 12.3.2, the undeveloped runoff coefficient for this intensity is 0.69.

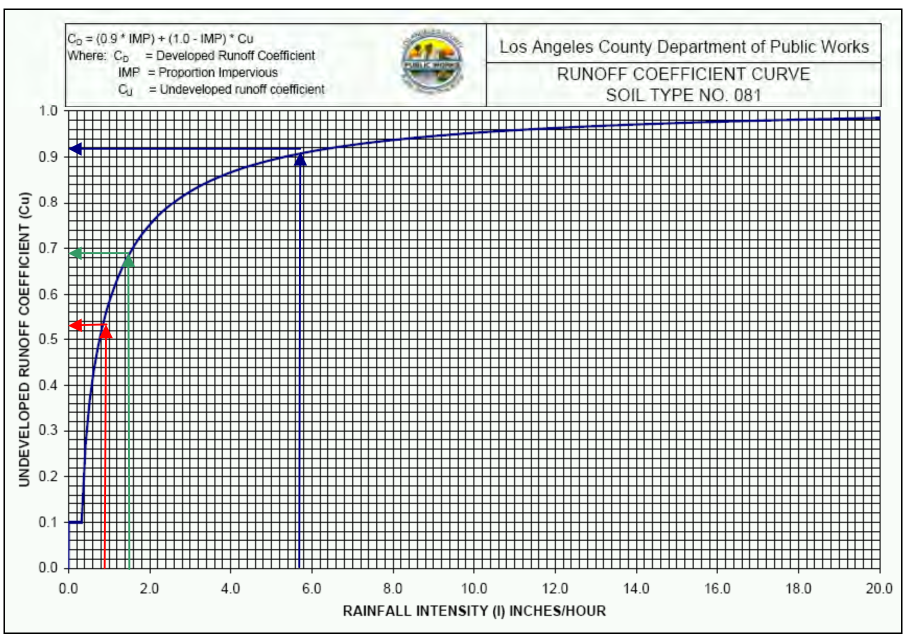

Figure 12.3.2
Soil Type 081 with Runoff Coefficients for 3 Time Steps Indicated.

Since this area has an imperviousness of 1%, the developed runoff coefficient as calculated using Equation 6.3.2 is also 0.69. The runoff for this time step is:

$$Q = C_d*I_t*A$$
$$= 0.69*1.52*67.7 = 71.0 \text{ cfs}$$

Table 12.3.1 shows the values used for the calculations at the end of each of the three time periods.

Table 12.3.1
Table of Runoff Calculations

Time (minutes) From	Time (minutes) To	Rainfall (in)	Intensity, I (in/hr)	Undeveloped Runoff Coefficient, C_u Fig. 7.3.3	Developed Runoff Coefficient, C_d Eq. 6.3.2	Area (acres)	Q = C_d *I*A (cfs)
1120	1128	0.20	1.52	0.69	0.69	67.7	71.0
1145	1153	0.76	5.71	0.90	0.90	67.7	348.0
1170	1178	0.12	0.89	0.53	0.53	67.7	23.52

Figure 12.3.3 shows the hydrograph made by connecting these points and assuming no flow at the start or end of the day. The shape would be further defined by calculating runoff at additional time increments.

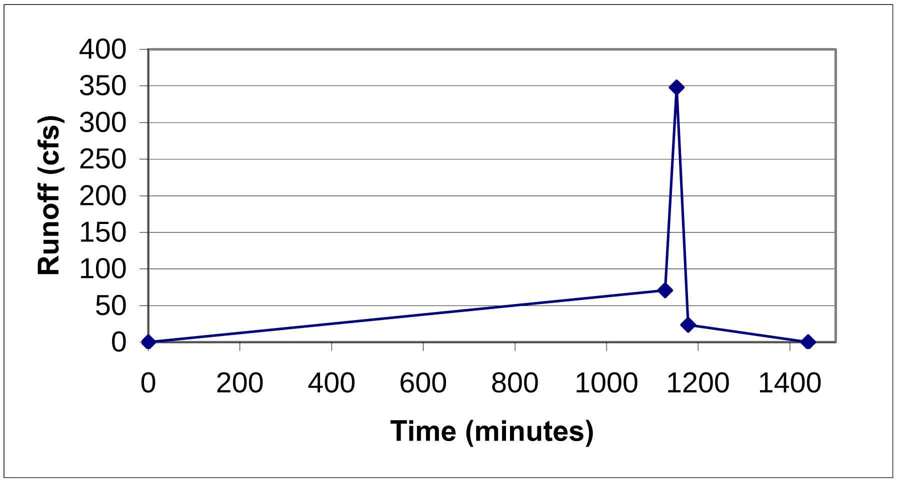

Figure 12.3.3
Hand Calculations Hydrograph for Subarea 1A

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Figure 12.3.4 shows the hydrograph defined using 1-minute time shifts throughout the 24-hour time period.

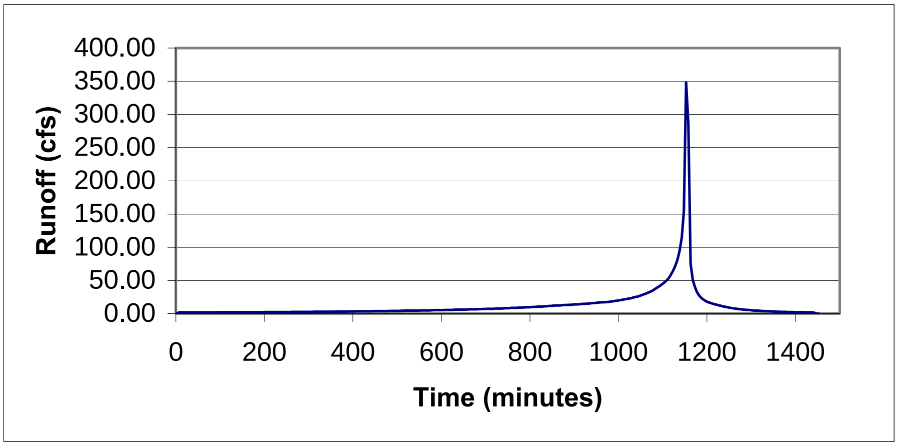

Figure 12.3.4
Subarea 1A Hydrograph, Using 1-minute Time Shifts

The hydrographs produced from successive subareas or laterals are routed and combined to produce hydrographs for successively larger watersheds. Section 7.3 describes the hydrologic routing process. The hydrographs are subjected to routing time lags and attenuation. The flow values for each time increment from all the hydrographs are added together. This hydrograph superposition allows large watersheds to be modeled using the modified rational method.

Table 12.3.2 compares the peak outflow from the Palmer Canyon watershed created by combining hydrographs peak-to-peak and hydrograph superpositioning for each time period. As shown, combining peak-to-peak always results in higher peak flow rates than hydrograph superposition after routing and channel storage.

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Table 12.3.2
Comparison of Peak Watershed Outflow using Peak-to-Peak Combination and Hydrograph Superposition

Method		Rational	Modified Rational
Flow Combination		Peak-to-Peak	Hydrograph Superposition
Subarea Id	Area (acres)	Total Q (cfs)	Total Q (cfs)
1A	67.7	350.3	350.3
3A	47.7	497.2	475.0
4A	82.9	821.6	799.4
6A	62.5	1,060.8	1,004.5
8A	31.5	1,177.7	1,092.3
9B	57.7	264.5	264.5
11B	60.8	498.2	490.0
13B	65.6	749.3	716.3
15B	48.9	924.0	836.6
16AB	233.0	2,101.7	1,928.4
17A	69.3	2,311.5	2,088.2
19A	46.0	2,448.4	2,173.2
Total	640.6	2,448.4	2,173.2

Figure 12.3.5 is the modified rational method hydrograph for the entire Palmer Canyon watershed.

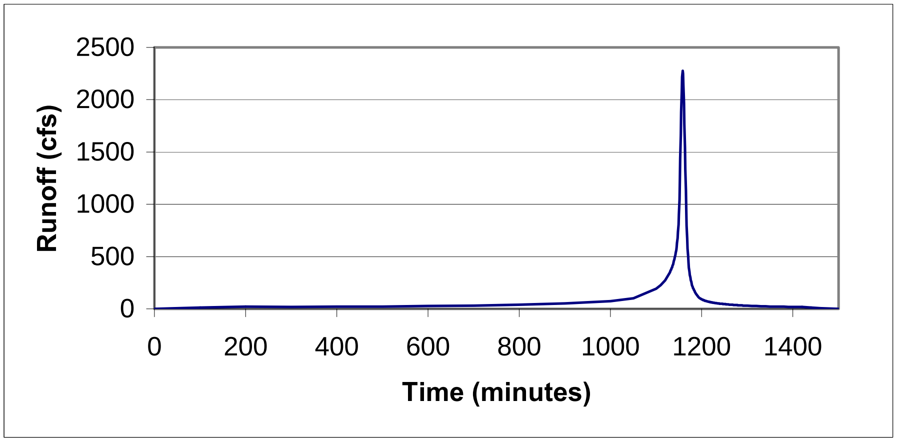

Figure 12.3.5
Modified Rational Method Hydrograph at Outlet of Palmer Canyon Watershed

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Hand calculations for hydrographs, hydrograph routing, and superposition require a lot of time and careful organization. The calculations are ideally suited for computer programming and have been included in several software packages. Use of this software is encouraged to reduce the time required to reach a solution. Chapter 15 contains a list of software for Modified Rational Hydrology Studies within the County of Los Angeles.

Figure 12.3.6 is a view of the Palmer Canyon watershed used in the previous example.

Figure 12.3.6
Palmer Canyon Watershed
November 2003

CHAPTER

13

Classification of Hydrologic Models

13.1 EVENT VERSUS CONTINUOUS MODELS

Hydrologic models are divided into two categories: event or continuous models. Models that calculate runoff from a single storm lasting up to several days are called event models. The Los Angeles County Modified Rational Method model is an *event* model. Models that account for changes in the watershed over a long period of time and through several storm events are called *continuous* models. The Stanford Model and its descendant Hydrologic Simulation Program – Fortran (HSPF) are examples of continuous models. It is important to understand the differences between these types of models.

Hydrologists and engineers typically use event models to calculate runoff from a design storm event. This event may last from several hours to several days with nearly continuous rain. Event models lack mechanisms to account for changes over time in watershed conditions such as soil moisture. Event models must therefore use assumed watershed conditions. These assumptions work well for specific design criteria, but do not provide adequate results for longer periods. Watershed conditions may change between storms and through dry periods due to infiltration, evaporation, and transpiration. Watersheds also change over longer periods due to fire, construction, and changes in land uses. Event models have the advantage of being relatively simple to create and run.

Continuous models attempt to represent the effect of soil moisture and processes such as evaporation, transpiration, and flow through the subsurface on the runoff process. Continuous models account for changes in watershed characteristics at each time period and are suited to modeling runoff over long periods. Continuous model inputs require several months or years of historic data that contain most expected watershed conditions. The increased data requirements over event based models make the continuous models more complex to develop and calibrate. The spatial and temporal

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variation of parameter values for soil infiltration rates, soil moisture capacity, evaporation rates, and rainfall are required. Table 13.1.1 contains examples of event and continuous models. The table also lists some of the parameters required by the models.

Table 13.1.1
Comparison of Event and Continuous Models

Model Type	Rainfall Input	Data Requirements	Examples
Event	Design Storm	Soil runoff characteristics, land use data, relevant rainfall duration.	HEC-HMS, SWMM, Modified Rational
Continuous	Historic Data or Design Storms	Land use, detailed soil and vegetation information, seasonal data, time series data including rainfall, runoff, evaporation, temperature, etc..	Stanford Model, HSPF, SWMM

13.2 LUMPED AND DISTRIBUTED PARAMETER MODELS

The Los Angeles County Modified Rational Method is classified as a lumped parameter model because parameters influencing runoff are lumped together and assumed uniform for each subarea. The model uses a combination of physical and analytical relationships to model runoff response to a rainfall design storm. Subareas are defined with reference to the drainage pattern of the watershed. Properties of a subarea such as rainfall, imperviousness, and soil properties are lumped for the entire subarea. Lumped parameter models usually require less data that is easier to obtain or estimate.

The alternative to a lumped parameter model is a distributed model. Instead of breaking up the watershed using drainage boundaries, a distributed model represents the properties of a watershed using small grid cells. These regularly spaced cells are assigned unique properties, reducing the simplification that occurs when parameters are lumped at the subarea level. Distributed modeling is compatible with watershed data inputs such as radar rainfall and soil moisture accounting. Distributed models generally require more data that may not be readily available.

CHAPTER 14

Divisions With Hydrologic and Hydraulic Responsibilities

In addition to the Water Resources Division, several divisions within the Los Angeles County Department of Public Works have responsibilities associated with hydrology and hydraulics. The divisions that provide these services are listed below along with key responsibilities that relate to hydrology and hydraulics.

14.1 BUILDING AND SAFETY DIVISION

The primary function of Building & Safety is the enforcement of Los Angeles County Building, Plumbing, Mechanical, and Electrical Codes, as well as other local and State requirements relevant to the construction and occupancy of public and private structures. The Division provides this enforcement through plan checking and inspection of new commercial and residential construction. The County's unincorporated area and 21 contracted cities are served by 25 branch or city inspection offices and a central administrative office. The Drainage and Grading Section provides the following services related to hydrology and hydraulics:

Hydrology Review Includes:

- Reviewing hydrologic studies for single lot residential and commercial projects based on Public Works' standards. The review identifies flood hazards due to inundation, overflow, or debris, and verifies that the appropriate levels of protection exist against these hazards.

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- Verifying single lot residential and commercial project compliance with the Department's National Pollution Discharge Elimination System (NPDES) permit, including the enforcement of Standard Urban Stormwater Mitigation Plan (SUSMP) compliance.

- Verifying that post-development flow rates in watercourses adjacent to the development are no greater than pre-development flow rates.

Hydraulics Review Includes:

- Reviewing proposed drainage facilities and storm drains for capacity, appropriate levels of protection, and negative impacts on existing drainage systems.

- Checking pre- and post-development flows, velocities, and flow areas at the upstream and downstream of proposed single lot residential and commercial projects to verify that no negative impacts, including diversions, are created.

- Enforcing compliance with the National Flood Insurance Program (NFIP), including FEMA and County floodplain and floodway regulations.

- Reviewing hydraulic models of floodway and flood plain encroachments to determine development requirements and effects to upstream and downstream properties.

Grading Review Includes:

- Verifying that grading plans for single lot residential and commercial projects do not affect off-site areas negatively in terms of hydrology or debris production.

- Verifying compliance with the Department's NPDES permit by reviewing grading plans and inspecting the installation of required BMP's.

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14.2 CONSTRUCTION DIVISION

The Construction Division is responsible for the administration and inspection of Public Works construction contracts; inspection of subdivision improvements; issuance and inspection of permits for road, drainage, and sewer projects; and utility coordination. In addition, the division awards and administers contracts to clean approximately 70,000 catch basins during the late summer months prior to each rainy season. Cleaning the basins improves storm water quality by minimizing the amount of debris that would otherwise flow through the storm drains and into the ocean. Construction Division's Permits and Subdivisions Section hydrology related responsibilities include:

- Confirming hydrology of tributary area and check the drainage area map of a proposed site with the existing sub-area map.

- Checking hydrology calculations using Public Works' standards. Check Design Hydrology peak flow rate and T_C calculations using the Public Works' T_C calculator.

- Submitting requests to Water Resources Division to perform hydrologic studies for the areas of interest, when no hydrologic study is available.

- Verifying that the allowable discharge flow rate, $Q_{Allowable}$ (cfs/acre), for the existing subarea has been obtained from Design Division.

- Comparing design hydrology with the system design hydraulics and requiring that any connections are designed based on the smaller value.

- Reviewing permit applications and construction projects for impacts of water releases into flood control facilities and coordinating with Water Resources Division on operational activities of Public Works' facilities.

14.3 DESIGN DIVISION

Design Division is responsible for preparing contract drawings, cost estimates, and specifications for Public Works' new construction, repair, retrofit, and rehabilitation projects. Projects include streets and highways, bridges, storm drains, water and sewer lines, debris control facilities, pumping plants, and facilities appurtenant to dams. The division also lends technical design support to other agencies and the public, and it publishes its *Standard Plan Manual* and *Standard Specifications Book* for construction contractors. The Design Division's Hydraulic Analysis Unit has the following duties:

- Providing the allowable discharge flow rate, $Q_{Allowable}$ (cfs/acre), which is the maximum discharge allowed for new connections to a drainage facility. The $Q_{Allowable}$ is based on the design hydrology study and any hydraulic capacity limitations of the subject drain or the downstream connecting system(s).

- Providing hydrologic data/information from facility design hydrologic studies including: the design storm frequency, scale-down factors, sub-area acreage, peak flow rates (including specific catch basin design subarea acreage and flow rates), and design reach peak flow rates throughout the system.

- Providing hydrology maps that graphically outline the limits of all subareas within the facility drainage area. Each subarea is individually identified with a corresponding number from the design hydrology study, as well as the acreage and peak flow rate.

- Providing hydraulic analysis calculations for drainage facilities. These include the hydraulic calculation sheets or Water Surface Pressure Gradient (WSPG) output data with the design flow rate, velocity, and hydraulic grade line (H.G.L.) or water surface elevation (W.S.E.) at various locations throughout the system. A WSPG hydraulic calculation for a proposed connection to a drainage facility must be based on the facility design H.G.L. or W.S. E. at the point of connection.

- Providing conceptual review on the preliminary hydraulic design of projects involving connections to, or modifications/realignment of, a drainage facility. The conceptual review determines the hydraulic,

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hydrologic, and/or structural feasibility of the proposal prior to proceeding with the design.

14.4 ENVIRONMENTAL PROGRAMS DIVISION

The Environmental Programs Division is responsible for five major environmental programs within the County: Hazardous Material Underground Storage Tank (UST) Regulation; Solid and Hazardous Waste Management Planning and Implementation; Stormwater Discharge/Water Quality Monitoring and Control; Industrial Waste Control; and administration of the County's Garbage Disposal Districts. In addition, Environmental Programs provides technical support and advice for County recycling, composting, and hazardous waste programs, reviews road and utilities improvement plans relative to sanitary sewers, reviews building construction plans for the Methane Gas Intrusion Protection System, and provides waste management advice and coordination. Environmental Program's specific hydrologic duties include:

- Reviewing SUSMP plans for non-residential projects within the Industrial Waste Unit's areas of jurisdiction. After the commercial or industrial developer receives approval of the peak mitigated flow, "Q_{pm}", from the County Building and Safety, Land Development, or the local City Building & Safety office, the developer submits the approved "Q_{pm}" report and the required sets of plans to the Industrial Waste Unit. A permit application and fees for plan checking and permit processing are required. See the website http://www.ladpw.org/epd/industrial_waste/index.cfm for more information.

- Checking the storm water treatment devices and post-BMPs for suitability to the "Q_{pm}" and the site's storm water constituents. The approved storm water treatment devices are placed under a SUSMP permit.

- Inspecting storm water treatment devices to ensure that the devices are properly maintained.

14.5 LAND DEVELOPMENT DIVISION

Land Development Division is responsible for plan reviews and approval of all types of Public Works' infrastructure and final maps as part of the land development subdivision process. These subdivisions range in size from two lot parcel maps to 12,000-acre master plan communities including residential, commercial, and industrial development. In addition, this Division reviews and approves proposals to comply with storm water quality requirements of the Regional Water Quality Control Board. Land Development Division's responsibilities regarding hydrology are:

Hydrology Review Includes:

- Reviewing development plans to determine if on-site hydrology meets Public Works' standards.
- Checking SUSMP compliance and requiring use of BMPs during and after construction.
- Checking for required debris control structures for areas upstream of tracts and on-site locations.
- Checking post-development flow rates in adjacent watercourses to ensure that they do not exceed pre-development flow rates.

Hydraulics Review Includes:

- Reviewing proposed on-site drains for capacity, maintenance issues, and adequate downstream capacity. Ensuring that appropriate levels of protection exist.
- Checking pre- and post-development flows, velocities, and flow areas at the upstream and downstream tract boundaries to prevent negative off-site impacts.
- Enforcing floodplain and floodway regulations.
- Reviewing HEC-RAS models of floodway encroachments for compliance with regulations to prevent negative effects to the upstream and downstream areas.

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Grading Review Includes:

- Reviewing grading plans to ensure that topographic changes do not affect off-site areas negatively in terms of hydrology or debris production.

14.6 WATERSHED MANAGEMENT DIVISION

Watershed Management Division is responsible for planning and implementing watershed management projects that protect the County's residents from flooding while integrating the elements of natural resources, groundwater, and stormwater conservation, improved stormwater runoff quality, and socio-economic, environmental, and recreational features. Watershed Management's hydrologic responsibilities include:

- Providing Flood Zone determinations for the public and lending institutions.

- Interpreting Flood Insurance Rate Maps (FIRMs) and identifying flood zone designations for properties and construction projects.

- Processing Letters of Map Revision (LOMR) and Conditional Letters of Map Revision (CLOMR).

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CHAPTER

15

Computer Programs for Use in Los Angeles County Hydrologic Studies

Computer programs are powerful tools that simplify hydrologic computations. Several hydrologic software packages include the Los Angeles County Modified Rational Method. The software packages listed in Table 15.1 have been reviewed for use in hydrologic studies within the County of Los Angeles. The table provides contact information for purchasing the software and provides a brief description of approved uses for the software.

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Table 15.1
Approved Computer Programs

Name	Version	Description	Publisher
Watershed Modeling System (WMS)	7.1 and later	Implements the Modified Rational Method with reservoir routing and optional GIS capability	Environmental Modeling Systems www.ems-i.com 1-801-302-1400
XP-SWMM	9.0 and later	Implements the Modified Rational Method with some enhancements and the ability to model hydraulics and water quality	XP Software www.xpsoftware.com 1-888-554-5022
HEC-HMS	2.2.2 and later	Physically based, single event model can be used for reservoir routing.	Corps of Engineers Hydrologic Engineering Center www.hec.usace.army.mil
LAR04		Implements the Modified Rational Method	Civildesign Corp www.civildesign.com 1-909-885-3806
RETARD		Performs reservoir routing using the Modified Puls method.	Civildesign Corp www.civildesign.com 1-909-885-3806
TC_calc_vol.xls TC_calc_depth.xls		Implements the Modified Rational Method into calculations for single subareas and small watersheds.	LA County Dept. of Public Works www.ladpw.org

15.1 WATERSHED MODELING SYSTEM (WMS)

Watershed Modeling System (WMS) is a hydrologic modeling software that incorporates many standard hydrologic models. A key capability of WMS is the extraction of model input parameters from GIS data such as DEMs, TINs, and shapefiles. The program also allows use of georeferenced images for

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backgrounds. WMS is modular and pricing is based on the number of modules purchased.

The Los Angeles County Modified Rational Method has been fully implemented in WMS. This implementation maintains the functionality of the prior F0601 code with several useful additions. WMS includes a graphical user interface to the model which facilitates data input and model creation. Reservoir routing, automatic T_C calculation, and automatic burned watershed simulations are recently added features.

15.2 XP-SWMM

The Storm Water Management Model (SWMM) is widely used to model storm drain systems. The United States Environmental Protection Agency (EPA) maintains this model. XP-SWMM is a Windows based interface for the SWMM model developed by XP Software.

XP-SWMM version 9.0 allows for the simulation of runoff, water quality, and hydraulic routing using the Los Angeles County Modified Rational Method. The XP-SWMM software has a graphical interface with the Modified Rational Method. Reservoir routing, automatic T_C calculation, and automatic burned watershed simulations are included features. A scenario manager also allows simultaneous simulation of multiple design storms. Future upgrades of XP-SWMM plan to include GIS capabilities.

15.3 HEC-HMS

HEC-HMS was developed by Hydrologic Engineering Center (HEC), Corps of Engineers. HEC-HMS does not support the Modified Rational Method. However, HEC-HMS was adopted as a replacement for the Mountain Hydrology Method (Q-S Method)[1]. Currently, Public Works uses HEC-HMS to model debris basins and dams.

15.4 LAR04/RETARD

The LAR04 program is a modified version of Public Works' F0601 program. The modifications include changing the program to a Windows console program, adoption of the latest soil and rainfall data files distributed by Public

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Works, and user options to select output data for design storms ranging from 2-year to 500-year events. There is also the option to output data in metric units, include volume calculations with hydrographs and, an input option for areas as small as 0.1 acres.

LAR04 is a text-based implementation of the Modified Rational Method similar to F0601. This program uses the Los Angeles County Flood Control District program source code for the F0601 series programs. It also includes an independent program module, which assists the user in preparing an input data file for use by the F0601 program.

The RETARD program reads F0601 hydrographs, up to a 4-day storm series, and performs detention basin calculations using the Modified Puls, or storage indication method. The resulting outflow hydrograph may be inputted into the LAR04/F0601 program.

15.5 T_C CALCULATOR

The T_C Calculator may be used to calculate runoff and runoff volumes for small subareas and for small watersheds. Since it has no routing capabilities, use for watersheds larger than 100 acres is discouraged because routing alters peak flows and changes timing. These changes normally reduce flow rates in a storm drain system.

[1] Los Angeles County Department of Public Works Hydrology Manual, 1982, page C-9

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APPENDIX A

Design Storm Unit Hyetograph

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APPENDIX B

Hydrologic Maps

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APPENDIX D

Proportion Impervious Data

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LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS

Acknowledgement Best Management Practices (BMP) Attachment

DATE: ______________________ PERMIT NO. ______________________

OWNER/APPLICANT: ______________________ PHONE: ( ) ________

PRINT NAME **WET SIGNATURE (REQUIRED)**

ADDRESS: ____

STREET CITY ZIP CODE

FAX: ( ) ________ CELL: ( ) ________ EMAIL ADDRESS: ________________

AGENT/CONTACT: ______________________ PHONE: ( ) ________

PRINT NAME **WET SIGNATURE (REQUIRED)**

ADDRESS: ____

STREET CITY ZIP CODE

FAX: ( ) ________ CELL: ( ) ________ EMAIL ADDRESS: ________________

hereby acknowledges reading, understanding, and agreeing to comply with the Best Management Practices (BMP) Attachment in accordance with Los Angeles County Code Chapter 12.80 Stormwater and Runoff Pollution Control.

SITE ADDRESS:____

Street City Zip Code

NEAREST INTERSECTION:______________________________THOMAS GUIDE:____________

PLEASE SUBMIT THIS DOCUMENT WITH THE APPLICATION

Best Management Practices (BMPs) Attachment

The Los Angeles County Department of Public Works (LACDPW) requires Permittees and their contractors to implement a program to effectively control water pollution during all Permit construction projects. This project shall conform with the requirements of the following County Code and Permits:

- Los Angeles, California County Code Chapter 12.80 Stormwater and Runoff Pollution Control
- Waste Discharge Requirements for Municipal Storm Water and Urban Runoff Discharges within the County of Los Angeles, and the Incorporated Cities Therein, Except the City of Long Beach (Order No. 01-182, National Pollutant Discharge Elimination System [NPDES] No. CAS004001),
- NPDES General Permit No. CAS000002, Order No. 99-08-DWQ, Waste Discharge Requirements for Discharges of Storm Water Runoff Associated with Construction Activities.

The Permittee or Authorized Representative and their contractors shall know and fully comply with the applicable provisions of these permits and Federal, State and local regulations that govern the Permittee or Authorized Representative's operations and the storm water discharges from the project site.

In order to ensure a minimum level of water quality control, the Permittee or Authorized Representative and their contractors shall effectively implement and maintain appropriate Best Management Practices (BMPs) shown in Table 1. In addition, the Permittee or Authorized Representative and their contractors shall comply with the following requirements:

- Sediments shall not be discharged to the storm drain system or receiving waters. Sediments generated on the construction site shall be retained.
- No construction-related materials: waste, spills, or residue shall be discharged from the project site to streets, drainage facilities, receiving waters, or adjacent property by wind or runoff.
- Non-storm water runoff from equipment, vehicle washing, or any other activity shall be contained within the project site using appropriate BMPs.
- Erosion from slopes and channels shall be prevented.
- Minimize grading during the wet season (October 15 through April 15). All erosion susceptible slopes shall be covered, planted, or protected in any way that prevents sediment discharge from the project site.

BMPs shall conform to the requirements in the LACDPW Construction Division's "Construction Site Best Management Practices (BMPs) Manual," and addenda thereto issued up to and including, the date of issuance of the Permit for the project. Copies of the Manual are available for purchase from:

Los Angeles County Department of Public Works
Cashier's Office
900 South Fremont Avenue
Alhambra, CA 91803
Telephone (626) 458-6959

Year-Round Implementation Requirements

The Permittee or Authorized Representative and their contractors shall have an effective program for implementing, inspecting, and maintaining water pollution control practices for wind erosion control, tracking control, non-storm water control, and waste management and materials pollution control.

Soil stabilization and sediment control practices shall be provided throughout the rainy season, defined as between October 15 and April 15, and whenever the National Weather Service predicts rain within 24 hours. The National Weather Service weather forecast shall be monitored and used by the Permittee on a daily basis.

The non-rainy season shall be defined as all days outside the defined rainy season. Disturbed soil areas within the project shall be protected in conformance with the requirements in the Construction Site BMP Manual with sediment controls implemented prior to a predicted rain event.

Maintenance and Inspection

The Permittee or Authorized Representative and their contractors shall be responsible throughout the duration of the project for installing, constructing, inspecting, maintaining, removing and disposing of the BMPs. Unless otherwise directed by LACDPW, the Permittee or Authorized Representative and their contractors are responsible for BMP implementation and maintenance throughout any temporary suspension of work. The Permittee or Authorized Representative shall reimburse LACDPW for the full costs of cleaning or repairing of storm drain, water course, or channel which may be necessary due to ineffective implementation of BMPs.

The project site shall be inspected by the Permittee or Authorized Representative or their contractors a minimum of once every week or at least once for projects that last only one week or less.

Report of Non-Permitted Discharge and Enforcement

If the Permittee or Authorized Representative or their contractors identify any non-permitted discharge into the storm drain system or receiving waters in a manner causing, or potentially causing, a condition of pollution, or if the project receives a written notice or order from any regulatory agency, the Permittee or Authorized Representative or their contractors shall immediately inform LACDPW Construction Division Permits Section by calling the assigned Field Office. The Permittee or Authorized Representative or their contractors shall submit a written report (see attached Notice of Non-Permitted Discharge) to the LACDPW within 5 days of the discharge event, notice or order.

The Permittee or Authorized Representative and their contractors are subject to enforcement action by Chapter 12.80 of the Los Angeles County Code that states, "*Any person, firm, corporation, municipality or district or any officer or agent of any firm, corporation, municipality or district violating any provision of this chapter shall be guilty of a misdemeanor. Such violation shall be punishable by a fine of not more than $1,000 or by imprisonment in the county jail for a period not to exceed six months, or by both fine and imprisonment. Each day during any portion of which such violation is committed, continued or permitted shall constitute a separate offense and shall be punishable as such (Ord. 98-0021§1(part), 1998).*"

In addition, the Permittee or Authorized Representative and their contractors are subject to enforcement action by the State Water Resources Control Board (SWRCB), Environmental Protection Agency, private citizens and citizen groups. The Permittee or Authorized Representative and their contractors shall be responsible for the costs and for liabilities imposed by law as a result of the Permittee or Authorized Representative or their contractor's failure to comply. Costs and liabilities include, but are not limited to, fines, penalties and damages whether assessed against LACDPW or the Permittee or Authorized Representative or their contractors, including those levied under the Federal Clean Water Act and the State Porter Cologne Water Quality Act.

Table 1
Construction Site BMPs

ID	BMP Name	Minimum Requirement(1)
Temporary Soil Stabilization		
SS-1	Scheduling	X(2)
SS-2	Preservation of Existing Vegetation	X(2)
SS-3	Hydraulic Mulch(3)	
SS-4	Hydroseeding(3)	
SS-5	Soil Binders(3)	
SS-6	Straw Mulch(3)	
SS-7	Geotextiles, Plastic Covers, & Erosion Control Blankets/Mats(3)	
SS-8	Wood Mulching	
SS-9	Earth Dikes/Drainage Swales & Ditches	
SS-10	Outlet Protection/Velocity Dissipation Devices	
SS-11	Slope Drains	
SS-12	Streambank Stabilization	
Temporary Sediment Control		
SC-1	Silt Fence(4)	
SC-2	Desilting Basin	
SC-3	Sediment Trap	
SC-4	Check Dam	
SC-5	Fiber Rolls(4)	
SC-6	Gravel Bag Berm(4)	
SC-7	Street Sweeping and Vacuuming	X(2)
SC-8	Sandbag Barrier(4)	
SC-9	Straw Bale Barrier(4)	
SC-10	Storm Drain Protection	X(2)
Wind Erosion Control		
WE-1	Wind Erosion Control	X(2)
Tracking Control		
TC-1	Stabilized Construction Entrance/Exit	
TC-2	Stabilized Construction Roadway	
TC-3	Entrance/Outlet Tire Wash	

Table 1 (continued) Construction Site BMPs		
ID	**BMP Name**	**Minimum Requirement**[1]
Non-Storm Water Management		
NS-1	Water Conservation Practices	
NS-2	Dewatering Operations[5]	
NS-3	Paving and Grinding Operations	
NS-4	Temporary Stream Crossing	
NS-5	Clear Water Diversion	
NS-6	Illicit Connection/Illegal Discharge Detection and Reporting	X[2]
NS-7	Potable Water/Irrigation	
NS-8	Vehicle Equipment Cleaning	X[2]
NS-9	Vehicle Equipment Fueling	X[2]
NS-10	Vehicle Equipment Maintenance	X[2]
NS-11	Pile Driving Operations	
NS-12	Concrete Curing	
NS-13	Material and Equipment Use Over Water	
NS-14	Concrete Finishing	
NS-15	Structure Demolition/Removal Over or Adjacent to Waters	
NS-16	Temporary Batch Plant	
Waste Management and Material Pollution Control		
WM-1	Material Delivery	X[2]
WM-2	Material Use	X[2]
WM-3	Stockpile Management	
WM-4	Spill Prevention and Control	X[2]
WM-5	Solid Waste Management	X[2]
WM-6	Hazardous Waste Management	
WM-7	Contaminated Soil Management	
WM-8	Concrete Waste Management	
WM-9	Sanitary/Septic Waste Management	X[2]
WM-10	Liquid Waste Management	

(1) Additional BMPs may be required based on actual field condition, Contractor operations, or construction operations.
(2) Not all minimum requirements may be applicable to every project. Applicability to a specific project shall be verified by the Permittee or Authorized Representative and their Contractor.
(3) The Permittee or Authorized Representative and their Contractors shall select one of the identified soil stabilization BMPs or a combination thereof.
(4) The Permittee or Authorized Representative and their Contractors shall select one of the identified sediment control barrier BMPs or a combination thereof.
(5) Dewatering BMPs are required for discharging accumulated precipitation (rain and snow melt) and for potential contact with groundwater during excavation. Separate permit requirements are applicable for construction dewatering of groundwater.

Notice of Non-Permitted Discharge

To: ____________________ **Date:** _____________

Subject: **Notice of Discharge**

Project Name:____

Permit Number:____

Date, time, and location of discharge:____

____

____

____

Type of operation that resulted in the discharge:_____________________________________

____

____

____

Describe any adverse impacts resulting from the discharge:______________________________

____

____

____

Describe existing BMP(s) in place prior to the discharge event:___________________________

____

____

____

Date and type of corrective action or BMPs deployed after the discharge:___________________

____

____

____

Proposed corrective actions to be taken to reduce, eliminate, and/or prevent recurrence of the discharge:____

____

____

____

Name of Contact Person	*Title*
Company	*Telephone Number*
Signature	*Date*

RB-AR33686

California Regional Water Quality Control Board

Los Angeles Region

Recipient of the 2001 *Environmental Leadership Award* from Keep California Beautiful

Linda S. Adams
Agency Secretary

320 W. 4th Street, Suite 200, Los Angeles, California 90013
Phone (213) 576-6600 FAX (213) 576-6640 - Internet Address: http://www.waterboards.ca.gov/losangeles

Arnold Schwarzenegger
Governor

December 15, 2006

Mark Pestrella, Assistant Deputy Director
Department of Public Works
County of Los Angeles
700 South Fremont Ave.
Alhambra, CA 91803

Directors, Department of Public Works and
Directors, Department of Planning
Municipal Permittees within County of Los Angeles

CLARIFICATION TO PART 4.D. DEVELOPMENT PLANNING PROGRAM, THE LOS ANGELES COUNTY MUNICIPAL STORM WATER PERMIT, ORDER No. 01-182, NPDES PERMIT No. CAS004001

Dear Mr. Pestrella and Municipal Directors:

Thank you for requesting clarification on the Development Planning requirements of the Los Angeles County Municipal Storm Water Permit (L.A. County MS4 Permit).

This letter restates the compliance expectation of the California Regional Water Quality Control Board, Los Angeles Region (L.A. Water Board), when it adopted the requirements in ‘Part 4 §D, Development Planning’ of the L.A. County MS4 Permit. Part 4.D contains specific provisions that are fully enforceable, and which were also contained in the Development Planning Model Program submitted by the L.A. County Permitees, and which was approved in 2000.

Our evaluation of the implementation of the Development Planning and Standard Urban Stormwater Mitigation Plan (SUSMP) requirements on land development projects in Los Angeles County has revealed that many Permittees’ planning and public works departments and their associated staff, including architects, planners and engineers have failed to integrate SUSMP implementation adequately with other storm water quality management strategies required in the L.A. County MS4 permit. The L.A. Water Board has identified several instances of inadequate or uncoordinated implementation by Permitttes for ‘Part 4.D Development Planning’.

U.S. EPA Guidance

In areas undergoing new development or redevelopment, the most effective method of controlling impacts from storm water discharges is to limit the amount of rainfall that is converted to runoff. By utilizing design techniques that incorporate on-site storage and infiltration, and minimizing the amount of directly connected impervious surfaces, the amount of runoff generated from the site can be significantly reduced (***Preliminary Data Summary of Urban Storm Water Best Management Practices***, EPA 821-R-99-012, August 1999).

The three provisions in Part 4.D are consistent with guidance in Chapter 5 of ***Preliminary Data Summary of Urban Storm Water Best Management Practices***. The U.S. EPA guidance states that in order to meet the goals of post-development peak discharge rate, volume and pollutant loading to receiving waters being the same as pre-development values, BMPs should be implemented to achieve three main objectives: flow control, pollutant removal and pollutant source reduction.

California BMP Manual

Similarly, Section 2.4 of the California Stormwater Quality Association (CASQA) BMP Handbook for Development and Redevelopment (2003), in its discussion on planning and design principles, reiterates the provisions in Part 4.D. These principles promote three basic strategies in the following order of preference based on effectiveness and costs: (1) reduce or eliminate post-project runoff; (2) control sources of pollutants; and (3) treat contaminated storm water runoff before discharging it to natural water bodies.

Groundwater Quality Protection Concern

Some Permittees have expressed a concern that infiltration of storm water may present risks to groundwater aquifers. Generally, the common pollutants in storm water are filtered or adsorbed by soil, and unlike hydrophobic solvents and salts, do not cause groundwater contamination. In any case, infiltration of 1-2 inches of rainfall in semi-arid areas like Southern California where there is a high rate of evapo-transpiration, presents minimal risks.

The Water Augmentation Study conducted by the Los Angeles and San Gabriel Rivers Watershed Council, in partnership with several agencies including water districts, municipalities, and the U.S. Bureau of Reclamation, indicates that the infiltration of storm water, with appropriate pretreatment, does not adversely impact groundwater quality (***Los Angeles Basin Water Augmentation Study, August 2005***). You may view the study at www.lasgrwc.org/WAS.htm

Infiltration of storm water discharges from heavy industrial areas is seldom appropriate. Where there is a real concern on the risk of groundwater contamination from preexisting soil contamination or heavy vehicular traffic when installing infiltration systems such as extended detention basins, the L.A. Water Board and the California Department of Transportation (Caltrans) developed guidance to ensure an adequate analysis for proper siting. See, ***Infiltration Basin -Site Selection Study, Volumes I, II, and III*** June 2003, CTSW-RT-03-025**,** http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/index.htm

Caltrans research indicates that infiltration basins and biofiltration BMPs are technically feasible if site site-specific considerations are taken into account (Caltrans CTSW-RT-01-050, ***BMP Retrofit Pilot Program, January 2004***).

Background of MS4 Development Planning Requirements

Standard Urban Storm Water Mitigation Plan

On March 8, 2000, the L.A. Water Board adopted the SUSMP, and required that municipalities incorporate into the planning and design phases post-construction storm water mitigation controls for specified development and redevelopment projects. Although the SUSMP action was petitioned by some municipalities to the State Water Resources Control Board (State Water Board), the State Water Board directed in Water Quality Order 2000-11 that, ***"the Permittees shall amend codes, if necessary, not later than January 15, 2001, to give legal effect to the SUSMP requirements. The SUSMP requirements shall take effect not later than February 15, 2001."***

On November 7, 2003, the L.A. Water Board transmitted the Development Planning Program Review Report after auditing four Permittee Programs (the Planning Review Report). The Planning Review Report presented and described discernible permit violations, deficiencies, and notable elements observed during the audit. Notably, the MS4 Development Planning program contained in Board Order No. 01-182 is built upon programs already established in previous Board Orders (90-079 and 96-054), after undergoing a very long process of public hearings and meetings before permit adoption.

Nearly six years later after the SUSMP was adopted, most Permittees' implementation of SUSMPs is deficient, because Permittees have not focused nor emphasized water quality pollution mitigation to protect the beneficial uses of receiving waters.

Consequently, the L.A. Water Board provides the following clarification consistent with the L.A. Water Board's mission of protecting water quality and preserving water resources:

A. Essential Post Construction Control Requirements

1. The three provisions in Part 4.D are the essential requirements for compliance with the Development Planning requirements of the L.A. County MS4 Permit. The three provisions are to: (1) maximize the percentage of pervious surfaces to allow percolation of storm water into the ground; (2) minimize the quantity of storm water directed to impervious surfaces and the MS4; and (3) minimize pollution emanating from parking lots through the use of appropriate treatment control BMPs and good housekeeping practices.

The basic site design planning considerations for post-construction storm water BMP implementation are to:

a. Preserve the natural drainage system, protect slopes and provide controls for stream protection. These controls are achieved through the basic control measures that include infiltration, retention/detention, bioretention and biofilters;

b. Integrate fully the opportunities to maximize the percentage of pervious surfaces and minimize the volume of storm water runoff;

c. Utilize a BMP treatment-train that (i) captures and infiltrates using infiltration basins, infiltration trenches, retention and/or detention BMPs; and/or (ii) provide flow through treatment in the order of preference for the prescribed storm water quality runoff volume **(Q_{wv})** based on the numerical mitigation criteria in Part 4.D;

d. Identify the combination of BMP treatment trains that are to be sized, designed and constructed based on **Q_{wv}** required for water quality. Using **Q_P** from 10, 20, or 50-year return-period for flood management is inappropriate for water quality purposes and not cost effective. Capturing and treating a larger percentage of the annual storm water runoff volume greater than **Q_{wv}** provides only a small increase in additional removal of pollutants and considerably increases the sizing and cost of the structural and treatment storm water controls; and

e. Establish in addition, for downstream channel protection, instead of **Q_P** a flow control criteria (Q_{HMC}) which takes into consideration flow volume, duration, and frequency to maintain the predevelopment distribution of in-stream flows above the critical flow for streambed erosion, thus preserving the pre-development capacity to transport sediment, while not accelerating down stream erosion. An appropriate hydromodification flow duration control criteria might be to set the Q_{HMC} such that the post-construction discharge rates and duration match the ranges from 10 percent of the pre-development 2-year 24 hour peak flow up to the pre-development 10 year 24 hour peak flow, unless an alternative criterion can be demonstrated as equally protective using hydrodynamic modeling.

2. <u>Measures and Approaches for Minimizing Impervious Surface Area</u>

a. Permittees must minimize the percentage of impervious surfaces to support the percolation and infiltration of storm water into the ground and/or minimize pollutants emanating from impervious surfaces by reducing the percentage of effective impervious area to a generally accepted standard of 5 percent or less of total project area.

The U.S. EPA storm water technology fact sheet for bioretention recommends that sizing criterion should be 5 to 7 percent of the drainage area multiplied by the rational method runoff coefficient "C" determined for the site (***Storm Water Technology Fact Sheet, Bioretention***, U.S. EPA Document No. EPA 832-F-99-012, September 1999). However, a lower sizing criterion may be more appropriate for

Southern California. A recent study determined that physical degradation of stream channels in semi-arid climates such as in Southern California may be detectable with watershed impervious cover between 3 and 5 percent (***Effects of Increases in Peak Flows and Imperviousness on the Morphology of Southern California Stream,*** SCCWRP, April 2005).

b. Permittees must also control pollution emanating from impervious surfaces such as roof-tops, parking lots, and roadways through the use of appropriate source controls such as the use of low impact development (LID) and integrated water resources management strategies that:

1. Emphasize conservation and the use of on-site natural features;
2. Integrate engineered small-scale hydrologic controls to more closely reflect pre-development hydrologic functions. Small-scale hydrologic controls are BMPs that create green infrastructure and spaces such as park-like open space, rainwater collection barrels, planter boxes, and garden-like areas that promote community awareness and improve storm water quality; and
3. Implement primarily a source control and minimize the need for large sub-regional and regional treatment control BMPs.

B. <u>Plan Preparation/ Review Procedures and Guidelines</u>

1. Permittees must possess clear and adequate legal authority in municipal storm water ordinances to address post-construction requirements in the L.A. County MS4 Permit. The legal authority must direct land developers to review and mitigate the adverse storm water quality impacts in the Environmental Impact Report (EIR), and to ensure that adequate post-construction control measures are incorporated during the development project's site planning and design phases. In addition, clear instructions should be provided on how to illustrate on plans the BMPs selected, adequate sizing, and BMP siting;

2. The selection of the treatment train of BMPs must be conducted through a methodical selection process that matches the type of BMP with the type and nature of pollutants that are expected to be generated from the site. For example, vortex separation devices installed in high commerce areas for removing trash and gross solids are not suitable for removing pollutants in dissolved state or smaller size/lighter weight fractions from vehicular traffic areas;

3. Permittees should also prescribe guidelines for the submittal of standard final SUSMP plans so that relevant storm water BMP locations and specifications in design sheets are clearly identified. Separate SUSMP detail plan sheets will facilitate technical review.

   Delineation of drainage area and/or sub-areas, natural drainage systems, storm drains, and other relevant parameters at pre-development and post-development water flow paths, outfall (drainage) locations, BMP detail plans, and other relevant information should be presented. Simply inserting post-development plans within the grading plans, storm drain plans, or civil plans with unrelated detail drawings, numbers, and

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construction notes makes it difficult to review and evaluate. Small-scale controls may be combined with the landscaping plans;

4. Plan view and sectional plans for small-scale hydrologic controls for a lot size and sub-drainage area of the sites should be prescribed; and

5. BMP design specifications must be incorporated in the SUSMP report together with hydrologic calculations for sizing BMPs. This report should support and show how criteria were adequately utilized in sizing BMPs (e.g., infiltration, retention/detention BMPs, bioretention facilities, etc.);

If you have any questions, please call Dr. Xavier Swamikannu at (213) 620-2094 or Carlos D. Santos at (213) 620-2093.

Sincerely,

Original Signed

Jonathan Bishop, P.E.
Executive Officer

cc: Michael Levy, Office of the Chief Counsel, State Water Board
Darrin Polhemus, Division of Water Quality, State Water Board
Bruce Fujimoto, Division of Water Quality, State Water Board

RB-AR33692



Low Impact Development Manual for Southern California:

Technical Guidance and Site Planning Strategies

Prepared for

the Southern California Stormwater Monitoring Coalition

in cooperation with the State Water Resources Control Board

By

The Low Impact Development Center Inc


RB-AR33693

April 2010

Prepared for the Southern California Stormwater Monitoring Coalition, in cooperation with the State Water Resources Control Board, by the Low Impact Development Center, Inc.

Southern California STORMWATER MONITORING Coalition

CALIFORNIA Water Boards

STATE WATER RESOURCES CONTROL BOARD

REGIONAL WATER QUALITY CONTROL BOARDS

The Low Impact Development Center, Inc.

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Executive Summary

Southern California is facing increased demands from urbanization, which can create adverse impacts to water quality and quantity. Urban areas can discharge polluted runoff and degrade alluvial channels. Two-thirds of urban streams have excessive nutrient pollution, and fecal coliform bacteria in these streams commonly exceed standards for water recreation (USGS, 2008). Water pollution not only impacts the beneficial uses of our receiving waters (e.g. aquatic life, recreation), but also represents a significant cost to cities as they strive to comply with increasingly stringent state and federal water quality regulations. The Southern California region, under the jurisdiction of three California Regional Water Quality Control Boards (RWQCBs), is faced with rapid population growth and continuous budget constraints. The region will meet the challenge of improving receiving water quality by incorporating low impact development (LID) stormwater techniques.

Stormwater is increasingly being managed through the strategies and principles of Low Impact Development, which is defined as an ecosystem-based approach to designing a built environment that remains a functioning part of an ecosystem rather than existing apart from it. It is an innovative approach to urban stormwater management that does not rely solely on conventional end-of-pipe structural methods; rather, it strategically integrates stormwater controls into the urban landscape. Targeted watershed goals and objectives can be addressed through the use of structural and non-structural LID techniques in order to reduce the discharge of pollutants and the effects of changes to runoff patterns caused by land use modifications (hydromodification).

Land developments in Southern California that drain to the Pacific coast and to inland waters and reservoirs have generated significant increases in stormwater runoff volume, which in turn has contributed to the discharge of pollutants into receiving waters, degraded aquatic habitat, impacted recreational use of these waters, and interfered with their use as water supply (California Department of Water Resources, 2009). LID for new development may only reduce the rate of increase of water quality degradation. Incorporating LID in redevelopment, where feasible, can replicate and enhance a site's hydrologic function, though it should be noted that creating a built environment that is a functioning part of an ecosystem in developed areas where water quality is already degraded may take extensive redevelopment and long periods of time, perhaps 50 to 100 years, before any benefits to water quality may be observed.

The purpose of this LID Manual is to serve as a resource that can be used to guide communities in the development of design, construction, and maintenance standards and specifications, as well as codes and ordinances, which can support their water quality management and regulatory compliance programs. It is intended to complement evolving local stormwater management requirements driven by the adoption of new municipal separate storm sewer system (MS4) permits under the Clean Water Act. New MS4 permits are increasingly requiring the adoption of LID techniques to minimize increases in runoff volume and peak discharge rates resulting from land development. Local permits are discussed in Appendix B.

Hydromodification has been identified as a leading source of water quality impairment in the United States (EPA, 2004). Hydrologic modifications change a site's runoff and transport characteristics, diminishing infiltration, interception, and evapotranspiration, thereby altering the distribution and flow of water across a site. LID is a design strategy that utilizes decentralized, small-scale source control structural and/or non-structural stormwater practices to meet certain technical requirements of federal, state, and local government stormwater management regulations, as well as natural resource protection and restoration goals. This approach can be used as an alternative or enhancement for conventional end-of-pipe stormwater pond technology. This alternative tool is important because it has the potential to lessen the energy impacts of large concentrated volumes of runoff from conventional end-of-pipe approaches on receiving waters and to reduce the development footprint and long-term maintenance considerations for end-of-pipe facilities. LID has also been used to meet targeted regulatory and resource protection objectives. LID addresses hydromodification through the use of "customized" small-scale source controls that allow the designer to select BMPs that best meet the watershed goals and objectives. This approach also allows for the creation of treatment trains, which use a system of different techniques to provide multiple opportunities to reduce pollutant loads.

How to Use This Manual

This manual provides site planning and design guidance, but given the varying site conditions and regulations throughout the region it is not practical to provide suggestions and guidance for every possible situation. The recommendations in this manual are not intended to supersede any local regulations. The manual consists of concepts and techniques presented in a format that will facilitate dialogue between developers, engineers, and local governments to encourage adaptation and integration of these strategies and techniques into local regulatory and watershed protection programs.

In summary, this is a manual of practice for LID that provides:

- Details on how to use LID Principles and LID Best Management Practices (BMPs) to reduce the impacts of land development or re-development on water resources at the project level.
- Guidance for municipalities, land use planners, land developers, consultants, design professionals who prepare stormwater engineering plans and specifications, and others in private industry and public service.
- A site planning and design reference that will facilitate the implementation of LID for projects in Southern California. It is designed to complement the Stormwater BMP Manual(s) that have been developed and are maintained by the California Stormwater Quality Association (CASQA).
- A tool that can be applied at the site level for the development of integrated water and stormwater management regulatory compliance and resource protection programs.

The Manual is structured as follows:

Executive Summary
Provides an overview of the Manual's structure and objectives.

Section 1: The Impacts of Development and How LID Can Help
Describes how LID can be used to address major water quality and regional environmental challenges.

Section 2: The LID Site Design Process

- **Step 1: Assess Site**
  Outlines the data to be collected prior to site design and directs the user to data resources.
- **Step 2: Define Goals**
  Describes how LID fits into the regulatory environment and how it can be used in green building.
- **Step 3: Implement LID Principles**
  Presents site planning strategies to minimize the generation of stormwater runoff.
- **Step 4: Use LID BMPs to Mitigate Impacts**
  Discusses the selection and application of LID BMPs mitigate unavoidable stormwater runoff.
- **Step 5: Evaluate Design**
  Identifies methods for assessing the successful application of LID to a given site. Discusses the use of a number of modeling methods to evaluate LID designs.

Section 3: Case Studies
Presents case studies showing how LID is applied in various contexts.

Appendix A: Lists of Plants Suitable for LID in Southern California
Provides lists of plants suitable for general landscaping, bioretention, and green roofs in Southern California.

Appendix B: California Planning and Regulatory Framework for LID
Discusses how LID fits into California's regulatory environment.

Appendix C: LID, LEED, and the Sustainable Sites Initiative
Details how LID can be used to achieve LEED or Sustainable Sites Initiative Certification.

Section 1: The Impacts of Development and How LID Can Help

There are many potential benefits associated with the use of Low Impact Development (LID) practices. In addition to stormwater management, LID implementation can result in environmental, economic, and community benefits.

Potential Environmental Benefits
- Improved water quality
- Maintenance of predevelopment runoff volume
- Maintenance of predevelopment runoff discharge rate
- Groundwater recharge
- Terrestrial and aquatic habitat preservation
- Reduced potable water and energy demand
- Improved air quality
- Carbon sequestration
- Recycling and beneficial reuse
- Reduction in urban heat island effect

Potential Economic Benefits
- Reduced construction and maintenance costs (see SPU Cost-Benefit Analysis in *References and Resources* below)
- Improved marketability
- Energy cost reduction and water conservation

Potential Community Benefits
- Improved aesthetic value
- Provides “green job” opportunities
- Educational opportunities
- Health benefits

The primary factor to be considered when evaluating how to reduce and mitigate the impacts of stormwater is the pattern of rainfall in the watershed. The Southern California region experiences strong seasonal rainfall variation, with the wet season typically extending from October through April and virtually no rain from May through October. The region’s diverse topography results in a high degree of regional variation in total rainfall and storm size and annual rainfall totals can vary greatly from year to year. These variations will affect the feasibility, effectiveness and as a result the selection of various LID practices.

In addition to evaluating local climatic conditions in LID selection and sizing for stormwater benefits, it is necessary to understand the local hydrologic cycle in order to maintain or mimic the natural hydrologic function of a site.

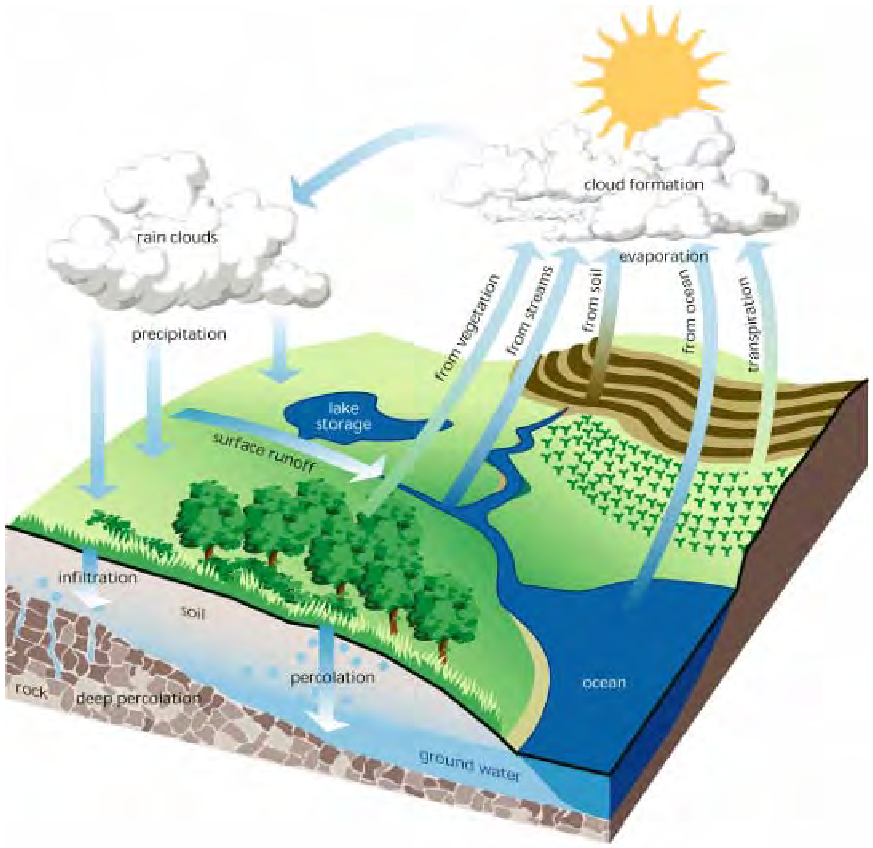

Figure 1. The Hydrologic Cycle.
Source: FISRG, 1998

Water cycles in the various regions of Southern California behave differently based on the amount of precipitation received. For example, in the northern part of Southern California, Pasadena receives 20 inches per year, while San Diego in the southwest receives just 10 inches. Los Angeles falls in the middle, averaging 15 inches per year. The low rainfall and high population of Southern California have lead to increasing concern over water importation. This, in turn, has led to efforts to manage groundwater resources and promote groundwater recharge (EMWD, 2005; OCWD, 2004).

Land development adds impervious surfaces such as rooftops, roads, and parking lots to the natural environment. As a result, the quantity and velocity of runoff increases, the amount of water that infiltrates to groundwater decreases, and pollutants deposited on the impervious surfaces are washed into stormwater conveyance systems and water bodies.

Typical alterations due to development may include:

- Increased imperviousness
- Increased runoff volume
- Reduced infiltration/groundwater recharge
- Introduction of new pollutants into watershed
- Increased pollutant concentrations
- Modifications to streams and channel banks

As a result of expansive development, the current hydrologic cycle in Southern California bears little resemblance to the natural system of a century ago. For example, in the 1920's approximately 95 percent of rainfall in Los Angeles was either infiltrated or evaporated, but that has dropped to approximately 50 percent as result of urban development (Green, 2007).

The primary goal of Low Impact Development is to preserve a site's predevelopment hydrology. The effects of changes to runoff patterns caused by land use modifications, or hydromodification, can be reduced by addressing targeted watershed goals and objectives through the use of structural and non-structural techniques that store, infiltrate, evaporate, and detain runoff. Achieving site design goals often requires consideration of the larger, less-frequent storm events that play a significant role in hydromodification, in addition to the small, frequent storms that are largely responsible for deteriorating water quality. Land use modifications may impact every aspect of site development and affect the hydrologic response of the site.

Figure 2 illustrates effects of development on the natural hydrologic cycle. The hydrologic response of a site is affected by every aspect of site development. Connected impervious areas and soil compaction characteristic of developed sites can cause runoff to be generated from even small amounts of rainfall. This results in an increase in volume and velocity of runoff, thereby increasing generation of sediment and suspended solids resulting from bank erosion.

Both LID and conventional stormwater management techniques attempt to control rates of runoff using accepted methods of hydrologic and hydraulic analysis, but conventional approaches typically include only the hydrologic components of precipitation, runoff conveyance and storage capacity. LID site design recognizes the significance of other components of the hydrologic cycle as well. How these other hydrologic components are taken into account will depend on the data available and purpose of the design. One LID design objective, for example, may be to preserve sediment load for a given site. There are many site design techniques that allow the site planner/engineer to create stormwater control mechanisms that function in a manner similar to that of natural control mechanisms. If LID techniques can be used for a particular site, the net result will be to more closely mimic the watershed's natural hydrologic functions or the water balance between runoff, infiltration, storage, groundwater recharge, and evapotranspiration. With the LID approach, receiving waters may experience fewer negative impacts in the volume, frequency, and quality of runoff, so as to maintain base flows and more closely approximate predevelopment runoff conditions.

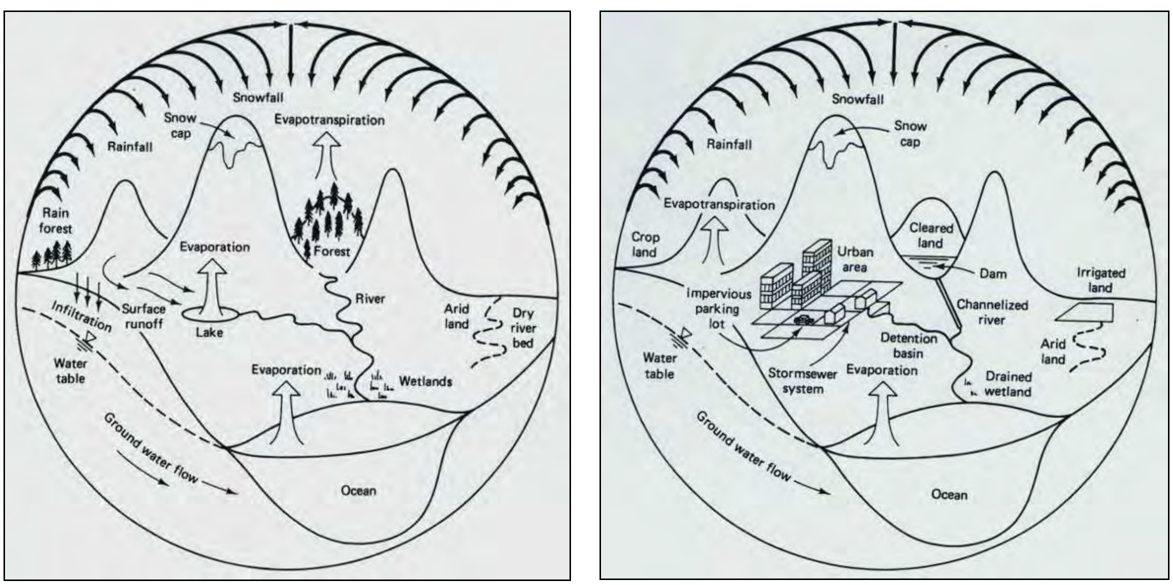

Figure 2. Natural Hydrologic Cycle (left); Hydrologic Cycle of a Developed Environment (right).
Source: McCuen, 1998

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Section 2: The LID Site Design Process

This manual establishes a framework for the LID site design process that informs all stages of planning and design. LID is not intended to be implemented as an afterthought, with a few BMPs placed on an otherwise conventionally designed site; proper implementation of LID techniques involves specialized site planning methods which are intended to be integrated into the overall site design. On a Low Impact Development project, consideration of natural resources such as soils, vegetation, and flow paths will influence the placement of buildings and paved surfaces, and as such LID needs to be considered at the earliest planning stages of a project.

A common misstep of developers and engineers is to wait until the final stages of development planning and design to attempt to incorporate LID, which often ends up requiring the loss of planned building space - or a costly re-design of the site. When LID is considered from the beginning, many designs can adequately meet the requirements for a project without significant loss of building space.

The process of planning a Low Impact Development project begins with a comprehensive understanding of the unique features of the site to be developed, which will guide the development of goals for minimizing the impact of the project. Next, a set of LID principles are included in the site planning process, to guide the creation of a site plan that works with the site's natural features and minimizes the generation of runoff. Once a sound site plan has been created, selected LID BMPs are included to capture and treat runoff where they are needed. The site plan is then evaluated to ensure that the stated goals have been met.

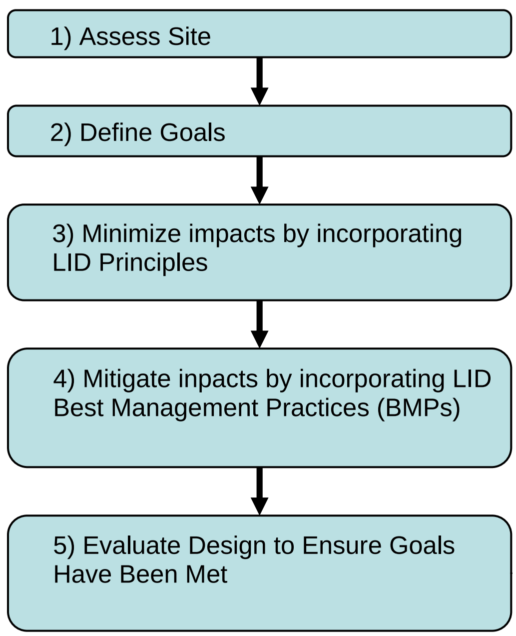

Figure 3. The LID Site Design Process.
Source: The Low Impact Development Center, Inc.

It is important to note that while the LID Site Design Process is presented in a linear fashion, in practice, steps three through five are an iterative process, where structural and non-structural design elements are added and adjusted in response to the modeling results until the project goals are met.

This design process is intended to be adaptable to a wide range of sites, economic constraints, and regulatory requirements, including those associated with new development, redevelopment, and retrofits, which may be subject to a variety of water quality, water quantity, and other requirements. These factors drive the site design, and guide the selection of the most appropriate practices and BMPs for the site.

The LID Site Design Process can be expected to require the balancing and rebalancing of a myriad of requirements placed on today's development projects in addition to those for water quality and water quantity, from the Americans with Disabilities Act requirements to xeriscaping requirements. Through the LID Site Design Process, the project professional must search for a balance that meets all requirements within the project budget.

The economics of LID are influenced by many factors, and the costs to implement LID will likely be a key factor in the level of LID implementation. New development projects are expected to provide the most economical opportunities for LID implementation. In new development, LID can be integrated into a project from its initiation when there are usually fewer project constraints and where LID features may be used in lieu of conventional, non LID features, potentially at savings to the project. Redevelopment and retrofit projects are expected to present more constraints to LID implementation, and these constraints are expected to make LID implementation on these types of projects more costly than in new development.

The economics of LID implementation warrants evaluation on both a capital and lifecycle basis. The capital cost analysis should include not only the cost to implement LID features, but also the potential savings in other features resulting from LID implementation. For example, a pervious paver parking lot may cost more to implement than a conventional asphalt concrete parking lot, but these costs may be offset by a reduction in storm drain costs or treatment control BMP costs made possible by the runoff reduction provided by the LID BMP. The lifecycle cost analysis should include not only the operation and maintenance costs, but also the potential savings in energy use and replacement costs. In the previous example, a pervious paver parking lot may have a life two the three times the life of an asphalt concrete parking lot, resulting in replacement savings. Perhaps the most complicated economic factor associated with LID is appropriately valuing the potential increase in marketability and desirability of LID projects.

Figure 4. Use of the LID Site Design Process to Maintain or Restore Hydrologic Function.
Source: The Low Impact Development Center, Inc.

Integration with MS4 Permit Requirements
LID principles have been incorporated into local MS4 permits. The exact structure of these requirements varies by municipality, therefore, an effort has been made to present a design method that is sufficiently general to conform to a variety of local requirements. Discussion of specific local permitting issues is included in Appendix B.

Step 1: Conduct Site Assessment

A comprehensive site assessment is a fundamental starting point in the development of an LID site design. The site assessment will be a compilation of data from a variety of sources. These sources range from on-site visual inspection to professional surveys and geotechnical reports. The most important component of the site assessment process is the evaluation of the existing soils and drainage on-site and how they relate to the selection of specific LID practices.

The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Web Soil Survey (WSS) is a common starting reference for the preliminary investigation of site suitability for LID. Soil Surveys include a plethora of planning level information for a site, from soil types to hydrologic soils groups. This resource can be used to develop a preliminary understanding of how LID would be best applied to the site. After the preliminary assessment of site soils has suggested the general site layout, then a site-specific geotechnical evaluation of soils is warranted. By conducting a geotechnical evaluation of site soils early in the LID Design Process, decisions regarding specific LID measures can be made with a higher degree of certainty, potentially reducing the number of iterations required to integrate LID into the site design.

The objective of the site assessment is a detailed site map, showing all of the data collected. This map will guide the selection and placement of site development (roads, parking lots and structures), structural, and non-structural BMPs.

The following list represents the foundation data for a comprehensive site assessment:

- Hydrology
- Topography
- Soils
- Geology
- Vegetation
- Eco-region
- Sensitive and Restricted Areas
- Existing Development
- Contamination
- Geological Considerations

Table 1 outlines each of the site assessment elements, what specific data should be collected and sources for the data of interest. Additional detail can be found in the sub-sections that follow.

Depending on the complexity of the site, a team of specialists may be required in order to conduct a thorough site assessment. These professionals may include: geotechnical engineers, surveyors, soil scientists, and restoration ecologists.

Table 1. Necessary Data Collection for Site Assessment.

Factor	Data of Interest	Data Sources	Development Stage
Hydrology	• Streams and receiving waters • Floodplains • Flow paths • Upslope drainage • Connection to existing drainage	• GIS maps • Professional property survey • National Atlas • FEMA Map Service Center	• Hydrology Study (usually prior to CEQA)
Topography	• 1' contours • Elevations of existing curbs and gutters	• Professional property survey • GIS maps • As-built drawings	• Phase One site assessment (usually part of due diligence)
Soils & Geological Considerations	• Hydrologic Soils Group • Soil texture • Impermeable or restrictive layers • Depth to bedrock • Depth to groundwater • Infiltration rate • Landslide potential	• NRCS soil maps • Professional soil testing • Assessment by geotechnical engineer	• Phase One site assessment • Geotechnical Report (usually prior to CEQA and included in CEQA document; often part of WQMP but best done earlier)
Vegetation	• Existing cover • Existing plant communities • Well-established trees	• GIS maps • Professional site survey	• Biological report (almost always done before CEQA and included in the circulated CEQA document)
Ecoregion	• Ecoregion	• USDA Forest Service • US EPA	• Biological reports
Sensitive and Restricted Areas	• Wetlands • Streamside Management Areas • Watercourse and Lake Protection Zones • Floodplains • Established trees • Intact forest • Habitat for threatened or endangered species • Easements • Underground storage tanks • Underground utilities	• Local County/City • California EPA • Deed search • Site survey	• Biological report • Jurisdictional delineation (almost always done before CEQA document prepared) • Special surveys (vireo, fairy shrimp, etc.) almost always done before CEQA document is prepared • Phase One
Existing Development	• Buildings • Paved areas • Landscaped areas • Utilities	• As-built site plans • Site Survey	• Many venues for gathering this information
Contamination	• Brownfield designation • Abandoned landfills • Groundwater contamination	• Local County/City • US EPA • California EPA • California Department of Toxic Substances Control	• Phase One

Source: The Low Impact Development Center, Inc.

LID Site Assessment – *Existing Hydrology*

One of the key pieces of the site assessment will be to map the site's existing hydrology. The map should include:

- Onsite streams and other water bodies
- Existing flow paths
- Floodplains
- Depth to groundwater
- Connections to and routing of existing storm drain systems
- Receiving waters
- Upslope drainage

Much of this information may be available from city and county municipal agencies. Where such data is not available, the site will need to be mapped by a qualified professional.

Existing flow paths and upslope drainage concerns can be assessed by examining topographic maps of the site.

Information on depth to groundwater can be found in the Natural Resources Conservation Service (NRCS) Web Soil Survey.

One of the best ways to get a sense of how water moves on the site is to visit during a heavy rain, taking note of where the water flows.

Additionally, the site should be placed in the context of the larger watershed. Identify any special concerns in the watershed. Find out whether the receiving waters are listed as impaired under section 303(d) of the Clean Water Act. The list is maintained by the State Water Resources Control Board (http://www.waterboards.ca.gov/water_issues/programs/tmdl/docs/303dlists2006/epa/state_usepa_combined.pdf). If the receiving water is listed, the development may be subject to additional regulatory requirements.

References and Resources

Cal-Atlas: http://atlas.ca.gov

USDA NRCS Web Soil Survey: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

USGS National Water Information Service: http://water.usgs.gov/nwis

LID Site Assessment – *Topography*

The topography of the site defines both the location and capacity requirements for potential LID implementations. The topography of upstream and downstream sites should also be considered with respect to any potential contribution to the total runoff generated during a storm event.

To design effective LID into new or existing sites requires a careful analysis of the topography and how and where stormwater runoff will concentrate and flow. Visiting the site during a storm event can provide an enormous amount of information regarding areas of concentration and flow. In the event preliminary data cannot be found, a topographic survey should be ordered prior to proceeding with the design phase of the project.

To be able to perform a detailed topographic site analysis, the following information must be acquired and evaluated:

- A detailed site topographic map showing the smallest contour interval possible; a contour map showing the contours at a 1-foot interval is preferred. For initial planning and scoping purposes, additional intervals can be interpolated from maps with larger intervals if necessary. If possible, try to obtain as-built drawings that may exist from previous construction.
- The location and elevation of existing drainage or stormwater structures, including the elevation of the rim of the structure where stormwater enters and the inverts of drainage pipes entering or exiting the structure.
- Elevation of all curbs and gutters on the site. The drawing should show top of curb and bottom of curb elevations. High and low points of walkways, driveways, and parking areas should also be noted.
- Location of drainage swales on the site. Indicate the flow direction in the channel for reference.

Check with the property owner for as-built drawings that might be available.

The local county GIS office may have a topography layer available that could provide working information, but keep in mind this data is typically not survey-quality data and should only be used for preliminary evaluation of the contributing watershed for your site LID BMPs.

USGS 1:24,000 Quad maps can be used to calculate the contributing watershed on larger sites.

References and Resources

USGS Topographic Maps: http://topomaps.usgs.gov/

LID Site Assessment – *Soils and Geology*

As many LID BMPs are designed to infiltrate runoff, understanding the site's soil type, characteristics, and profile will help focus efforts on measures that are most appropriate for managing stormwater on the site. This section describes considerations for assessing the site's soils that will help inform the placement of buildings and paved areas, and suggest the most suitable BMPs and where they would be best placed.

Failure to understand the characteristics and capabilities of the specific site soils results in poorly functioning LID designs. Proper understanding of the analysis and application of soil type and its capacity to infiltrate stormwater and mitigate non-point pollutants is imperative to the success of any LID implementation.

The following is a summary of soil considerations that should be assessed for the site. Additional information on each of these is provided below:

- Initial Soils Assessment
    - Hydrologic Soils Group

- On-Site Soils Assessment
    - Measured infiltration rates
    - Trench / Boring Logs
    - Depth to or presence of limiting soil types, i.e. expansive soils, caliche, fragipan, corrosive soils
- Geologic Assessment
    - Depth to bedrock
    - Depth to water table
    - Susceptibility to landslides

Initial Soils Assessment

Information regarding a site's hydrologic soils group can generally be gathered from available regional soils studies and may **only** be used as a preliminary source for soil characterization and early planning. When this information is used to estimate infiltration rates or BMP sizes, a safety factor of 10 is appropriately applied – and can usually be reduced once in situ testing has been completed. Site specific soil testing, by a qualified civil or geotechnical engineer, is essential before preliminary and final design and implementation of LID projects in order to confirm soil properties including infiltration capacity and should be done as early in the design process as possible.

The Natural Resources Conservation Service (NRCS) has compiled soils data on the U.S. Department of Agriculture (USDA) website. The online soil survey is called the Web Soil Survey (WSS) and can be viewed at the following URL: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm.

In the event the WSS is unable to provide a soil map for the site of interest, which is often the case in areas of urban development, soil maps may be available from state or municipal government agencies. The local NRCS office may have access to published printed soil survey data which has not yet been posted online.

Soil series are assigned a Hydrologic Soil Group (HSG) rating, A through D, which describes the physical drainage and textural properties of each soil type and is useful for stormwater, wastewater, and other applications. This HSG rating is usually based on a range of permeability, as well as certain physical constraints such as soil texture, depth to bedrock, and seasonal high water table (SHWT). Soil types assigned an HSG Group A classification are very well drained and highly permeable (sand, loamy sand, sandy loam); Group D soils (clay loam, silty clay loam, sandy clay, silty clay, clay) are poorly drained and often situated in a valley bottom or floodplain. HSG-rated B and C soils offer good (B; silt loam, loam) to fair (C; sandy clay loam) drainage characteristics (USDA-SCS, 1986). The heavier D soils have little if any infiltration potential during rainfall events and produce much greater surface runoff in response to rainfall. Many soils in Southern California are classified with a HSG rating of C or D, which are usually not especially conducive to and will limit applicability of infiltration practices. In fact, data for the six counties covered by Regional Boards 4, 8, and 9 indicates that 3 percent of the soils are classified as A, 17 percent of soils are classified as B, 30 percent as C, 33 percent as D, and 16 percent as Urban Soils. It should be noted that the permeability ranges listed for the HSG ratings are based on the minimum rate of infiltration obtained for bare soil after prolonged wetting (USDA-SCS, 1986). A vegetative cover can increase these rates 3 to 7 times (Lindsey et. al., 1992).

These NRCS soil maps can be used to identify areas with potentially high infiltration rates (HSG Group A and B), which are potential areas for locating infiltration-based BMPs. Where possible, buildings and paved surfaces should be sited on less permeable soils.

Although initial soils information may be estimated using regional soils studies (typically using web-based or GIS data), in most cases this will not be an adequate replacement for on-site analysis. Additionally, it is important to adequately understand and characterize the infiltration capacity of the entire soil profile, as deeper soils may be more limiting to infiltration than surface soils.

On-Site Soils Assessment

Infiltration Testing

Infiltration tests should be performed in areas where infiltration-based BMPs are proposed and typically a minimum infiltration rate of 0.5 inch per hour is required. A variety of field testing techniques can be used to determine infiltration rate, including basin flooding, sprinkler infiltrometers, cylinder or double-ring infiltrometers, and lysimeters. Appropriate techniques should be selected based on the method of stormwater application being considered and may be subject to local guidance. Basin flooding and cylinder infiltrometer tests are preferred for the design of stormwater retention facilities (US EPA, 1998). The standard US Public Health Service percolation test used to design septic drain fields is not recommended.

Trench / Boring Logs
Once potential building and BMP locations have been identified, a qualified soil scientist or geotechnical engineer should dig test pits to gather more detailed information on the soils present at these locations. Test pits are required to confirm the types of soils present onsite, and will uncover the presence of soil layers that may impede infiltration, such as caliche or fragipan. Test pits will also determine the depth to bedrock and will help to establish the high groundwater elevation.

In developed sites being evaluated for redevelopment or retrofits, soil bulk density should be measured in a number of areas to determine the level of soil compaction, which can dramatically impede the movement of water into the soil.

Other Limiting Factors
Many of the soils in Southern California contain fairly shallow, moderately cemented restrictive layers of lithic or paralithic bedrock. These restrictive layers will limit the applicability of infiltration designs. Another likely challenge to infiltration is a type of soil known as caliche, which is found in many areas of the region. Caliche is a layer of soil in which the soil particles have been cemented together by lime (calcium carbonate, $CaCO_3$). It is usually found as a light-colored layer in the soil or as white or cream-colored concretions (lumps) mixed with the soil. Layers will vary in thickness from a few inches to several feet, and there may be more than one caliche layer in the soil.

Caliche is also problematic for vegetation in at least three ways. First, the caliche layer can be so tight that roots cannot penetrate through it. The result is that plants have only the soil above the caliche to use as a source of nutrients and water and normal root development is restricted. Second, the same conditions that restrict root penetration also reduce water movement. Water applied to the soil cannot easily move through the profile if a restrictive caliche layer is present. The restricted water penetration can contribute to problems arising from inadequate root aeration and can lead to accumulations of salt in the soil surface. Both problems, lack of aeration and salt accumulation, reduce the vigor of growing plants. Third, the pH and free calcium carbonate in a caliche soil are often high enough to cause iron to become unavailable for plants. The symptoms of iron deficiency are a yellowing of the youngest plant leaves while the veins in the leaves remain green. Iron deficiencies are further aggravated by the water saturation of the soil.

In some cases, near-surface caliche layers can be broken apart through mechanical means during site grading. This is typically accomplished by deep ripping, a process that involves using a bulldozer to drag a long tine through the soil on a checkerboard pattern. This process may remove the water penetration restriction, but may not mitigate the other challenges associated with caliche soils.

Many areas in Southern California have soils that are corrosive to metals and concrete. These soils are characterized by: high moisture content, high dissolved salts, and high acidity. Caltrans has established the following criteria for corrosive soils (Caltrans, 2003):

- Chloride concentration ≥ 500 ppm,
- Sulfate concentration ≥ 2,000 ppm, or
- pH ≤ 5.5

If one or more of these conditions is met, the site may require corrosion mitigation prior to the installation of any underground BMPs.

Pollutant Removal

Unpaved surfaces provide both infiltration and pollutant removal functions. Soils have a high capacity to remove soluble and insoluble pollutants from stormwater. Many factors influence a soil's pollutant removal capacity. Fully understanding soil pollutant removal involves a detailed understanding of hydrology, soils physics and chemistry, aquatic chemistry, biology, and botany. Factors that influence pollutant removal include the quality of the infiltrating water, and soil characteristics such as age, pH, mineral content, organic matter content, oxidation-reduction potential (redox), as well as the soil flora and fauna at the surface and in the subsurface.

Soil provides the medium for decomposition of organic material that is deposited on the land surface. Soil is the habitat for a vast spectrum of micro- and macro-organisms that form a natural recycling system. The rhizosphere (the rooting zone) includes roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots, other insects and insect larvae (grubs), earthworms and rodents. Processed nutrients in the rhizosphere are in turn used by the vegetative systems that develop on the soil mantle. When precipitation is infiltrated, pollutants from surface activities move into this soil treatment system, which effectively and efficiently breaks down most non-point source pollutants (biologically), removes them from the stormwater by cation exchange (chemically), and/or physically filters them through soil particles.

One important measure of chemical pollutant removal potential is cation exchange capacity (CEC), which describes the soil's ability to adsorb positively charged ions. A soil's CEC is a function of its clay and organic contents. Soils with a CEC of at least 10 milliequivalents per 100 grams are very efficient as a treatment medium, and offer the best opportunity to reduce or completely remove most common stormwater pollutants, such as phosphorus, metals and hydrocarbons. Non-point source pollutants that are solutes, such as nitrate, are the exception. Nitrates typically move with the infiltrating rainfall and do not undergo significant reduction or transformation, unless an anaerobic environment with the right class of microorganisms is encountered.

Phosphorus is a key pollutant of concern in many watersheds. Soils can act as either a source or a sink for certain forms of phosphorus, depending on their innate phosphorus content, measured by the P-index (Hunt et al, 2006). This can be of particular concern when soil is used as a pollutant filter, such as in bioretention. Use of high P-index soils in bioretention can lead to the bioretention cell exporting rather than removing certain forms of phosphorus. Table 2 summarizes the ideal soil properties for infiltration and pollutant removal. It is important to note that LID principles can be adapted to any site soil conditions. This table is intended only to facilitate the identification of areas where infiltration BMPs would be best suited, and to flag any special soil conditions that may need to be considered.

Table 2. Ideal Soil Properties for Infiltration and Pollutant Removal.

Property	Ideal range for infiltration/ pollutant removal
USDA textural classification	Sand, loamy sand, sandy loam, or loam
HSG	A or B
Infiltration rate	0.5 in/hr
CEC	> 10 milli-equivalents/100 grams
Organic Content	1.5 – 10%
P-index	< 25
pH	5.5-7.5
Depth to impermeable layers	> 5 feet
Depth to groundwater	> 10 feet

Source: The Low Impact Development Center, Inc.

Geologic Assessment

The primary geologic factors that influence selection and placement of LID BMPs are the depth to bedrock and the water table, and susceptibility to landslides. The depths to bedrock and the water table can be easily obtained as part of the site soils assessment described above.

Landslides

Southern California's physiography makes certain areas prone to landslides. Landsliding is a form of mass wasting, or gravity-caused erosion, and is a natural process which occurs readily in certain earth materials. The action of landsliding is heavily influenced by the saturation of soil and rock masses and is, to the dismay of thousands of its residents, a natural process on California's hill slopes.

LID design in areas prone to landslides, especially those that utilize infiltration, should be given careful consideration and should be subject to review by a licensed civil or geotechnical engineer. Since soil saturation is a primary cause of landslides, infiltration should be limited in areas of high landslide risk. Local construction best practices should also be considered when implementing LID in an area that is subject to landslides.

References and Resources

California Department of Transportation (Caltrans). 2003. *Corrosion Guidelines*. www.dot.ca.gov/hq/esc/ttsb/corrosion/CorrGuidelinesSept03.pdf

California Geological Survey - Educational Resources Center http://www.conservation.ca.gov/cgs/information/Pages/EdResCenter.aspx

California GeoTour: An Index to On-line Geologic Field Trip Guides of California http://www.consrv.ca.gov/cgs/geotour/

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Lindsey, G., L. Roberts, and W. Page. 1992. *Inspection and Maintenance of Infiltration Facilities*. Journal of Soil and Water Conservation, 47(6): 481-486.

NRCS Web Soil Survey Website: http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm

NRCS – Published Soil Surveys for California http://soils.usda.gov/survey/printed_surveys/state.asp?state=California&abbr=CA

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USGS Education – California: Geography, Geology, Hazards, and Natural History Information http://education.usgs.gov/california/resources.html

USGS - Geologic Information for Southern California http://scamp.wr.usgs.gov/

USGS - Landslide Hazards Program http://landslides.usgs.gov/

USGS - Landslide Types and Processes http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

USGS - National Geologic Map Database http://ngmdb.usgs.gov/

USGS - National Landslide Overview Map of the United States
http://landslides.usgs.gov/learning/nationalmap/

LID Site Assessment – *Vegetation*

Knowledge of the plant communities occurring onsite is a factor in developing a site design that is well-integrated into the natural environment. Although development pressures have removed or strongly modified much of the natural vegetation in the area, ongoing development, redevelopment, and restoration efforts may present opportunities to protect and/or recapture some of the region's native plant communities.

When a site is disturbed by either natural events or human intervention, invasive species have the opportunity to gain a toe hold and dominate indigenous plant communities. Invasive species are plants that have been recently introduced and have the ability to thrive beyond their range of natural dispersal. Typically invasive species are characterized as adaptable, aggressive and have a high reproductive capability. These characteristics allow them to monopolize the limited resources available after a site disturbance has occurred and to outcompete native plant species. It is critical to identify these invaders during site assessment and, as part of the plant community restoration plan, to minimize the introduction and establishment of invasive plants into the landscape. Where a site is completely dominated by invasives, it may be possible to restore native vegetation into the planned landscaping. A qualified restoration ecologist should be consulted to create an appropriate restoration plan.

Southern California's natural vegetation reflects the region's climate and diverse topography and soils. The structure and function of the area's natural plant communities are strongly influenced by drought, seasonal flooding, elevation, slope and aspect, geological variation, fire history, and unique occurrence of the Santa Ana winds. The vegetation exhibits high levels of species diversity and endemism, and provides habitat for a great range of animals.

A site assessment should include a survey of existing vegetation onsite, identifying:

- Existing or historical plant communities
- Existing invasive species
- The presence/location(s) of dense/native plant cover
- The presence/location(s) of well-established trees

The following points briefly summarize important characteristics of several major plant communities in Southern California to help in identifying native plant cover versus invasive species. (Bornstein et al, 2005; Lenz and Dourley, 1981; Las Pilitas Nursery):

- Coastal Scrub:
    - primarily small to medium shrubs, subshrubs, or succulents
    - some species produce large green leaves with winter rains and small grayish leaves in summer; other species are drought-deciduous
    - annual precipitation is generally 10-20 inches
    - relatively narrow temperature range
    - plants can be somewhat sparsely distributed in the landscape
    - tend to be found in flat to moderately-sloped areas; slopes may be rocky
    - shallow to moderate soil depth

Figure 5. Coastal Scrub.
Source: © Marc Hoshovsky, California Department of Fish and Game

- Chaparral:
  - most extensive type of vegetation in California
  - primarily medium to large shrubs with thick, small, evergreen leaves; also contains fire-adapted annuals
  - can form dense thickets
  - many types of chaparral are recognized, depending on dominant species and combinations of species; this variation reflects different elevations, moisture levels, and soil types
  - annual precipitation is generally 12-35 inches, occurring in infrequent, heavy events
  - found on hills and lower mountain slopes in areas with generally mild winters; often on steep slopes that are very hot in summer
  - fairly drought-tolerant and adapted to fire; many shrub species can sprout from stumps following fire
  - shallow, usually well-drained, rocky soils

Figure 6. Chaparral.
Source: California Chaparral Institute

- Grassland:
    - comprises bunchgrasses, sedges, and annual and perennial wildflowers
    - merges with chaparral or oak woodland at higher elevations
    - annual precipitation is generally 6-20 inches
    - soils range from: deep alluvial fan and floodplain, to moderately deep upland with high organic matter, to low terrace land soils having moderately dense subsoils, to poorly drained valley basin soils
    - no longer abundant (largely replaced by agricultural land uses)
    - invasive exotic grasses and other herbs have impaired some remaining California grassland

Figure 7. Grassland.
Source: I. Anderson Center for Biological Diversity

- Coastal Oak Woodland:
    - discontinuous overstory of Coast Live Oak, other oak trees, or California Walnut
    - canopy coverage can vary, with a mix of shrubs and grasses occurring in the understory
    - annual precipitation is generally 15-25 inches with substantial runoff
    - soils are generally deep terrace land or upland soils

Figure 8. Oak Woodland.
Source: Daniel Griffin, University of Arkansas Tree-Ring Laboratory

- Riparian Woodland:
    - species composition varies with elevation
    - soils vary, depending on composition of materials deposited along waterways
    - plants generally require year-round presence of nearby surface water

Figure 9. Riparian Woodland.
Source: V.L. Holland, Ph.D.; Biological Sciences Department, California Polytechnic State University

- Pinyon-Juniper Woodland:
    - consists of juniper on shallower slopes and pinyon pine on higher and steeper slopes in mountain regions
    - plant community may have a variety of other trees, shrubs, and succulents
    - annual precipitation is generally 10-30 inches

Figure 10. Pinyon-Juniper Woodland.
Source: Joel Michaelsen; Department of Geology, UC Santa Barbara

- Pine Forest:
  - lower montane coniferous forest, with a great number of potential species (canopy and understory)
  - elevation generally ranges from 5,000 to 8,000 feet
  - annual precipitation is generally 25-80 inches (much of it falls as snow)
  - deep upland soils with moderate to high acidity

Figure 11. Pine Forest.
Source: Joel Michaelsen; Department of Geology, UC Santa Barbara

- Creosote Bush Scrub:
  - open, sparse desert community dominated by Creosote bush and prickly pear cactus
  - elevation generally less than 3,500 feet
  - annual precipitation is generally 5-10 inches
  - alkaline soils

Figure 12. Creosote Bush Scrub.
Source: Carrie Tai

- Joshua Tree Woodland:
  - desert community dominated by Joshua trees, shrubs and wildflowers
  - elevation generally ranges from 2,500 to 5,000 feet
  - annual precipitation is generally 5-10 inches
  - neutral soils

Figure 13. Joshua Tree Woodland.
Source: Carrie Tai

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LID Site Assessment – *Ecoregion*

Ecoregions and Native Plant Communities

Landscaping within a Low Impact Development project can be modeled on native plant communities found within an area's ecoregion. According to the World Wildlife Fund, an ecoregion is a "large area of land or water that contains a geographically distinct assemblage of natural communities that:

- share a large majority of their species and ecological dynamics;
- share similar environmental conditions, and;
- interact ecologically in ways that are critical for their long-term persistence."

Ecoregions can be described at a variety of spatial scales and further delineated into different subregions, such as provinces and sections. Two ecological subregions occur within the jurisdictions of Regional Water Quality Control Boards 4, 8 and 9, and have direct significance to this manual (USDA-FS, 1997):

1. Southern California Coast
2. Southern California Mountains and Valleys

In addition to the above subregions, large portions of Los Angeles, San Bernardino, Riverside, and San Diego Counties fall within three other ecoregions to the east:

1. Mohave Desert
2. Sonoran Desert
3. Colorado Desert

The ecoregions for the three RWQCB Regions in the project area are very broadly outlined; they can be further subdivided into sections and subsections within the hierarchical framework of ecoregions. Individual subsections have characteristic topography, soils, climate, and associated vegetation types. These features are summarized in Table 3 and Table 4 for the subsections that occur in the project area. Understanding the unique elements in a specific ecoregion the BMP is located in will inform the choices of plant materials incorporated into the BMP. This consideration will enhance the survival and sustainability of the selected plant material as well as provide habitat and cover for native wildlife.

Table 3. Climate and Vegetation of the Southern California Coast Ecoregion.

Subsection	Mean Annual Temp. & Precip.	Surface Water	Predominant Vegetation	Less Common Vegetation
Santa Ynez – Sulphur Mountains	45° - 60° F 18-30 in	Rapid runoff; all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Montane Hardwood Forest; Chamise Chaparral; Mixed Chaparral	Coastal Scrub; Duneland; Grassland
Oxnard Plain – Santa Paula Valley	56° - 60° F 12-18 in with summer fog	Santa Clara River is perennial, Calleguas Creek is year-round; no natural lakes	Coastal Scrub	Saline Emergent Wetland; Grassland; Coastal Oak Woodland; Valley Foothill Riparian Woodland
Simi Valley – Santa Susana Mountains	52° - 62° F 16-20 in	Rapid runoff; streams dry in summer; no natural lakes	Coastal Scrub; Chamise Chaparral; Coast Oak Woodland	Valley Oak Woodland; Montane Hardwood Forest; Grassland; Valley Foothill Riparian Woodland; Montane Riparian Forest
Santa Monica Mountains	54° - 62° F 15-25 in	Rapid runoff; streams dry in summer; no natural lakes	Coastal Scrub; Chamise Chaparral; Mixed Chaparral	Coast Oak Woodland; Grassland; Valley Foothill Riparian Woodland; Montane Riparian Forest; Valley Oak Woodland
Los Angeles Plain	58° - 64° F 12-20 in with summer fog	Most streams dry in summer; no natural lakes	Coastal Scrub	Coast Oak Woodland; Chamise Chaparral; Mixed Chaparral; Valley Foothill Riparian Woodland; Saline Emergent Wetland; Duneland; Grassland
Coastal Hills	56° - 62° F 12-16 in with summer fog	Rapid runoff; mix of perennial and summer-dry streams; no natural lakes; some reservoirs	Coastal Scrub; Coast Oak Woodland	Chamise Chaparral; Mixed Chaparral; Valley Foothill Riparian Woodland; Grassland
Coastal Terrace	58° - 62° F 10-12 in with summer fog	Rapid runoff except for terraces with vernal pools; mix of perennial and summer-dry streams; no natural lakes	Coastal Scrub; Chamise Chaparral	Coast Oak Woodland; Saline Emergent Wetland; Torrey Pine Stands; Vernal Pools; Duneland; Grassland; Mixed Chaparral; Valley Foothill Riparian Woodland

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table 4. Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	Surface Water	Predominant Vegetation	Less Common Vegetation
San Raphael – Topatopa Mountains	45° - 60° F 18-30 in	Rapid runoff; rain except at higher elevations; all but larger & high-elevation streams dry in summer; no natural lakes	Chamise Chaparral; Mixed Chaparral	Coastal Oak Woodland; Coastal Scrub; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Jeffrey Pine Forest; White Fir Forest; Grassland; Wet Meadow
Northern Transverse Ranges	40° - 54° F 12-30 in	Rapid runoff; rain except at higher elevations; all but larger & high-elevation streams dry in summer; no natural lakes	Juniper Woodland; Jeffrey Pine Forest; Montane Hardwood Conifer Forest; Chamise Chaparral; Mixed Chaparral;	Coastal Scrub; Montane Hardwood Forest; Pinyon-Juniper Woodland; Montane Chaparral; Subalpine Conifer Forest; White Fir Forest; Grassland; Wet Meadow
Sierra Pelona – Mint Canyon	45° - 60° F 12-20 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; sag ponds along San Andreas Fault	Chamise Chaparral; Mixed Chaparral; Coastal Oak Woodland	Coastal Scrub; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Jeffrey Pine Forest; Juniper Woodland; Montane Chaparral; Grassland; Wet Meadow;
San Gabriel Mountains	45° - 60° F 20-30 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; sag ponds along San Andreas Fault	Chamise Chaparral; Mixed Chaparral	Jeffrey Pine Forest; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Grassland; Montane Chaparral; Coastal Oak Woodland; Pinyon-Juniper Woodland; Wet Meadow
Upper San Gabriel Mountains	40° - 50° F 30-40 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Jeffrey Pine Forest	Lodgepole Pine Forest; Subalpine Conifer Forest; Montane Chaparral; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Oak Woodland; Juniper Woodland; Wet Meadow
Santa Ana Mountains	45° - 62° F 15-25 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes (but some drainage to Lake Elsinore)	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral	Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Scrub; Jeffrey Pine Forest; Montane Chaparral; Grassland; Vernal Pools

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table 4 (cont.): Climate and Vegetation of the Southern CA Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	Surface Water	Predominant Vegetation	Less Common Vegetation
San Gorgonio Mountains	45° - 60° F 20-30 in	Rapid runoff; rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Chamise Chaparral; Mixed Chaparral; Jeffrey Pine Forest	Subalpine Conifer Forest; Montane Chaparral; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Coastal Oak Woodland; Pinyon-Juniper Woodland; Coastal Scrub; Grassland
Upper San Gorgonio Mountains	40° - 50° F 30-40 in	Rapid runoff; much precipitation is snow; all but larger streams dry in summer; previously natural lakes replaced by reservoirs	Jeffrey Pine Forest	Mixed Chaparral; Subalpine Conifer Forest; Lodgepole Pine Forest; Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; White Fir Forest; Pinyon-Juniper Woodland; Wet Meadow; Alpine Meadow
Fontana – Calimesa Terraces	62° - 64° F 20-20 in	Rapid runoff (even from alluvial fans); all but larger streams dry in summer; Santa Ana River flows year-round; no natural lakes	Coastal Scrub; Grassland	Mixed Chaparral; Juniper Woodland; Valley Foothill Riparian Woodland
Perris Valley and Hills	58° - 64° F 10-16 in	Rapid runoff (except from floodplains and lake basins); all but larger streams dry in summer; sag ponds along Elsinore Fault Zone; reservoirs	Coastal Scrub; Grassland	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral; Juniper Woodland; Vernal Pools
San Jacinto Foothills – Cahuilla Mountains	50° - 60° F 10-20 in	Rapid runoff (except from alluvial plains); all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Coastal Scrub	Chamise Chaparral; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Mixed Chaparral; Montane Chaparral; Juniper Woodland; Jeffrey Pine Forest; Pinyon-Juniper Woodland; Grassland
San Jacinto Mountains	40° - 58° F 16-30 in	Rapid runoff (except from alluvial plains); rain except at higher elevations; all but larger streams dry in summer; no natural lakes	Jeffrey Pine Forest; Lodgepole Pine Forest; Mixed Chaparral	Coastal Oak Woodland; Juniper Woodland; Pinyon-Juniper Woodland; Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; Chamise Chaparral; Subalpine Conifer Forest; White Fir Forest; Wet Meadow; Grassland

Sources: USDA-FS, 1997, and CA-DFG, 2009

Table 4 (cont.): Climate and Vegetation of the Southern California Mountains and Valleys Ecoregion.

Subsection	Mean Annual Temp. & Precip.	Surface Water	Predominant Vegetation	Less Common Vegetation
Western Granitic Foothills	55° - 62° F 14-20 in	Rapid runoff; all but larger streams dry in summer; no natural lakes	Coastal Oak Woodland; Chamise Chaparral; Mixed Chaparral; Coastal Scrub	Montane Hardwood Conifer Forest; Montane Hardwood Forest; Montane Chaparral; Grassland; stands of Tecate cypress
Palomar – Cuyamaca Peak	50° - 58° F 18-40 in	Rapid runoff; all but larger streams dry in summer; sag ponds along Elsinore Fault Zone; level of Lake Henshaw (natural) has been raised artificially; reservoirs	Chamise Chaparral; Mixed Chaparral	Coastal Oak Woodland; Grassland; Jeffrey Pine Forest; Montane Hardwood Conifer Forest; Subalpine Conifer Forest; White Fir Forest; Montane Chaparral; Coastal Scrub; stands of Cuyamaca cypress and Tecate cypress

Sources: USDA-FS, 1997, and CA-DFG, 2009

References and Resources

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USDA-FS. 1997. *Ecological Subregions of California: Section and Subsection Descriptions.* Washington, DC: USDA Forest Service, Natural Resources Conservation Service, and Bureau of Land Management. http://www.fs.fed.us/r5/projects/ecoregions/index.htm

World Wildlife Fund. *Ecoregions*. http://www.worldwildlife.org/science/ecoregions/item1847.html

LID Site Assessment – *Sensitive and Restricted Areas*

Mapping of all sensitive and restricted areas on the site is required as part of the site planning and layout. Conservation easements that have been dedicated on the site will require special attention since these areas may fall under the control of regulatory agencies, such as the United States Army Corps of Engineers (USACE) or the State Department of Fish and Game (DFG).

Work that would affect the natural function of areas of environmental interest is often regulated by Federal or State agencies and must be identified and delineated. Additionally, several jurisdictions in Southern California have completed Multiple Species Habitat Conservation Plans, which identify key species and their associated habitats and may set requirements for conservation or mitigation.

Other types of easements and rights of way should also be identified prior to the selection of LID practices. Access easements can be established for sub-grade, on-grade and aerial utilities, and will dictate specific limitations to potential locations of LID BMPs.

Required Information

The following sensitive and restricted areas should be identified and delineated on the project site plan:

- Wetlands
  - http://www.ceres.ca.gov/wetlands/
- Streamside Management Areas / Watercourse and Lake Protection Zones
  - http://www.swrcb.ca.gov/water_issues/programs/nps/encyclopedia/2b_sma.shtml
- Floodplains
  - http://www.fema.gov/plan/prevent/fhm/dfm_dfhm.shtm
  - http://www.water.ca.gov/floodmgmt/lrafmo/fmb/fes/
  - Contact appropriate local agency for additional flood hazard areas
- Habitat for threatened or endangered species
  - Local MSHCP
  - http://www.dfg.ca.gov/habcon/
- Environmental easements on the property such as woodland, wetland, farmland, scenic areas, historic areas, wild and scenic rivers and other undisturbed natural areas that have been recorded as perpetual conservation easements in the property deed
- Location of buried storage tanks and utilities
  - As-built plans
  - Utility companies

References and Resources

California Watershed Assessment Manual http://www.cwam.ucdavis.edu/

Orange County Watersheds http://www.ocwatersheds.com/

Regional Water Quality Control Board Region 4 – Los Angeles
http://www.waterboards.ca.gov/losangeles/

Regional Water Quality Control Board Region 7 – Colorado http://www.waterboards.ca.gov/coloradoriver/

Regional Water Quality Control Board Region 8 – Santa Ana http://www.waterboards.ca.gov/santaana/

Regional Water Quality Control Board Region 9 – San Diego http://www.waterboards.ca.gov/sandiego/

San Diego County Multiple Species Habitat Conservation Program
http://www.sandiego.gov/planning/mscp/

State of California Conservation Easements Registry http://easements.resources.ca.gov/

Western Riverside County Regional Conservation Authority Multiple Species Habitat Conservation Plan
http://www.wrc-rca.org/library.asp

LID Site Assessment – *Existing Development*

On sites which are being redeveloped or retrofit with LID, it will be necessary to obtain detailed maps of the existing development on the site. Typical site surveys that are used in the design of the project will inherently contain most of the required information, and any non-standard information can be easily gathered by the surveyor. The existing topography (as described in the sections above) should also be included in the maps of the existing development. As-built site plans can also be obtained when available, but it should be noted that as-built drawings should be field-checked to ensure that they accurately reflect the site as it currently exists. The information listed below will be used to select possible locations for LID BMPs on the site and can identify opportunities for reduction of impervious surfaces.

The following features should be identified and delineated on the project site plan:

- Buildings and foundations
- Parking areas, including the number and layout of parking spaces
- Driveways
- Vehicular access roads
- Paved sidewalks and paths
- Turf
- Landscaped areas
- Underground utilities, such as electric, gas, water, sewer, stormwater, telephone and cable TV
- Underground storage tanks

LID Site Assessment – *Contamination*

Potential soil and groundwater contamination should be considered on all redevelopment sites. Sites with existing soil contamination are called brownfields. Identified brownfields and former agricultural sites are managed by the USEPA, Cal/EPA, and the CA Department of Toxic Substances Control. Each of these agencies maintains lists of known brownfields. For preliminary investigation, the following websites can provide information on known brownfield sites:

- EPA Brownfield Website: http://www.epa.gov/brownfields
- CA Department of Toxic Substances Control links:
    - http://www.dtsc.ca.gov/SiteCleanup/Brownfields/,
    - http://www.dtsc.ca.gov/SiteCleanup/Cortese_List.cfm
- Cal/EPA link: http://www.calepa.ca.gov/brownfields/

Site contamination can be an issue in the redevelopment of urban, industrial and agricultural sites. Urban soils may be contaminated with lead deposited by vehicle exhaust or deteriorating paint. Industrial sites may be contaminated with a variety of chemicals, and may have been subject to intentional or unintentional dumping, resulting in soil or groundwater contamination. Former agricultural sites may be contaminated with pesticides or other chemicals, or may have high concentrations of mineral salts or nutrients. All redevelopment sites must be investigated for underground storage tanks, abandoned landfills, or other sources of groundwater contamination.

Brownfields require an approach to LID that is somewhat different from the common emphasis on infiltration, which could mobilize pollutants in the soil, contaminating groundwater. Rather, the emphasis on brownfield sites should be on minimizing the generation of runoff via source control, detention of runoff to reduce peak flows, and the treatment of runoff prior to discharge. Keep in mind that contaminated soil is often capped prior to redevelopment, creating a high degree of site impermeability, which can be expected to generate a large volume of runoff.

Use of planning strategies and BMPs that prevent the generation of stormwater can be especially beneficial on sites with contaminated soils, as they reduce the volume of stormwater that must be stored and treated. Where applicable and feasible, green roofs, which retain rooftop rainfall, can greatly reduce runoff volume, as can capture and reuse strategies that do not involve contact with the soil. Maximizing vegetative cover will reduce runoff volumes, promote evapotranspiration, prevent erosion of contaminated soil during storm events, and may provide pollutant removal via phytoremediation. Locating buildings and other paved surfaces on contamination hotspots will help to prevent infiltration through those areas.

BMPs commonly used for infiltration, such as bioretention or permeable pavements, should be lined with clean soil or an impermeable barrier, and equipped with underdrains to discharge treated stormwater into the storm sewer. This will allow the use of these BMPs to store and treat stormwater runoff, but prevent contact between stormwater and the contaminated soil.

References and Resources

City of Emeryville, CA. *Stormwater Guidelines for Green, Dense Redevelopment*. http://www.epa.gov/smartgrowth/pdf/Stormwater_Guidelines.pdf

US EPA. 2008. *Case Studies for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*. http://www.epa.gov/nps/lid/

US EPA. 2008. *Design Principles for Stormwater Management on Compacted, Contaminated Soils in Dense Urban Areas*. http://www.epa.gov/nps/lid/

Step 2. Define Goals

LID can address both regulatory requirements and broader issues of environmental stewardship. Once you have a clear understanding of the site conditions and constraints, you can clearly define the project's goals for incorporating LID techniques. These goals may be imposed by local, state, or federal regulations, or may be the result of a desire to handle the site's stormwater in an environmentally responsible manner. A well-defined set of goals will inform the site design and selection of BMPs for the project.

Regulatory Goals

Regulatory requirements governing stormwater management often include minimum requirements for implementation of LID. Since these requirements vary depending on the local NPDES permit, the first step in defining a project's goals should be to evaluate the local regulatory requirements for the project.

Common Regulatory Requirements

- Water Quality Requirements, e.g.:
  - Treat the 85th percentile runoff volume
  - Treat the runoff flow rate generated by a rainfall intensity of 0.2 in/hr

- Hydromodification Requirements, e.g.:
  - Reduce/Match peak runoff discharge rate
  - Hydrograph matching
  - Flow duration control

LID to Help Meet Water Quality Requirements
Incorporation of LID Principles (described in Step 3) into a project will help reduce the runoff volume and peak rate, which will reduce treatment requirements. LID BMPs (described in Step 4) can be selected, sized and implemented to treat polluted runoff.

LID to help meet Hydromodification Requirements
Incorporation of LID Principles (described in Step 3) into a project will help reduce the runoff volume and peak rate, which will reduce the capture volume required for hydromodification mitigation. LID BMPs can then be implemented to address the remaining hydromodification requirements. Where LID infiltration or capture/reuse BMPs are feasible, they will most effectively meet hydromodification requirements as they remove runoff from the system. LID filtration BMPs can also be used to address hydromodification, but the design approaches provided in Step 4 herein may need to be modified to limit outflow from the BMP to meet the regulatory requirements.

LID vs Flood Control
The primary purpose of Low Impact Development is to preserve a site's predevelopment hydrology. Achieving this goal often requires consideration of the larger, less-frequent storm events that play a significant role in hydromodification, in addition to the small, frequent storms that are largely responsible for water quality. It is important to note that under predevelopment conditions, site runoff will occur during large storms. This runoff plays an important role in the geomorphology of receiving waters, reshaping channels and supplying sediment and nutrients. LID is not intended to interfere with these large, channel forming events; rather it is intended to prevent degradation due to excessive discharge of highly polluted runoff from small, frequent storms.

Many communities have long had specific requirements for flood control. Flood control and stormwater management requirements may be set forth by different municipal departments or even different agencies, but nonetheless, these requirements often have similarities that can simultaneously be addressed by applying the LID techniques. Similarly, agencies may have landscaping requirements or green space preservation requirements that can be related to Low Impact Development.

Environmental Stewardship

In addition to meeting the minimum regulatory requirements, implementing LID measures as described in this manual promotes Environmental Stewardship, which can add to the desirability / marketability of a project.

Benefits of Environmental Stewardship through LID

- Achieve LEED certification (details are included in Appendix C)
- Achieve Sustainable Sites Initiative certification (details are included in Appendix C)
- Maintain or restore water balance
- Protect habitat
- Preserve or create green space
- Harvest rainwater for reuse

How Much is Enough?

The goal evaluation process will define the level of LID implementation required for most projects. Due to the variables associated with the factors that define LID goals for a project, it is not possible for this manual to provide a single answer regarding the required extent of LID implementation. Furthermore, what may be considered an acceptable level of LID implementation in one area may be quite different acceptable levels in other areas.

Once the goals for LID implementation are determined for a project, the level can be compared to the following metrics.

Table 5. Levels of LID, Water Quality Treatment, and Hydrologic Control.

Level of Low Impact Development	Evaluation Metrics to be Achieved by Project	Notes
"Limited" Impact Development	Water Quality Treatment • 85th percentile average annual runoff captured and treated before release	Caution required. New runoff may create hydrologic conditions of concern.
"Limited" Impact Development	Hydrologic Control • Post development hydrograph significantly altered from predevelopment hydrograph through retention.	Caution required. Runoff reduction may create hydrologic conditions of concern by starving downstream waters of low flows. The reduction or elimination of low flows may have restorative benefits to downstream waters where prior developments have altered predevelopment hydrology.
Low Impact Development	Water Quality Treatment • 85th percentile average annual runoff captured and treated before release Hydrologic Control • Mimics predevelopment runoff volume for regionally appropriate events (e.g., 1yr, 2yr, 5yr, and 10yr, 24hr storm events)	Elevated peak flows may create hydrologic conditions of concern.
Low Impact Development	Water Quality Treatment • 85th percentile average annual runoff captured and treated before release Hydrologic Control • Mimics predevelopment runoff volume and peak flows for regionally appropriate events (e.g., 1yr, 2yr, 5yr, and 10yr, 24hr storm events)	Maintenance or restoration of predevelopment runoff hydrograph prevents downstream degradation.

Source: The Low Impact Development Center, Inc.

Step 3: Implementing LID Principles

Introduction

Once the site assessment has been performed and goals for implementing LID on the project have been defined, specific LID strategies can be selected and implemented to address the potential impacts of development discussed in Section 1 of this manual.

LID strategies can be broadly divided into two types:
- **LID Principles** that **minimize** the causes (or drivers) of project impacts, and
- **LID BMPs** that help **mitigate** unavoidable impacts.

Incorporating LID Principles at the beginning of the development planning process is the most cost effective way to implement LID successfully. When properly done, such measures can greatly reduce the extent of impacts that must be mitigated with BMPs. As such, a project proponent should exhaust all available and applicable measures to minimize impacts, before moving on to mitigating the remaining impacts.

It is important to note that LID Principles apply to each of the phases of a project, including: planning, design, construction and occupation.

Table 6. Examples of LID Principles and Where Within a Project Lifecycle They Can Be Implemented.

Phase	LID Principles (minimization)	LID Principles/ BMPs (mitigation)
Planning	• Preserve natural infiltration capacity • Preserve existing drainage patterns • Protect existing vegetation and sensitive areas	N/A
Design	• Minimize impervious area • Disconnect impervious areas	• Infiltration BMPs • Capture/Reuse BMPs • Filtration BMPs
Construction	• Minimize construction footprint • Minimize unnecessary compaction • Minimize removal of native vegetation and trees	• Revegetate disturbed areas
Occupation	• Implement source control BMPs	• Maintain BMPs appropriately

Source: The Low Impact Development Center, Inc.

Step 3 in this manual provides examples of LID Principles and how they can be incorporated into a project. The use of these strategies will help to maximize the effectiveness of the LID implementation, further improving and integrating stormwater management into the site. An LID project should attempt to incorporate each of these strategies to the extent appropriate, however the unique combination of features of the project site, as determined by the site assessment, will help inform the selection process. Creating a site plan that works with the site's natural features will generate a more hydrologically functional site and result in a site design that more closely mimics its predevelopment hydrograph, which in turn will help reduce the requirement for mitigation measures.

The simplest way to maintain the predevelopment hydrologic function of a site is to minimize the development footprint, preserving existing topography and drainage patterns. However, many development projects involve complete landform manipulation, where the entire site is cleared and graded. On such sites, where such grading is unavoidable, predevelopment hydrologic function can be reproduced with a proper mix of design strategies, especially minimizing impervious area, and the use of supplemental BMPs to store and treat excess runoff.

Maximize Natural Infiltration Capacity

A key component of LID is taking advantage of a site's natural infiltration and storage capacity. This will limit the amount of runoff generated, and therefore the need for mitigation BMPs. The site soils/geology assessment described previously in this manual will help to define areas with high potential for infiltration and surface storage.

These areas are typically characterized by:

- Hydrologic Soil Group A or B soils
- Mild slopes or depressions
- Historically undeveloped areas

Table 7. Available Techniques to Preserve Natural Infiltration Capacity.

Phase	Available Techniques
Planning	• Avoid placing buildings or other impervious surfaces on highly permeable areas. • Cluster buildings and other impervious areas onto the least permeable soils.
Design	• Where paving of permeable soils cannot be avoided, loss of infiltration capacity can be minimized by using permeable paving materials.
Construction	• Minimize construction footprint • Minimize unnecessary compaction
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Promoting infiltration in close proximity to buildings, paved structures, or steep slopes has the potential to create geotechnical hazards, such as slope destabilization or premature failure of structures. A geotechnical engineer should always be consulted when designing infiltration-based BMPs to ensure that site conditions are suitable and any potential concerns have been addressed.

Preserve Existing Drainage Patterns and Time of Concentration

Integrating existing drainage patterns into the site plan will help maintain a site's predevelopment hydrologic function. Preserving existing drainage paths and depressions will help maintain the time of concentration and infiltration rates of runoff, decreasing peak flows. The best way to define existing drainage patterns is to visit the site during a rain event and to directly observe runoff flowing over the site. If this is impossible, drainage patterns can be inferred from topographic data, though it should be noted that depression micro-storage features are often not accurately mapped in topographic surveys. Analysis of the existing site drainage patterns during the site assessment phase of the project can help to identify the best locations for buildings, roadways, and stormwater BMPs.

Minimize site grading that eliminates small depressions, which can provide storage of small storm volumes. Where possible, add additional depression "micro" storage throughout the site's landscaping. Mild gradients can be used to extend the time of concentration, which reduces peak flows and increases the potential for additional infiltration. While of course risk of serious flooding must be minimized, the persistence of temporary "puddles" during storms is beneficial to infiltration. If a site is visited during dry weather, these areas can sometimes be identified by looking for surficial dried clay deposits.

Table 8. Available Techniques to Help Preserve Existing Drainage Patterns and Increase the Time of Concentration.

Phase	Available Techniques
Planning	• Avoid channelization of natural streams • Establish set-backs and buffer areas from natural streams. • Where natural streams will be converted to engineered streams, provide sinuosity to increase the time of concentration. • Minimize mass grading of project site to avoid elimination of small depressions, which can provide storage of small storm volumes.
Design	• Avoid channelization of natural streams. • When designing channels, use mild slopes and increase channel roughness to extend time of concentration • When possible, use pervious channel linings to maximize opportunity for infiltration.
Construction	• Minimize construction footprint
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Protect Existing Vegetation and Sensitive Areas

A thorough site assessment will identify any areas containing dense vegetation or well-established trees. When planning the site, avoid disturbing these areas. Soils with thick, undisturbed vegetation have a much higher capacity to store and infiltrate runoff than do disturbed soils. Reestablishment of a mature vegetative community can take decades. Sensitive areas, such as wetlands, streams, floodplains, or intact forest, should also be avoided. Development in these areas is often restricted by federal, state and local laws.

Vegetative cover can also provide additional volume storage of rainfall by retaining water on the surfaces of leaves, branches, and trunks of trees during and after storm events. This capacity is rarely considered, but on sites with a dense tree canopy it can provide additional volume mitigation.

Table 9. Available Techniques to Protect Existing Vegetation and Sensitive Areas.

Phase	Available Techniques
Planning	• Establish set-backs and buffer zones surrounding sensitive areas • Incorporate established trees into site layout
Design	• Design site to deter human activity within sensitive areas (i.e. fences, signs, etc)
Construction	• Provide and maintain highly visible flagging and/or fencing around sensitive areas or vegetation that is to be protected.
Occupancy	• Establish use/access restrictions to sensitive areas

Source: The Low Impact Development Center, Inc.

Minimize Impervious Area

One of the principal causes of environmental impacts due to development is the creation of impervious surfaces. Impervious cover can be minimized through identification of the smallest possible land area that can be practically impacted or disturbed during site development. Below is a partial list of techniques that can reduce the amount of impervious area that will be created as part of a project. It is important to note that local laws and ordinances may dictate minimum requirements for road widths or building setbacks that cannot be reduced due to public health and safety concerns. In certain situations, it may be possible to achieve changes to codes and ordinances. Additional information can be found in the EPA Green Infrastructure Municipal Handbook, which is accessible online at: http://cfpub.epa.gov/npdes/greeninfrastructure/munichandbook.cfm.

Table 10. Available Techniques to Minimize Impervious Surfaces.

Phase	Available Techniques
Planning	• Build vertically rather than horizontally - add floors to minimize building footprint. • Cluster development to reduce requirements for roads and preserve green space. • Minimize lot setbacks (which in turn minimize driveway lengths) • Reduce road widths to minimum necessary for emergency vehicles
Design	• Install sidewalks on only one side of private roadways • Use alternative materials such as permeable paving blocks or porous pavements on driveways, sidewalks, parking areas, etc. • Create smaller parking spaces intended for compact cars.
Construction	• Minimize unnecessary compaction. The infiltrative capacity of soils can be greatly reduced when they are compacted, often to the point that they perform similarly to impervious surfaces. Work with a geotechnical engineer to determine the minimum level of compaction necessary to provide structural stability.
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

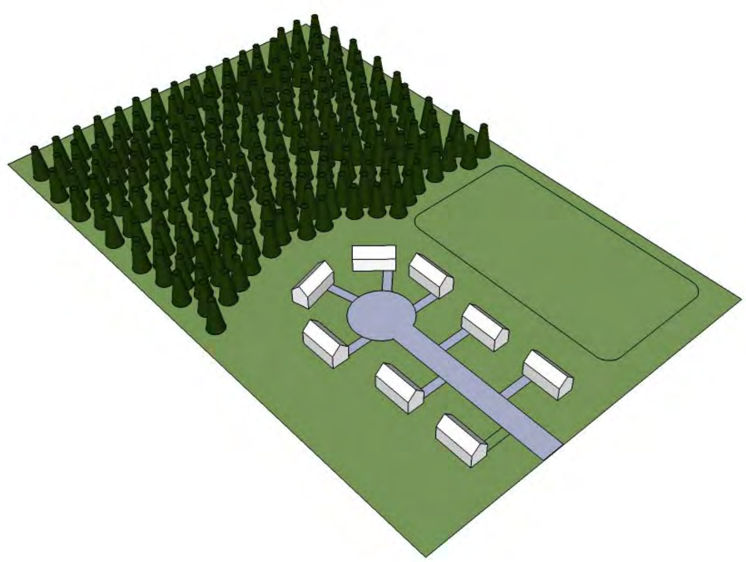

Figure 14. Residential development, showing housing clustered in one part of the site, preserving forest cover and creating space for a playing field (e.g. soccer, football, or other recreational area).
Source: The Low Impact Development Center, Inc.

Disconnect Impervious Areas

Runoff from 'connected' impervious surfaces commonly flows directly to a stormwater collection system with no opportunity for infiltration into the soil. For example, roofs and sidewalks commonly drain onto parking lots, and the runoff is conveyed by the curb and gutter to the nearest storm inlet. Runoff from numerous impervious drainage areas may converge, combining their volumes, peak runoff rates, and pollutant loads. Disconnecting impervious areas from conventional stormwater conveyance systems allows runoff to be collected and managed at the source or redirected onto pervious surfaces such as vegetated areas. This reduces the amount of directly connected impervious area (DCIA), and will reduce the peak discharge rate by increasing the time of concentration (T_c), maximize the opportunity for infiltration by reducing the velocity of flows and providing for greater contact time with the soil, and maximize the opportunity for evapotranspiration during transport.

Disconnection practices may be applied in almost any location, but impervious surfaces must discharge into a suitable receiving area for the practices to be effective. Information gathered during the site assessment will help inform the determination of appropriate receiving areas. Typical receiving areas for disconnected impervious runoff include landscaped areas and/or other LID Mitigation BMPs (i.e. filter strips or bioretention). Runoff must not flow toward building foundations or be redirected onto adjacent private properties. Setbacks from buildings or other structures may be required to ensure soil stability, particularly for practices that are designed to concentrate and infiltrate runoff. Consult with the project geotechnical engineer to identify areas where infiltration can be accommodated.

Discharge areas must be located down gradient from runoff discharges. In a residential setting, this could mean that roof runoff discharges to either the front yard or the back yard, depending on the site configuration. As compared to conventional development, some potential techniques for redirecting flows to vegetated areas may require local design standards to be revisited.

Table 11. Available Techniques to Disconnect Impervious Areas.

Phase	Available Techniques
Planning	• Plan site layout and mass grading to allow for runoff to be directed into distributed permeable areas such as turf, recreational areas, medians, parking islands, planter boxes, etc. • Avoid channelization of natural on-site streams
Design	• Provide permeable areas within medians and parkways that are designed to accept runoff from adjacent areas (i.e. via curb cuts). • Construct roof downspouts to drain to pervious areas such as planter boxes or adjacent landscaping. • Use permeable paving materials such as paving blocks or porous pavements on driveways, sidewalks, parking areas, etc.
Construction	N/A
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

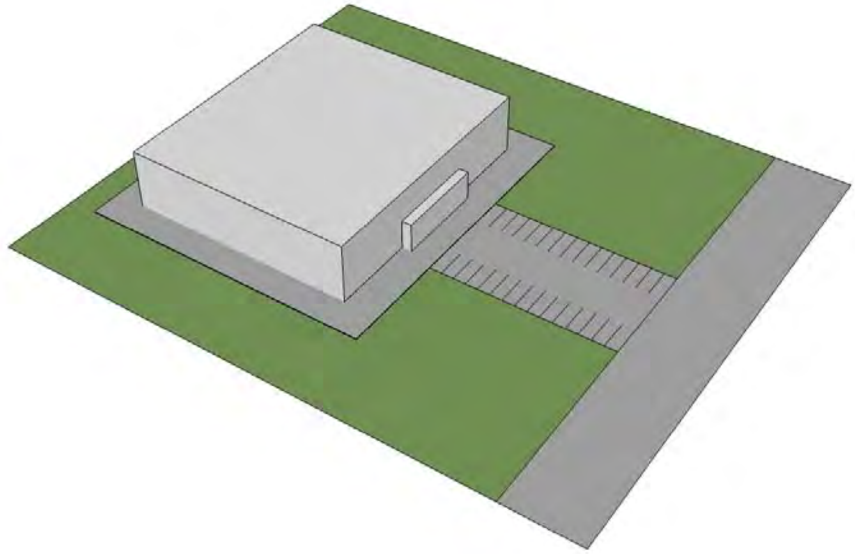

Figure 15. Commercial site showing directly connected impervious areas. The roof drains to the sidewalk, which drains to the parking lot, and then directly onto the street.
Source: The Low Impact Development Center, Inc.

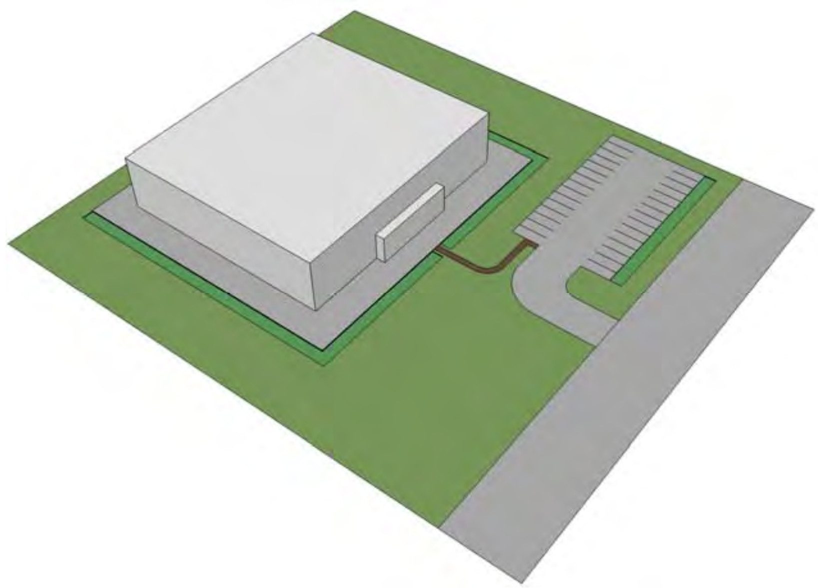

Figure 16. Commercial area in which impervious surfaces have been disconnected. Runoff from the roof and sidewalk are captured by bioretention cells. Sidewalks are separated from the parking lot by a large vegetated area. The parking lot drains to a bioretention cell rather than directly to the street.
Source: The Low Impact Development Center, Inc.

Minimize Construction Footprint

Minimizing the amount of site clearing and grading can dramatically reduce the overall hydrologic impacts of site development. This applies primarily to new construction but the principles can be adapted to retrofit and infill projects as well.

Soil compaction resulting from the movement of heavy construction equipment can reduce soil infiltration rates by 70-99 percent (Gregory et al, 2006). Even low levels of compaction caused by light construction equipment can significantly reduce infiltration rates. In addition, compaction can destroy the complex network of biota in the soil profile that support the soil's ability to capture and mitigate pollutants. Soil compaction severely limits the establishment of healthy root systems of plants that may be used to revegetate the area. For these reasons, it is very important to avoid unnecessary damage to soils during the construction process. The use of clearly defined protection areas will help to preserve the existing capacity of the site to store, treat and infiltrate stormwater runoff.

Site designers should work with civil and geotechnical engineers to determine which areas must be graded and compacted to provide soil stability, and which areas may be left undisturbed.

Table 12. Available Techniques to Minimize the Construction Footprint.

Phase	Available Techniques
Planning	• Many of the planning techniques identified in the above sections will help minimize the construction footprint.
Design	N/A
Construction	• Minimize the size of construction easements. • Locate material storage areas and stockpiles within the development envelope. • Limit ground disturbance outside of areas that require grading. • Identify and clearly delineate access routes for the movement of heavy equipment. • Establish and delineate vegetation and soil protection areas.
Occupancy	N/A

Source: The Low Impact Development Center, Inc.

Establish Vegetation and Soil Protection Areas

Vegetative protection areas (e.g. stream, river, lake and other watercourse buffers, vegetation protection areas, existing trees) should be clearly delineated with highly visible fencing materials to prevent incursion of equipment or the stockpiling of materials during construction. Tree trunks should be sheathed during construction to prevent or minimize damage to the bark.

Use of Mulch and Load Distributing Matting

Mulch blankets can be used to protect soil from compaction during construction. The use of timbers or other types of load distributing materials can also be used to limit the effect of heavy equipment movement on the site.

Pre / Post Construction Soil and Plant Treatments

Consideration should be given to pre-construction treatment of the soil to mitigate the stresses on existing shrubs and trees. This can include soil aeration and specific fertilization protocols that would encourage plant vitality. A local restoration ecologist should be engaged well in advance of the start of construction to develop a plan based on specific site conditions since some of these practices are carried out prior to construction.

Inspection Guidelines and Procedures

Management of soil, water, and vegetation protection measures during the construction process will only be effective if it is carefully implemented and meticulously policed during all phases of construction. Even if overlooked for a single day, significant damage can be done. The cost of damage remediation will be far greater than the cost of avoiding it. Areas intended for infiltration should be treated especially carefully. Avoid the use of heavy machinery or discharge of sediment-laden runoff in these areas.

Techniques implemented on the construction site to minimize the construction footprint should be included in the project documentation and contractors working on the project should review and agree to comply with them while working on the jobsite. Construction site inspections should include inspection of such protocols to ensure they are maintained throughout construction.

Revegetate Disturbed Areas

Introduction

Maximizing plant cover protects the soil and improves ability of the site to retain stormwater, minimize runoff, and help to prevent erosion. Plants have multiple impacts on downstream water quality. First, the presence of a plant canopy (plus associated leaf litter and other organic matter that accumulates below the plants) can intercept rainfall, which reduces the erosive potential of precipitation. With less eroded material going to receiving waters, turbidity, chemical pollution, and sedimentation are reduced. Second, a healthy plant and soil community can help to trap and remediate chemical pollutants and filter particulate matter as water percolates into the soil. This occurs through the physical action of water movement through the soil, as well as through biological activity by plants and the soil microbial community that is supported by plants. Third, thick vegetative cover can maintain and even improve soil infiltration rates.

When revegetating areas that will not be landscaped as part of the project, preference should be given to native vegetation, which is uniquely suited to the local soils and climate. However, consideration of the location of the plants in the landscape with regards to wildfire safety can sometimes make the use of native species unsuitable. Information about typical native species occurring in common local vegetative communities can be found in LID Site Assessment – Vegetation section of this manual. Additional information can be found by contacting local Master Gardeners or seeking the advice of local plant nurseries, which will have specific knowledge of plants suitable for your particular application. The Las Pilitas Nursery in Santa Margarita has compiled a detailed database of California native plants which is accessible online at: http://www.laspilitas.com/comhabit/california_communities.html. The website can be used to aid in determining the correct plant communities by searching by either ZIP code or town. In cases where use of native vegetation is impractical or impossible, use of non-natives adapted to similar climate regimes, such as the Mediterranean, may be appropriate. Appendix A can help with selection of plant species suitable for Southern California. This strategy will maximize the successful establishment of plantings, and minimize the need for supplemental irrigation.

Soil Stockpiling and Site Generated Organics

The regeneration of disturbed topsoil can take years under optimal conditions, and sometimes can take many decades (Brady and Weil, 2002). Proper stockpiling, storage, and reapplication of disturbed topsoil can greatly accelerate this process. Improper soil storage and restoration can significantly decrease the biological activity of the soil, decrease the successful establishment of plantings, and increase the ability of undesirable invasive species to dominate the disturbed landscape.

Soil stockpiling and the use of in situ grubbed plant material and duff as mulch or soil amendments should be encouraged. This will reduce the need for importation of top soil to improve soil quality, and will encourage reestablishment of soil flora and fauna after site disturbance. Successful soil stockpiling and reuse begins in the early stages of project planning.

The use of topsoil harvested from the local site can improve the productivity and rate of re-vegetation of a disturbed site. In addition to stockpiled soil, vegetative material grubbed from the site and free of invasive species can be tilled back into the soil to increase organic content.

Restoration of disturbed areas using native soils which have been properly stockpiled during the construction phase of the project is the preferred method of post construction soil restoration. Proper assessment of the site during the pre-construction phase of the project is critical to maintaining soil quality, both structural and biological, during the period the soil is stockpiled. Determination of the volume of soil to be stockpiled and designating an area large enough on site to accommodate the stockpiled soil should be considered early in project design.

Consideration must be given to maintenance of the flora and fauna present in the stockpiled soil in addition to its physical condition. Improper storage such as soil that is too wet or stockpiled to deeply, can render what were active biological soil communities sterile. This will severely impact the ability of the soil to support a healthy plant community. If necessary, a local soil scientist familiar with regional soils can provide testing services to evaluate soil condition prior to and after construction and recommend appropriate remediation steps to restore the soil's predevelopment ability to infiltrate stormwater runoff and support a healthy plant community.

Additional information about the impact of soil stockpiling can be found in the following document which was prepared for the District 11 office of the California Department of Transportation.

Restoration in the California Desert - http://www.sci.sdsu.edu/SERG/techniques/topsoil.html

Firescaping

Fire is a part of the ecosystems of Southern California. Over the years, wildfires have repeatedly destroyed homes and caused loss of life. In response to this natural phenomenon, extensive research has been done and, in the interest of public safety, guidelines have been codified into law. When considering any planting or re-vegetation plan consideration must be given to minimizing the risks of fire with proper plant selection and maintenance. Keep in mind that all plants are flammable given the right conditions; selection and maintenance of plants to mitigate flammability go hand in hand. A plant with a low flammability rating which is allowed to accumulate dead wood or excessive levels of duff in and around the plant will elevate the risk of flammability significantly.

California law (Public Resources Code 4291) requires a minimum 100-foot space around homes on level ground to protect the structure and provide a safe area for firefighters. If a home is located on a slope, additional distance is required and plant spacing, selection, and design must be modified to maintain proper fire safety margins.

A four zone system has been developed to create a maximum buffer around structures located in high risk wildfire zones. Each zone has very specific landscaping and management requirements to minimize flammability of the landscape.

The four zones are broken down as follows:

Zone One – The garden or clean and green zone
Zone Two – The greenbelt or reduced fuel zone
Zone Three – The transition zone
Zone Four – Native or Natural Zone / Open Space

The landscape plant selection and design for any bioretention or re-vegetation project should be compliant with the requirements of the specific zone in which it will be located. For assistance in determining the correct zone plant selection and spacing, contact your local fire department or insurance company for assistance. Additional resources are provided below for specific information about successful firescaping plant selection and design requirements.

Additional Information

California Department of Forestry and Fire Protection (CAL FIRE) - http://www.fire.ca.gov

California Master Gardeners - http://camastergardeners.ucdavis.edu

Center for Fire Research - http://firecenter.berkeley.edu

University of California Agriculture and Natural Resources SAFE Landscapes - http://groups.ucanr.org/SAFE/

Xeriscape Landscaping

As water use, the frequency of drought, and the impact of organic waste generated from landscape management increase in California, methods to deal with these problems have been developed. The concept of xeriscape was originally developed by the Denver Water Department in 1978. The word was coined by combining the Greek word *xeros* ("dry") with landscape. Since 1978, the xeriscape has become a widely-accepted alternative to traditional landscape design in dry areas.

Xeriscape landscaping is a landscape design and plant selection scheme that is used to minimize required resources and waste generated from a landscape. Defined as “quality landscaping that conserves water and protects the environment” the principles of xeriscape should be employed in any project that creates or restores the landscape. Consulting local resources, such as your local county extension agent, Master Gardeners, Landscape Architects, or local garden centers and nurseries, will help to select plant material suitable for a specific geographic location.

Xeriscape landscaping is based on seven principles:

- Planning and design
- Soil analysis
- Appropriate plant selection
- Practical turf areas
- Efficient irrigation
- Use of mulches
- Appropriate maintenance

Xeriscape landscaping has many benefits which include:

- Reduced water use
- Decreased energy use
- Reduced heating and cooling costs resulting from optimal placement of trees and plants
- Minimal runoff from both stormwater and irrigation resulting in reduction of sediment, fertilizer and pesticide transport
- Reduction in yard waste that would normally be landfilled
- Creation of habitat for wildlife
- Lower labor and maintenance costs
- Extended life of existing water resources infrastructure.

A xeriscape-type landscape can reduce outdoor water consumption by as much as 50 percent without sacrificing the quality and beauty of your home environment. It is also an environmentally sound landscape, requiring less fertilizer and fewer chemicals. Xeriscape-type landscape is low maintenance, saving time, effort and money.

The Water Conservation in Landscaping Act of 2006 requires local agencies to adopt landscape water conservation ordinances. Agencies can either adopt the Department of Water Resources' Model Water Efficient Landscape Ordinance, or create their own ordinances, which must be at least as effective. The model ordinance is available at: http://www.water.ca.gov/wateruseefficiency/landscapeordinance/.

Additional Information

Caldwell, E. 2007. *With xeriscaping, grass needn't always be greener*. USA Today July 17, 2007. http://www.usatoday.com/tech/science/2007-07-15-xeriscaping_N.htm

California Department of Water Resources - Water Use Conservation Methods http://www.water.ca.gov/wateruseefficiency/landscape/

CalRecycle Website: http://www.calrecycle.ca.gov/Organics/xeriscaping/

University of California Cooperative Extension, and California Department of Water Resources. 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*; California Department of Water Resources: Sacramento, CA. http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf

USEPA Office of Water. 1993*. Xeriscape Landscaping: Preventing Pollution and Using Resources Efficiently* (EPA-840-B-93-001). USEPA: Washington, DC. Available through the EPA NSCEP Website. http://www.epa.gov/nscep/ - Search by document number listed above.

Xeriscape Council of New Mexico – Xeriscape reference list. http://www.xeriscapenm.com/xeriscaping_references.php

Planning / Inspection Guidelines

The quality and size of plant material should be clearly defined in the landscaping and re-vegetation plans and the establishment period for the re-vegetation and landscaping should be clearly identified, including any specific establishment guidelines. While native plants are typically the lowest maintenance option for re-vegetation and landscaping any post-installation maintenance required will be dictated by the characteristics of the selected plant community.

Implement Source Control Measures

The discharge of many common stormwater pollutants from a project site can be greatly minimized by practicing vigilant source control. The most common stormwater pollutant impairments in Southern California fall into ten categories:

- Suspended solids
- Oxygen demanding substances
- Nitrogen compounds
- Phosphorus
- Microbial pathogens
- Heavy metals
- Oil and grease
- Toxic organic compounds (e.g. pesticides)
- Trash

Table 13 provides additional details on the sources of these pollutants/indicators.

Table 13. Pollutants in Stormwater.

Pollutant	Origin	Discharge Source(s)	Location
Suspended Solids	• Small particles of clay, silt, sand, other soil materials, small particles of vegetation, and bacteria	Soil erosion Motor vehicles Building materials	Deposited on impervious surfaces
Oxygen demanding substances	• Natural origin • Excess biodegradable materials or waste discharge	Excess organic waste products such as lawn clippings and leaves	Landscaped areas
Nitrogen compounds	• Excess residential, agricultural, and commercial fertilizer use • Animal wastes • Plant decay • Atmospheric deposition	Turf grass Non native ornamental landscapes	Highly managed landscapes in both residential and commercial developments
Phosphorus	• Excess fertilizer use • Decaying vegetation, such as lawn clippings and leaves • Present in animal waste	Maintained commercial and residential landscapes Golf courses	Highly managed landscapes in both residential and commercial developments
Microbial pathogens	• Present in animal waste	Runoff from areas where waste has been deposited	Landscaped and natural areas Trails and walkways
Heavy metals	• Released in vehicle emissions • Released by tire wear • Break pads • Leach from asphalt shingles	Motor vehicles Asphalt shingles	Driveways, roadways, highways, parking and storage lots Roofs
Oils and Grease	• Leaks or spills from motor vehicles	Motor vehicles	Driveways, roadways, highways, parking and storage lots
Toxic organic compounds	• Pesticides	Pesticides used for commercial, agricultural and residential applications	Runoff from treated landscapes and agricultural areas
	• Polycyclic aromatic hydrocarbons (PAHs)	Motor vehicle fuel leakage and spillage Asphalt pavement Asphalt roof runoff	Roads and parking lots Runoff from buildings with asphalt roofing materials (shingles, membrane and other types of roofs)
	• Solvents	Industrial, commercial and residential cleaners, degreasers and lubricants	
Trash	Non-biodegradable plastics and coated paper products. Depending on storm intensity, a large variety of debris that would be classified as trash can be mobilized.	Human activities	Parking lots and roadways Sidewalks Parks and recreation areas

Source: Davis and McCuen, 2005

Suspended Solids (TSS)

The largest source of suspended solids is soil erosion. Protecting and revegetating soil is the best practice for reducing TSS. Implementation of industry standard erosion and sediment control measures during construction is a very effective method to control the transport of TSS on- and off-site during and after the construction process. Innovative Erosion and Sedimentation (E&S) practices, such as compost socks and compost berms, have become widely accepted as effective TSS control practices.

Proper site design, incorporating maximum vegetative cover and the appropriate use of mulching to minimize exposed soil, dramatically reduces the levels of TSS generated during and after construction. Pretreating for TSS prior to runoff entering other BMPs will significantly extend the functional lifespan of the BMP.

Oxygen demanding substances

High levels of organic material in runoff increase the population of aerobic microorganisms, resulting in reduced dissolved oxygen content. Typical levels of biodegradable organic compounds do not contribute a major oxygen demand in runoff. Properly disposing of organic materials can help minimize the creation of oxygen demanding substances.

Nitrogen compounds / Phosphorus

High levels of nutrients, such as nitrogen and phosphorus, in runoff contribute to eutrophication in receiving waters. Although runoff from agricultural fields and feed lots is a major source of these pollutants, urban areas with improperly managed landscapes can also be substantial sources. The nutrient content in runoff can be reduced at the source by limiting application of fertilizers to landscaped areas to the minimum necessary. Measures that lower nutrient runoff potential by limiting fertilizer application and reducing the requirement for supplemental application include the use of conservation design principles, the reduction of high maintenance turf grass, and integration of native plants into the landscape.

Microbial pathogens

The primary source of microbial pathogens is feces from wild and domestic animals. Domestic animal feces should be managed with a combination of public awareness and municipal regulation requiring owners to remove waste left by their pets. At moderate levels, microbial pathogens can be mitigated by naturally occurring biota found in bioretention cell soils.

Heavy metals, oil, and grease

Automobiles, trucks, and buses are the primary source of heavy metals, oils, and grease found in urban settings. Source control for automotive sources includes fixing leaks, performing maintenance in covered/appropriate areas, and washing vehicles in the grass.

Toxic organic compounds

Toxic organic compounds are found in pesticides used on high maintenance landscapes. The proper selection, application, and timing of application of pesticides can be the most effective way to control the source of pesticide toxicity. In the event levels of these pollutants are found that exceed EPA standards, appropriate local or state agencies should be contacted. If the source of the pollutants can be identified, it should be remediated by trained personnel.

Trash/floatables

Trash is found anywhere there is a human presence. Providing trash cans with lids at convenient locations and installing educational signs can help to prevent trash and floatables from entering the system. Conventional stormwater conveyance infrastructure can be retrofitted with devices to intercept trash and floatables at multiple locations within a drainage area. This reduces the maintenance required by concentrating the trash in fewer locations on the site, where it can be removed during scheduled maintenance of the facility.

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Step 4: Use LID BMPs to Mitigate Impacts

For many projects, it will not be possible to completely meet the minimum goals for the project with LID Principles alone. In such cases, LID BMPs can be implemented to mitigate remaining project impacts. It should be noted that although such LID BMPs may be necessary to meet the goals, the vigilant implementation of LID Principles can significantly reduce the required size of such mitigation BMPs.

This chapter provides descriptions, basic design guidance, and selection criteria for the most commonly used LID BMPs. Detailed information on the five primary BMPs used in LID (Bioretention, Capture/Reuse, Permeable Pavement, Vegetated Roofs, and Soil Amendments) is provided. Other BMPs are described briefly, and links are provided to more detailed sources of information.

The LID BMPs discussed in this manual can be divided into two broad types based on how they function. LID BMPs are either retention BMPs or non-retention BMPs; with the first comprised of BMPs that retain runoff onsite either via infiltration, evapotranspiration, or capture and use, and the latter being comprised of BMPs that filter or treat runoff and allow it to discharge offsite. Depending on any site constraints identified in the LID Site Assessment (Section 1 in this Manual), many LID BMPs can be configured to function as either type. Below is a summary list of various common types of BMPs.

Table 14. BMP Functions of the LID BMPs Discussed in this Manual.

BMP	Capture and Reuse	Infiltration	Filtration
Bioretention (infiltration design)		✓	✓
Bioretention (filtration design)			✓
Porous Pavement (infiltration design)		✓	✓
Porous Pavement (filtration design)			✓
Capture/Reuse	✓		✓*
Vegetated Roofs			✓
Soil Amendments		✓	✓
Downspout Disconnection		✓	✓
Filter Strips			✓
Vegetated Swales			✓
Infiltration (Retention) Basins		✓	✓
Infiltration Trenches		✓	✓
Dry Wells		✓	✓
Dry Ponds (Extended Detention Basins)			✓
Constructed Wetlands			✓
Wet Ponds			✓
Media Filters / Filter Basins			✓
Proprietary Devices			✓
* depends on design			
Many filtration BMPs can result in substantial runoff reduction via infiltration or evapotranspiration.			

Source: The Low Impact Development Center, Inc.

The selection of an appropriate set of BMPs for a given site should be based on the project goals and site capabilities and constraints. Several factors must be taken into account:

- LID goals (peak flow reduction, storage volume needed, pollutant removal)
- Site configuration (e.g. space available)
- Site constraints (e.g. slopes, depth to groundwater)
- Operation and maintenance requirements
- Cost

The following tables can be used to compare BMPs.

Table 15. BMP Performance – Hydrologic Impacts.

BMP	Volume Reduction	Peak Flow Reduction	Groundwater Recharge
Bioretention (infiltration design)	●	●	●
Bioretention (filtration design)	○	●	○
Porous Pavement (infiltration design)	●	●	●
Porous Pavement (filtration design)	○	●	○
Capture/Reuse	◉	○	○
Vegetated Roofs	○	●	○
Soil Amendments	◉	◉	◉
Downspout Disconnection	◉	◉	◉
Filter Strips	◉	○	◉
Vegetated Swales	◉	○	◉
Infiltration (Retention) Basins	●	●	●
Infiltration Trenches	◉	○	◉
Dry Wells	◉	○	◉
Dry Ponds (Extended Detention Basins)	○	●	○
Constructed Wetlands	◉*	●	○
Wet Ponds	◉*	●	○
Media Filters / Filter Basins	○	◉	○
Proprietary Devices	○	○	○

Key: ● High effectiveness ◉ Medium effectiveness ○ Low effectiveness

Rankings are qualitative.

- "High effectiveness" means that one of the BMP's primary functions is to meet the objective.
- "Medium effectiveness" means that a BMP can partially meet the objective but should be used in conjunction with other source controls.
- "Low effectiveness" means that the BMP provides minimal benefit to the objective and another BMP should be used if that objective is important.

* Wetlands and wet ponds constructed on soils with high permeability are difficult to keep saturated during Southern California's extended dry season. For this reason, they are rarely used, and only on highly impermeable soils.

Source: Adapted from WERF, 2006.

Table 16. Environmental Benefits of BMPs.

BMP	Runoff Quality Enhancement	Water Conservation (Recharge/Reuse)	Heat Island Reduction	Energy Conservation	Air Pollution Reduction	Habitat
Bioretention	✓	✓	✓		✓	✓
Permeable Pavement	✓	✓				
Capture/Reuse	✓	✓				
Vegetated Roofs	✓		✓	✓	✓	✓
Soil Amendments	✓	✓				✓
Downspout Disconnection		✓				
Filter Strips	✓	✓	✓			
Vegetated Swales	✓	✓	✓		✓	
Infiltration (Retention) Basins	✓	✓				
Infiltration Trenches	✓	✓				
Dry Wells	✓	✓				
Dry Ponds (Detention Basins)	✓					
Constructed Wetlands	✓		✓		✓	✓
Wet Ponds	✓					✓
Media Filters/Filter Basins	✓					
Proprietary Devices	✓					

Source: Adapted from WERF, 2006.

RB-AR33751

Table 17. BMP Performance – Influent/Effluent Water Quality.

BMP	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Bioretention without underdrain	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Bioretention with underdrain	34/15.5[*]	1.68/1.14[†]	0.61/0.16[*]	107/46[*]	30.8/2.5[‡]	641.5/86.5[§]	Moderate[**]	
Permeable Pavement without underdrain	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Permeable Pavement with underdrain	xx/17.0[††]	xx/1.23[††]	xx/0.09[††]	xx/17[††]	xx/0.018[‡‡]	No data	Moderate	
Capture and Reuse	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Vegetated Roofs	No data	1.3/1.63***	0.012/0.057***	No data	N/A	xx/22§	Moderate	
Downspout Disconnection	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Soil Amendments	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Vegetated Filter Strips	114/27.6[§§]	1.12/0.66[‡‡]	0.38/0.86[§§]	355/79[§§]	No data	No data	Low	
Vegetated Swales	114/58.9[§§]	No data	0.38/0.62[§§]	355/96[§§]	No data	13,492/5,947[§]	Low	
Infiltration Basins	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Infiltration Trenches	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge

Source: Data assembled by the Low Impact Development Center, Inc.

Table 17 (Cont.): BMP Performance – Influent/Effluent Water Quality.

BMP	Sediment (mg/L)	Nitrogen (mg/L)	Phosphorus (mg/L)	Metals – Zn (µg/L)	Oil and Grease (mg/L)	Bacteria (#/100mL)	Temp	Notes
Dry Wells	0	0	0	0	0	0	Excellent	Infiltration practices are assumed to have zero discharge
Dry Ponds	114/46.6[§§]	0.96/0.98[‡‡]	0.38/0.28[§§]	355/136[§§]	2.72/2.54[‡‡]	2,218/1,741[§]	Poor	
Constructed Wetlands	37.8/17.8[††]	2.12/1.15[††]	0.27/0.14[††]	47/31[††]	No data	2,097/257[§]	Poor[**]	
Wet Ponds	114/11.8[§§]	2.29/1.46[‡‡]	0.38/0.54[§§]	355/37[§§]	0.82/0.88[‡‡]	2,693/446.4[§]	Poor[**]	
Media Filters / Filter Basins	114/11.3[§§]	No data	0.38/0.25[§§]	355/36[§§]	No data	1,820/541.3[§]	Poor	Includes Austin sand filter, Delaware sand filter, Multi-chambered treatment trains
Proprietary Devices	varies	varies	varies	varies	varies	varies	Poor	Performance is device-specific

Key: [*]Davis, 2007 [§]Clary et al, 2008 [†]Hunt et al, 2008 [‡]Hong et al, 2006 [***]Teemusk and Mander, 2007
[**]Jones and Hunt, 2008 [§§]Caltrans, 2004 [††]Geosyntec, 2008 [‡‡]International Stormwater BMP Database, 2009

Source: Data assembled by the Low Impact Development Center, Inc.

Table 18. BMP Site Suitability Criteria.

BMP	Soil HSG				Depth to groundwater		Depth to impermeable layer/bedrock		Slope			High Landslide Risk	Soil Contamination
	A	B	C	D	< 10'	> 10'	<5'	>5'	0-5%	5-15%	> 15%		
Bioretention	✓	✓				✓		✓	✓	✓if terraced			
Bioretention with underdrain			✓	✓	✓	✓	✓	✓	✓	✓ if terraced		✓	✓ with liner
Permeable Pavement	✓	✓				✓		✓	✓				
Permeable Pavement with underdrain			✓	✓	✓	✓	✓	✓	✓			✓	✓with liner
Capture/Reuse	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Vegetated Roofs	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Soil Amendments	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Downspout Disconnection	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Filter Strips	✓	✓	✓	✓		✓		✓	✓				
Vegetated Swales	✓	✓	✓	✓		✓		✓	✓	✓			
Infiltration (Retention) Basins	✓	✓	✓			✓		✓	✓				
Infiltration trenches	✓	✓	✓			✓		✓	✓				
Dry wells	✓	✓	✓			✓		✓	✓				
Dry ponds (detention basins)	✓	✓	✓			✓		✓	✓				✓ with liner
Constructed Wetlands		✓	✓	✓	✓	✓	✓	✓	✓				✓ with liner
Wet ponds		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓ with liner
Media filters / Filter Basins	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Proprietary Devices	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: The Low Impact Development Center, Inc.

Table 18 (Cont.): BMP Site Suitability Criteria.

BMP	Available space			Maintenance		
	Low	Med	High	Low	Med	High
Bioretention		✓		✓	✓	
Bioretention with underdrain		✓		✓	✓	
Permeable Pavement	✓				✓	✓
Permeable Pavement with underdrain	✓				✓	✓
Capture/Reuse	✓			✓		
Vegetated Roofs	✓				✓	
Soil Amendments	✓	✓	✓	✓		
Downspout Disconnection		✓	✓	✓		
Filter Strips		✓			✓	
Vegetated Swales		✓		✓	✓	
Infiltration (Retention) Basins		✓			✓	✓
Infiltration trenches	✓			✓		
Dry wells	✓			✓		
Dry ponds (detention basins)			✓		✓	
Constructed Wetlands			✓		✓	✓
Wet ponds			✓		✓	
Media filters / Filter Basins	✓				✓	
Proprietary Devices	✓					✓

Source: The Low Impact Development Center, Inc.

Table 19. Maintenance Considerations for LID BMPs.

Source Control	Level of Effort	Frequency
Bioretention	**Minimal to Moderate:** Vegetation management required; occasional removal of captured debris	Semi-annual vegetation management, inspection
Permeable Pavement	**Moderate:** Rejuvenation may be needed (vacuum sweeper/power washing); vegetation management; pavement may have to be completely changed	Semi-annual vacuuming, inspection
Capture/Reuse	**Low:** No vegetation management; no removal of captured pollutants	Weekly emptying between storm events Semi-annual inspection
Vegetated Roofs	**Moderate:** Vegetation management	Semi-annual inspection Vegetation management
Soil Amendments	**Minimal:** No vegetation management; no removal of captured pollutants	Annual inspection
Downspout Disconnection	**Minimal:** No vegetation management; no removal of captured pollutants	Annual inspection
Filter Strips	**Low to Moderate:** Management of vegetation; occasional removal of captured pollutants	Weekly mowing Semi-annual inspection
Vegetated Swales	**Low to Moderate:** Minimal removal of captured pollutants; vegetation management	Weekly mowing Semi-annual inspection
Infiltration Basins	**Moderate to High:** Rejuvenation may be needed (scarifying surface/raking); possible removal of vegetation; removal of captured materials	Semi-annual inspection
Infiltration Trenches	**Low:** Removal of captured debris; periodic inspection	Semi-annual inspection
Dry Wells	**Low:** Removal of captured debris; periodic inspection	Semi-annual inspection
Dry Ponds	**Moderate:** Removal of captured debris; vegetation management; periodic inspection	Weekly mowing Semi-annual inspection Sediment removal every 5-25 years
Constructed Wetlands	**High:** Management of vegetation; removal of floating debris and trash; sediment and vegetation removal; maintain water level during dry periods	Semi-annual inspection Vegetation management
Wet Ponds	**Moderate:** Removal of captured debris; vegetation management; mosquito control	Semi-annual inspection, debris removal, Annual vegetation harvesting
Media Filters	**Moderate:** Inspection and removal of captured debris; sediment removal.	Quarterly inspection, debris removal
Proprietary Devices	**Moderate:** Inspection and removal of captured debris; sediment removal.	Quarterly inspection, debris removal

Source: Adapted from WERF, 2006

Infiltration Feasibility

In many jurisdictions, infiltration-based BMPs are given preference over capture- or filtration-based BMPs. The feasibility of using infiltration is determined primarily by the nature of the soils and topography at the site. The following checklist can be used for a preliminary assessment of the feasibility of using infiltration-based BMPs on a site; however, a geotechnical engineer should be consulted anytime infiltration is being considered. In areas where infiltration-based BMPs are planned, appropriate infiltration and percolation tests must be performed to verify soil and subsoil infiltration and percolation rates.

Table 20. Site Factors Influencing the Feasibility of Infiltration.

Site Factor	Acceptable Range
Hydrologic Soil Group	A or B
Soil infiltration rate	At least 0.5 in/hr
Slope	Less than 5% Note: terraced bioretention designs can accommodate slopes up to 15%
Depth to bedrock or impermeable layers	Varies based on site conditions
Depth to seasonal high water table	At least 10 feet
Setback from buildings with basements	At least 50 feet*
Setback from buildings without basements	At least 5 feet*
Landslide risk	Low
Soil contamination	None

* Infiltration designs can be used adjacent to structures if an impermeable membrane is used to protect the structure and if otherwise compatible with engineering specifications. All distances noted are subject to the geotechnical engineer's review and approval based on specific site conditions.

Source: The Low Impact Development Center, Inc.

Cost

In 2009, the Water Environment Research Foundation (WERF) published the second version of its BMP and LID Whole Life Cost Models. The spreadsheet tools are intended to guide the determination of capital and maintenance costs for nine selected stormwater management practices that include:

1. Extended detention basins;
2. Retention ponds;
3. Swales;
4. Permeable pavement;
5. Green roofs;
6. Large commercial cisterns;
7. Residential rain gardens;
8. Curb-contained bioretention; and
9. In-curb planter vaults.

By inputting basic values such as drainage area, treatment volume, construction materials, and maintenance frequencies, the models will estimate BMP project costs.

Literature reviews and costing methods used by queried U.S. stormwater agencies were used to develop the models. The models can provide planning-level estimates of costs or site-specific costs depending upon the level of information that the user can provide. Each of the models contains default cost values from project research. Adding a few inputs (e.g., drainage area, rainfall, and treatment volume) will provide planning level capital, maintenance, and whole life costs. The model uses default assumptions, design equations, and unit costs derived from manufacturers, RS Means 100, or reported costs from stormwater agencies. Using the models in this manner provides general cost estimates as the cost factors are based on national averages and do not take into account regional or site specific design factors. The models do note that regional cost data were not normalized to national cost data and data from multiple locations were averaged to determine the model default values.

The models can also provide site-specific cost estimates as nearly every cost component of each model can be customized, allowing inputs that reflect geographic influences and individual site conditions. The models can also be used to provide varying degrees of specificity as each cost component can be provided by the user or a combination of default values and user provided values can be used.

The models and User Guide are available for free at WERF web site: http://www.werf.org/AM/Template.cfm?Section=Search_Publications&TEMPLATE=/CM/ContentDisplay.cfm&CONTENTID=10836.

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Bioretention

Bioretention cells are small-scale, vegetated, shallow depressions that address pollutants contained in stormwater runoff by filtration through an engineered soil medium. Biological and chemical reactions in the soil matrix and root zone remove pollutants, and runoff volume is reduced through plant uptake and infiltration into the underlying subsoil. Where infiltration is impossible, bioretention cells are fitted with underdrains to discharge treated stormwater into the storm drainage system. Properly constructed bioretention cells replicate the hydraulic function of an undisturbed upland ecosystem. By intercepting, detaining, and infiltrating runoff, bioretention cells reduce the volume of stormwater flows and reduce on-site erosion. They may be designed on-line or off-line from the primary stormwater conveyance system.

Bioretention can be designed as an integrated landscape feature that improves water quality while reducing runoff quantity. Bioretention offers considerable flexibility in terms of how it can be integrated into a site, and can complement other structural management systems, such as porous pavement parking lots and infiltration trenches, as well as non-structural stormwater BMPs.

Bioretention vegetation serves to improve water quality and reduce runoff quantity. The plants absorb some pollutants, while microbes associated with the plant roots and soil degrade pollutants. In addition to filtering pollutants, the soil medium allows storage and, where feasible, infiltration of stormwater runoff, providing volume control. Soil media serve as a bonding surface for nutrients to enhance pollutant removal. Additional treatment capacity is provided by a surface mulch layer, which traps sediments that can carry high pollutant loads. The most successful bioretention cells mimic nature by employing a rich diversity of locally-adapted plant types and species, which provides them with good tolerance of pests, diseases, and other environmental stressors.

Figure 17. Bioretention Cell in Parking Lot, Caltrans District 11 Headquarters, San Diego, CA.
Source: Wallace Roberts & Todd, Inc.

Cost

Bioretention cells often replace areas that would have been landscaped and maintenance-intensive, so the net cost can be less than the conventional alternatives. In addition, the use of bioretention can decrease the cost for stormwater conveyance systems on a site. Bioretention cells cost approximately $3-4 per square foot for simple residential designs, and $10-40 per square foot for commercial installations (LIDC, 2007).

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Groundwater recharge (if soils are sufficiently permeable and no underdrain is placed underneath)
- Habitat creation
- Enhanced site aesthetics
- Reduced heat island effect

Limitations

- Terraced designs must be used on steep slopes
- Infiltration design requires sufficiently permeable soils, depth to groundwater and depth to impermeable layers
- Infiltration design should be located at least 100 feet from drinking water wells
- Maximum tributary area should be less than 5 acres
- Requires regular trash removal and maintenance of vegetation
- May require irrigation during dry periods

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Water Supply Impacts

Water supply impacts vary, and are associated with water needed for initial plant establishment and subsequent maintenance. Water will likely be needed for maintenance irrigation, unless the species chosen are adapted to the site's precipitation, soils, and microclimate, and have adequate conditions to survive and grow without supplemental irrigation. In these cases, the long-term supply impact is essentially neutral. For a retrofit project in which an existing "conventionally" landscaped area (e.g., turf or higher water-use plants) is replaced with bioretention, the water supply impact should be positive (i.e., less water is needed) compared to the existing developed condition. Detailed guidance on the irrigation needs of landscape plantings has been published by the California Department of Water Resources (UCCE and CDWR, 2000).

Applications

Bioretention can take many forms, from the simple residential "rain garden", to the "planter box" complete with underdrain and engineered filtering media. Bioretention is appropriate for use in commercial, institutional, residential, industrial, and transportation applications. The common forms of bioretention and potential applications are provided below.

Potential Applications

Residential	YES
Commercial	YES
High-density	LIMITED
Industrial	YES
Recreational/Institutional	YES
Highway/Road	YES
Parking Lots	YES

Residential

Residential settings often provide favorable conditions in which to incorporate bioretention. Bioretention cells can be installed in lawn areas or locations that would otherwise have been landscaped. Roof drainage, driveway, street/sidewalk and yard drainage can be treated with bioretention. A range of treatment train options are available in residential applications. Downspouts, for instance, can deliver stormwater directly to the surface of a bioretention cell or a grass yard, or a vegetated channel can be used as pretreatment for bioretention cell influent.

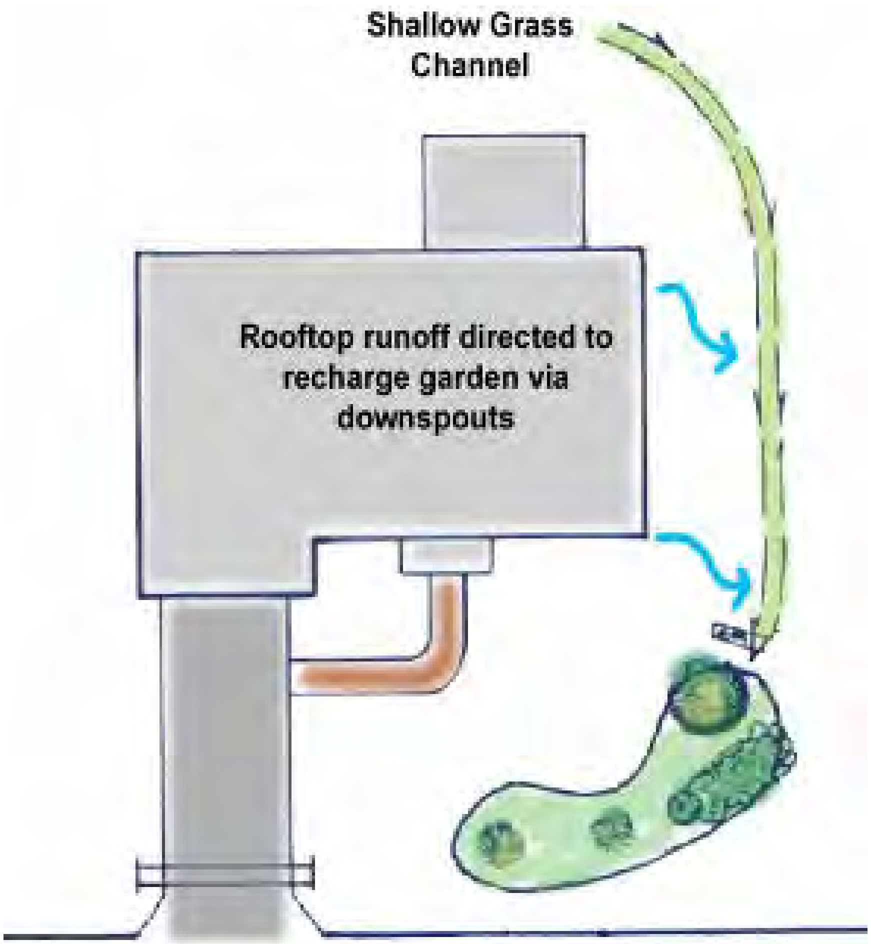

Figure 18. Single-Family Residential Lot Drainage Schematic.
Source: Claytor and Schueler, 1995, with modifications by Cahill Associates

Figure 19. Roof leader draining to bioretention cell.
Source: Wild Ones Natural Landscapers, Ltd., Applewood, MI.

<u>Planter Box</u>
In urban settings, bioretention can be incorporated into planter boxes. As part of a disconnection strategy, roof downspouts may be directed to vegetated planter boxes to store and filter stormwater. Planter boxes offer "green space" in tightly confined urban areas that provide a soil/plant mixture suitable for stormwater capture and treatment.

Planter boxes are most commonly used in urban areas adjacent to buildings and along sidewalks. Locations close to roof downspouts are preferable when used a part of a disconnection program. Planter boxes may be constructed of any durable material. When built adjacent to buildings as a receptacle for downspout runoff, they are often constructed of the same material as the building. Otherwise they may be constructed of concrete to blend in with the sidewalk or metal when they are stand-alone units. Planter boxes constructed adjacent to buildings should be fitted with waterproofing membranes on the building side to prevent seepage of captured water into the building.

Figure 20. Planter box capturing roof runoff.
Source: The Low Impact Development Center, Inc.

Commercial - Parking Lot Landscaped Filter Basin (LFB)
Stormwater management and green space areas are limited in parking areas. In these situations, bioretention can create functional areas out of existing landscaping. Bioretention can be retrofit into existing parking lot islands, or designed into parking lot medians and perimeters.

Figure 21. Parking Lot Bioswale, Oxnard, CA.
Source: Ed Gripp

- *Curbless Parking Lot Bioretention*
  A bioretention cell can be located adjacent to a parking area with wheel stops rather than curbs, allowing stormwater to flow as a distributed “sheet” of water over the parking lot edge and directly into the cell. Shallow grades must direct runoff at reasonable velocities.

- *Curbed Parking Lot Bioretention*
  Runoff can be directed along a parking lot island by using a curb and gutter. Once runoff reaches a low point along the curb perimeter, water enters the bioretention cell through a curb cut. If the runoff volume exceeds the ponding depth available, water will overflow the bioretention cell and enter a standard inlet.

<u>Roadway</u>
Bioretention cells can be used alongside roadways. Runoff is conveyed along the concrete curb until it reaches the end of the gutter, where it spills into the vegetated area. A schematic of this type of arrangement is shown below.

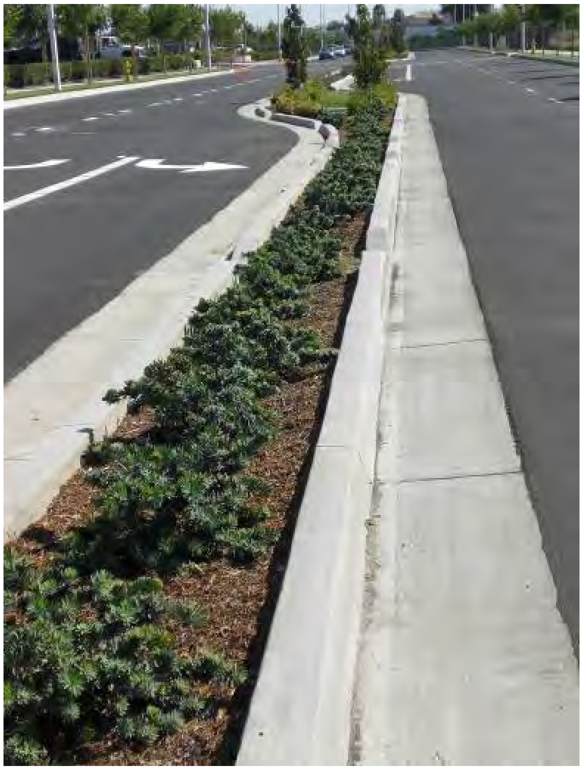

Figure 22. Linear Bioretention, Downey, CA.
Source: Bill DePoto

<u>Dry Swales</u>
In addition to the common “cell” design, bioretention can be incorporated into vegetated swales. Such structures can be used to provide infiltration and water quality treatment while conveying larger flows to supplemental storage BMPs.

Figure 23. Bioretention cell for street/yard drainage, Los Angeles, CA.
Source: Bill DePoto

Site Factors

- Depth to water table: Ten (10)- foot minimum for infiltration (Regional Boards and local agencies may have differing requirements.)
- Depth to bedrock: Varies with site conditions (Regional Boards and local agencies may have specific requirements.)
- Soil permeability: soils are typically required to have a minimum of 0.5 inches per hour for infiltration
- Feasibility on steeper slopes: medium

When working in areas with steeper slopes (up to 15 percent), it is critical to first verify that these BMPs are feasible. A geotechnical engineer should be consulted to evaluate the suitability of installing a bioretention cell on or near a steep slope, to identify the risk of creating an unstable condition; underdrains may be required for slope applications. When they do occur on slopes, bioretention cells should be terraced laterally along slope contours to minimize earthwork and provide level areas for infiltration.

Percolation tests should be performed by a qualified professional to verify soil permeability in the locations where bioretention cells are planned. If soils are found to have percolation rates less than 0.5 in/hour, bioretention cells should be fitted with underdrains and treated as filtration rather than infiltration practices.

Many local jurisdictions are developing standard specifications for the location, sizing, configuration, and/or maintenance of LID BMPs and such requirements where they exist should be used. Where local specifications for bioretention do not exist, the following guidelines can be used.

Building Setbacks
- Buildings with basements: 50 feet, down-gradient from foundation
- Buildings without basements: 5 feet

Planter box bioretention facilities can be placed adjacent to buildings if they are fit with waterproofing membranes adjacent to the building wall.

Pedestrian Traffic
Pedestrian traffic across bioretention cells causes compaction, decreasing the infiltration rate of the soil. Walking across bioretention cells should be discouraged by providing alternative pathways and by planting densely.

Pretreatment (may be necessary to help prevent clogging)
Pretreatment consists of sediment removal through a vegetated buffer strip, cleanout, stabilized inlet, water quality inlet, or sediment trap prior to runoff entry into the bioretention cell. Pretreatment of runoff should be provided wherever excessive sediment is likely to enter the bioretention cell and cause concern for decreased functionality of the BMP. Rooftop runoff may need little or no pretreatment.

Flow Entrance
Options:
- Water may enter via an inlet (e.g., flared end section) or trench drain
- Sheet flow into the facility over grassed areas or level spreader
- Curb cuts with grading for sheet flow entrance
- Roof leaders with direct surface connection

Entering velocities must be non-erosive where concentrated runoff enters the bioretention cell – use inlet energy dissipaters such as rocks or splash blocks.

Figure 24. Bioretention cell for street/yard drainage, Downey, CA.
Source: Bill DePoto

Figure 25. Curb cut directing water from the street into a bioswale.
Source: Haan-Fawn Chau

<u>Ponding Area</u>
For most areas, maximum 3:1 side slopes or flatter are recommended to enhance safety and buffer the erosive force of incoming runoff. In planter boxes or other areas where vertical walls are necessary, use energy dissipators to control erosion.

Surface ponding depth is generally 6 to 12 inches. Drawdown times vary by jurisdiction, but are generally in the range of 24-72 hours to minimize vector issues and prevent depletion of oxygen in the soil.

<u>Bioretention Soil Medium/Volume Storage Bed</u>
Bioretention soil medium (BSM) depth should be between 24 and 36 inches where only herbaceous plant species will be utilized. If trees and woody shrubs will be used, soil media depth may need to be increased, depending on plant species (especially in poorly drained sites). Provided they meet drainage criteria, native soils can be used as part of the soil medium.

The BSM is generally composed of: 50 percent sand, 30 percent topsoil, and 20 percent organic material by volume (LIDC, 2003). The formula can be varied to some extent, but major changes may impact both hydraulic and pollutant removal performance and should be studied carefully. Engineered soil media meeting the specification described in Table 21 can be expected to have infiltration rates ranging from 25 – 130 in/hr (Hsieh and Davis, 2005).

Table 21. Bioretention Soil Medium (BSM) Specification.

Component	Properties
Sand	Conforms to ASTM C33 Fine Aggregate
Organic Material	Compost or shredded hardwood mulch
Topsoil	
• Sand (2.0 – 0.050 mm)	50 – 85% by weight
• Silt (0.050 – 0.002 mm)	0 – 50% by weight
• Clay (less than 0.002 mm)	10 – 20% by weight[1]
• Organic Matter	1.5 – 10% by weight
• pH	5.5 – 7.5 (NOTE: pH can be corrected with soil amendments if outside acceptable range)
• Magnesium	Minimum 32 ppm (NOTE: magnesium sulfate can be added to increase Mg)
• Phosphorus (Phosphate - P_2O_5)	Not to exceed 69 ppm P-index should be less than 25
• Potassium (K_2O)	Minimum 78 ppm (NOTE: potash can be added to increase K)
• Soluble Salts	Not to exceed 500 ppm

Source: The Low Impact Development Center, Inc., 2003

Surface Mulch or Organic Layer

- Acts as a filter for pollutants in runoff
- Protects underlying soil from drying and eroding
- Reduces likelihood of weed establishment
- Provides a medium for biological growth, decomposition of organic material, and adsorption and bonding of heavy metals

Two to three inches of shredded hardwood mulch (aged at least 6 months to 1 year), leaf compost, or other comparable product should be uniformly applied immediately after planting to prevent erosion, enhance metal removal, and aid plant establishment. Wood chips should be avoided as they tend to float during inundation periods.

Mulch or compost should not exceed 3 inches in depth so as not to restrict oxygen flow, and should not be placed directly against the stems or trunks of plants.

Plants

Proper plant selection is essential for bioretention areas to be effective. Typically, generalist plant species native to the area are best suited to the variable environmental conditions encountered in a bioretention cell, as they need to withstand a wide range of soil and moisture regimes. See the plant list in Appendix A for recommended species based on ecoregion. When designing the planting, it is important that plant species are located according to their tolerance of inundation and prolonged soil saturation; less tolerant species should be located at the higher elevations. It should be noted, however, that bioretention cells drain rapidly, and therefore do not develop anoxic soil conditions. Trees, shrubs, and herbaceous

[1] If the proposed topsoil is known to contain expansive clays, clay content should not exceed 10% by weight.

perennials may be used in a bioretention cell. They should be selected with other functions in mind (e.g., shade, screening versus clear views, color, etc.), in addition to suitability for bioretention and to the ecoregion. For bioretention cells that will have an underdrain, it is also important to select species that do not have invasive roots, which have a tendency to clog perforated drainage pipes. A landscape architect can help with plant selection and bioretention cell design.

Verify that candidate plants can tolerate snowmelt chemicals, if applicable (at high elevations).

In most cases, seed is not the preferred method for plant establishment in a bioretention cell. The fluctuating water levels make it difficult for the seed to readily establish, and the random nature of seeding may result in an undesirable plant layout for some situations. Instead, it is strongly recommended that containerized live plants be utilized: plugs or 1-gallon for herbaceous plants, 1- to 5-gallon for shrubs, and 5-gallon to 24-inch box for trees. Plant spacing depends on mature plant size and desired density of plant cover.

Plant species composition generally depends on how often water is expected to pond in the bioretention cell. For Southern California, species will likely need to be drought-tolerant plants that can handle occasional inundation during the rainy season.

Underdrain

In areas with HSG group A or B soils, bioretention cells may often be constructed without underdrains in order to maximize infiltration. In areas with less-permeable (typically HSG Group C or D soils), underdrains may be required to ensure adequate drainage. Underdrains are typically constructed of a 6" diameter perforated pipe connecting to an existing stormwater conveyance structure or outlet. Underdrains should be surrounded by at least a six inch layer of ASTM No. 57 aggregate.

Enhanced Nitrogen Removal

The underdrain can be placed several inches above the bottom of the bioretention cell, creating an extended detention zone that will provide an opportunity for enhanced nitrogen removal by denitrification (Hsieh et al, 2007).

Overflow

Provide for the direct discharge of excess runoff during large storm events when the subsurface and surface storage capacity is exceeded.

Examples of outlet controls include domed risers, inlet structures, weirs, and similar devices.

Figure 26. Positive Overflow Device: Domed Riser.
Source: Macomb County Michigan Public Works Office

Figure 27. Inlet Structure, Downey, CA.
Source: Bill DePoto

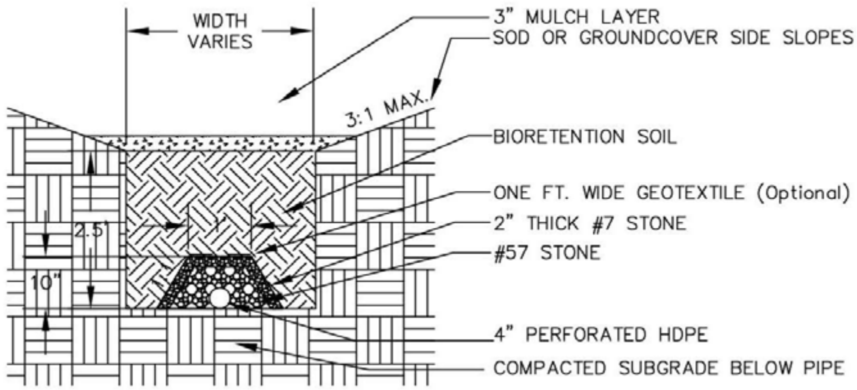

Figure 28. Detailed cross-section of a bioretention cell.
Source: LID Center

Sizing criteria for systems without underdrain
Surface area depends on storage volume requirements and permeability of the BSM and underlying native soil. Runoff volume is based on local regulatory requirements, such as a specific design storm (e.g. 2-year, 24-hour) or total runoff (85^{th} percentile), and is calculated using one of the methods described in Step 5 of this manual, or by the method specified by local regulations. The total storage volume of a bioretention cell, V_{BMP}, accounts for both surface ponding and the available pore space within the soil medium.

Maximum Total Depth
The maximum total depth of the bioretention cell (ponding depth, BSM depth and gravel storage depth) is limited by the infiltration rate of the surrounding soil. This depth can be calculated using the following formula (RCFC & WCD, 2006):

$$D_m(in) = \frac{t(hr) \times I(in/hr)}{s}$$

where I = site infiltration rate (in/hr)
s = safety factor, and
t = drawdown time (usually 48-72 hours).

The safety factor, s, accounts for uncertainty in the true site infiltration rate. If the infiltration rate is not based on onsite testing, use s = 10, for planning purposes only. Before finalizing design, conduct in situ double-ring infiltrometer tests to establish true infiltration rates, and use pits or borings to examine subsoils for restrictive layers. Then, a safety factor not less than s = 3 is to be applied.

This total depth can then be divided among the surface ponding depth and subsurface BSM depth:

$$D_m = D_p + D_b$$

where D_p = ponding depth, and
D_b = BSM depth.

Surface Area
The size of the bioretention cell is determined by calculating the area necessary to store the design volume at the maximum depth, taking into account the available storage volume within the BSM. The area of the bioretention cell can be calculated using the following formula, assuming that the bioretention cell is constructed with a level surface:

$$A\ (ft^2) = \frac{V_{BMP}\,(ft^3) \times 12(in/ft)}{D_p\,(in) + D_b\,(in) \times R_b}$$

where A = BMP surface area (ft^2)
V_{BMP} = BMP design volume (ft^3), and
R_b = BSM void ratio (usually about 0.3).

The total surface area needed may be divided into multiple cells. This configuration, for example, may be useful to collect runoff from both the front and back of a building.

Sizing criteria for systems with underdrain
In poor soils or other locations where infiltration is not feasible, bioretention cells are constructed with underdrains, and therefore serve as detention rather than retention systems. Where underdrains are used, maximum depth is not limited by the infiltration rate of the surrounding soil. The depth of the bioretention cell may be determined based on other design considerations, such as necessary storage volume, plant rooting depth, and pollutant removal performance. Typical values are given below:

Ponding depth	6 inches
BSM depth	24-36 inches

The total storage volume, V_{BMP}, accounts for both surface ponding and the available pore space within the soil medium. The total area required can then be calculated using the above equation for surface area.

Construction Guidance

The following is a typical construction sequence. However, alterations will be necessary depending on design variations.

1. Install temporary sediment control BMPs as required by permitting authority.
2. Complete site grading, minimizing compaction as much as possible. If applicable, construct curb cuts or other inflow entrance, but provide protection so that drainage is prohibited from entering the construction area. Construct pretreatment devices (filter strips, swales, etc.) if applicable.
3. Stabilize grading, except within the bioretention area.
4. Excavate bioretention cell to proposed invert depth and scarify the existing soil surfaces. Do not compact soils.
5. Install perforated underdrain if applicable. The underdrain system shall be placed on a 3-ft wide bed of No. 57 aggregate, covered with 6 inches of No. 57 aggregate and topped with 2 inches of No. 7 aggregate.
6. Backfill bioretention cell with Bioretention Soil Medium (BSM) in 12-inch layers. Each layer should be compacted by saturating the bioretention cell.
7. Install automatic irrigation system if applicable.
8. Allow the BSM to settle for 24 hours.
9. Complete final grading to achieve proposed design elevations, leaving space for upper layer of compost or mulch as specified on plans.
10. Plant vegetation according to planting plan.
11. Apply mulch layer.
12. Install erosion protection at surface flow entrances where necessary.
13. Perform infiltration testing to verify system performance.

Figure 29. Newly Planted Bioretention Cell in El Monte, CA.
Source: Bill DePoto

Maintenance Considerations

Properly designed and installed bioretention cells require some regular maintenance, most frequently during the first year or two of establishment.

Bioretention cells will require supplemental irrigation during the first 2-3 years after planting. Drought-tolerant species may need little additional water after this period, except during prolonged drought, when supplemental irrigation may become necessary for plant survival. Verify that the maintenance plan includes a watering schedule for the establishment period and in times of extreme drought after plants have been established.

While vegetation is being established, remove weeds by hand (weeding frequency should decrease over time, as plants grow).

Although plants may need occasional pruning or trimming, bioretention cells should generally not be mowed on a regular basis. Trim vegetation as necessary to maintain healthy plant growth. In some instances, where it is desired to maintain fast-growing, annual herbaceous plant cover, annual mowing may be appropriate.

Replace dead plants. If a particular species proves to be prone to mortality, it may need to be replaced with a different species that is more likely to succeed on this particular site.

Mulch should be re-applied when erosion is evident. In areas expected to have low metal loads in the runoff, mulch as needed to maintain a 2-3 inch depth. In areas with relatively high metal loads, replace mulch once per year.

Bioretention cells should be inspected at least two times per year for sediment buildup, trash removal, erosion, and to evaluate the health of the vegetation. If sediment buildup reaches 25 percent of the ponding depth, it should be removed, taking care to minimize soil disturbance. If erosion is noticed within the bioretention cell, additional soil stabilization measures should be applied. If vegetation appears to be in poor health with no obvious cause, a landscape specialist should be consulted.

An important concern for bioretention applications is their long-term protection and maintenance, especially if undertaken in multiple (adjacent) residential lots where individual homeowners provide maintenance. In such situations, it is important to provide management guarantees that ensure their long-term functionality (e.g., deed restrictions, covenants, and maintenance agreements).

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Pervious Pavement

Pervious pavement consists of a permeable surface course underlain by a storage reservoir consisting of a uniformly graded aggregate bed or premanufactured structural stormwater units. An optional filter layer with subdrains may be incorporated for installations on soils that do not support infiltration. The surface course may consist of pervious bituminous asphalt, pervious concrete, various types of permeable pavers, reinforced turf or gravel, or clear binder pavements.

Variations

1. Pervious Bituminous Pavement
2. Pervious Concrete
3. Permeable Pavers
4. Reinforced Turf/Gravel
5. "Clear" Binder Pavements

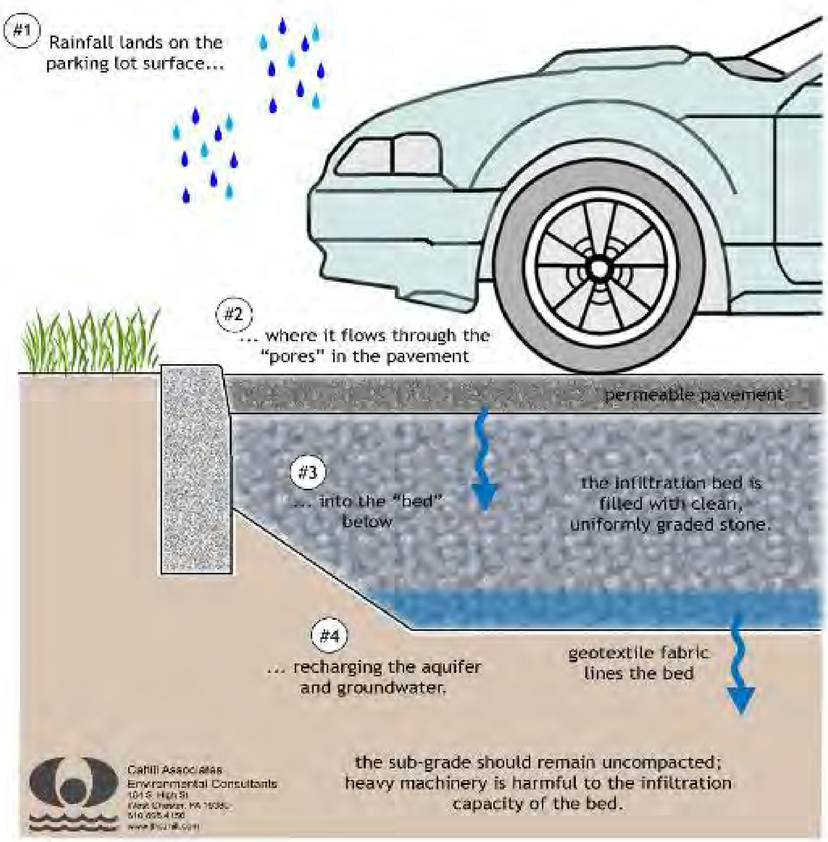

Figure 30. Cross-section showing design components of a permeable pavement with subsurface infiltration bed. Where infiltration is infeasible, underdrains can be fitted into the subsurface bed.
Source: Cahill Associates

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature

- Groundwater recharge (if soils are sufficiently permeable and no underdrain is placed underneath)
- Reduced heat island effect
- Dual purpose

Limitations

- Should not be used to capture runoff from unpaved areas without pretreatment, such as a vegetated filter strip
- Should not be used in areas with high danger of pollutant spills
- Not suitable for high traffic areas
- Requires regular maintenance
- Not suitable for slopes greater than 3 percent

Water Quality

Pervious pavement systems are effective in reducing such pollutants as total suspended solids, metals, and oil and grease. The pervious pavement surface, the (optional) filter layer, and the underlying soils below the infiltration bed filter particulate pollutants. Pervious pavement systems will provide limited treatment of dissolved pollutants, such as nitrates.

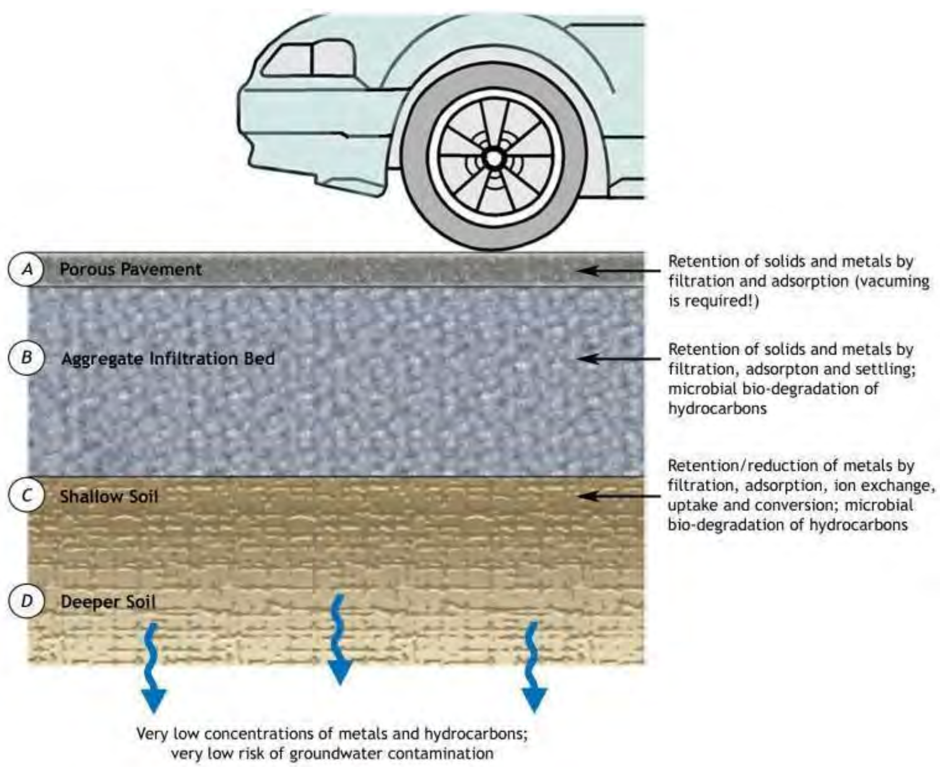

Figure 31. Water quality benefits of pervious pavement with subsurface infiltration.
Source: Cahill Associates

Table 22. Water Quality Benefits of Pervious Pavement With a Subsurface Infiltration Bed.

System Component	Mechanism(s)	Contaminants Retained/Reduced	References
Porous Pavement	Filtration and Adsorption	Total Suspended Solids (TSS), Heavy Metals, Hydrocarbons, COD, and De-icing Salt (less required, more retained) (Note: maintenance by vacuuming is required)	Ferguson, 2005; Legret and Colandini, 1999; Pagotto et al., 2000; UNHSC, 2007
Infiltration Bed or filter layer	Filtration, Adsorption, Settling, Microbial Bio-Degradation	TSS, Metals, and Hydrocarbons, plus Total Organic Carbon, COD, Nitrogen	Balades et al, 1992 & 1995; Diniz and Espey, 1979; Legret and Colandini, ,1999; Newman et al, 2002; Pratt et al, 1999; Swisher, 2002; Thelen and Howe, 1978
Shallow Soil	Filtration, Adsorption, Ion Exchange, Microbial Bio-Degradation, Conversion, and Uptake (only with high plant activity)	Metals and Hydrocarbons, including PAHs	Barraud et al, 1999; Dierkes and Geiger, 1999; Legret et all 1999; Swisher, 2002
Deeper Soil	Filtration, Adsorption, Ion Exchange, Conversion, and Uptake (only with high plant activity)	Metals and Hydrocarbons, plus Organics and Bacteria; Very Low Risk of Groundwater Contamination	Barraud et al, 1999; Boving et al, 2006; Dierkes, 1998; Dierkes and Geiger, 1999; Mikkelsen, 1997; Pitt et al, 1994; Roseen et al, 2006

Source: Cahill Associates

Peak Flow Rate Mitigation

Properly designed pervious pavement systems provide effective management of peak flow rates due to the provided storage reservoir.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Cost

The majority of added cost of a pervious pavement/infiltration system lies in the underlying stone bed and optional filter layer, which is generally deeper than a conventional bed and lined with non-woven geotextile. However, for new construction projects, this additional cost can be partially offset by the significant reduction in the required drainage infrastructure (i.e. inlets and pipes). Pervious pavement areas with subsurface infiltration beds can reduce or eliminate the need (and associated costs, space, etc.) for large detention basins. When these factors are considered, pervious pavement with infiltration has proven itself less expensive than the impervious pavement with associated traditional stormwater management. Recent installations have averaged between $2,000 and $2,500 per parking space, for the pavement and stormwater management systems.

- Pervious asphalt, with additives, is generally 10 to 20 percent higher in cost than standard asphalt on a unit area basis. Unit costs for pervious asphalt (w/o infiltration bed) range from about $1.75/SF to $3.50/SF.

- Pervious concrete, as a material, is generally more expensive than asphalt and requires more labor and experience for installation due to specific material constraints. Unit costs for 6-inch thick pervious concrete (w/o infiltration bed) section are typically between $6-7/SF.

- Permeable pavers vary in cost depending on type and manufacturer.

NOTE: The data provided is based on average market costs. For greater accuracy a site and market specific cost estimate should be developed.

Table 23 and Table 24 summarize the costs associated with Phases I and II, respectively, of a pervious pavement demonstration project completed in 2005 at the San Diego County Operations Center in Kearny Mesa. Phase I included pervious asphalt, concrete, and pavers, while Phase II included only pervious asphalt (different mixes than in Phase I) and concrete.

Table 23. San Diego COC Phase I – Pervious Pavement Costs.

Pavement Replacement Square Foot Costs 2005						
	Demolition & Excavation	Installation of Sub Base	Pavement Costs	Square Foot Costs*	Annual Est. Square Foot Maintenance Costs	Comments
Porous Asphalt	$ 2.75	$ 1.88	$ 1.87	$ 6.50	$ 0.04	18" – Excavation/Backfill 3" – Porous Asphalt
Standard Asphalt	$ 2.13	$ 1.04	$ 1.32	$ 4.49	$ 0.06	6" – Excavation/Backfill 6" – Asphalt
Porous Concrete	$3.19	$ 1.88	$ 6.34	$ 11.41	$ 0.02	18" – Excavation/Backfill 5-1/2" – Pervious Concrete
Standard Concrete	$ 1.51	$ -----	$ 3.42	$ 4.93	$ 0.01	No new base material 6" – Reinforced Concrete
Porous Pavers	$ 2.75	$ 1.88	$ 9.63	$ 14.26	TBD	18" – Excavation/Backfill 3" – Paver
*Square foot cost are based on actual cost received by the County of San Diego						

Source: Cahill Associates

Table 24. San Diego COC Phase II – Pervious Pavement Costs.

Pavement Replacement Square Foot Costs 2007						
	Demolition & Excavation	Installation of Sub Base	Pavement Costs	Square Foot Costs*	Annual Est. Square Foot Maintenance Costs	Comments
Porous Asphalt	$ 3.39	$ 3.40	$ 2.01	$ 8.80	$ 0.04	18-30" – Excavation/Backfill 3" – Porous Asphalt
Standard Asphalt	$ 2.13	$ 1.04	$ 1.32	$ 4.49	$ 0.06	6" – Excavation/Backfill 6" – Asphalt
Porous Concrete	$3.64	$ 3.40	$ 7.10	$ 14.14	$ 0.02	18-30" – Excavation/Backfill 5-1/2" – Pervious Concrete
Standard Concrete	$ 1.51	$ -----	$ 3.42	$ 4.93	$ 0.01	No new base material 6" – Reinforced Concrete
*Square foot cost are based on actual cost received by the County of San Diego						

Source: Cahill Associates

Applications

Pervious pavement is well-suited for parking lots, walking paths, sidewalks, playgrounds, plazas, tennis courts, and other similar uses. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater functions of the pavement and willing to maintain it. Pervious pavement can be used in low-traffic roadways, but should not be used on roadways carrying more than 25,000 vehicles per day. The thickness of the pervious pavement system works to distribute traffic loads, and can decrease the need for compaction of the subsoil. Pervious pavement can also be layered on top of impermeable asphalt, where it can help to quickly remove water falling on the pavement surface, reducing splash and spray from vehicles. This reduces the amount of pollutants washed from vehicles, limiting water quality degradation. In areas where fire lanes are required to be impermeable, the impermeable surface should be sloped toward the pervious pavement. The reservoir layer should extend beneath the entire pavement surface.

Pervious pavements can be used in residential, commercial, institutional, and industrial applications in both urban and suburban environments. Pervious pavements have been widely applied in retrofit situations as existing standard pavements are replaced. Pervious pavements should not be used in industrial and commercial applications where pavement areas are used for material storage or the potential for surface clogging is high due to high traffic of construction vehicles.

Potential Applications

Residential	YES
Commercial	YES
High-Density	YES
Industrial	LIMITED
Recreational/Institutional	YES
Highway/Road	LIMITED

Parking Areas

Figure 32. Parking Lot, City of Downey, CA.
Source: California Watershed Engineering

Figure 33. Pervious Paver Parking Stalls, Redlands, CA.
Source: Jeff Endicott

Figure 34. Pervious Paver Driveway, Chino, CA.
Source: Jeff Endicott

Pervious Pavement Walkways
Pervious pavement, both as asphalt and concrete, can also be used in walkways and sidewalks. These installations typically consist of a shallow (8 in. minimum) aggregate trench that is sloped to follow the surface slope of the path. In the case of steeper surface slopes, the aggregate infiltration trench may be "terraced" into level reaches in order to maximize its infiltration capacity, at the expense of additional aggregate.

Figure 35. Pervious Concrete Sidewalk, Santa Monica, CA.
Source: Bill DePoto

Playgrounds / Basketball / Tennis

Figure 36. Pervious asphalt basketball court at 2nd Ward Neighborhood Park in Upper Darby, PA.
Source: Cahill Associates

Streets and Alleys

Figure 37. Pervious asphalt street in residential neighborhood in Portland Oregon.
Source: Cahill Associates

Figure 38. Pervious paver parking edge in residential neighborhood in Portland Oregon.
Source: Cahill Associates

Figure 39. Porous friction course over traditional asphalt.
Source: Caltrans

Variations

Pervious Bituminous Asphalt

Pervious bituminous asphalt pavement was first studied in the early 1970's by the Franklin Institute in Philadelphia and consists of standard bituminous asphalt in which the fines have been screened and reduced, allowing water to pass through small voids. Pervious asphalt is placed directly on the stone bed in a single 3 ½ to 4-inch lift that is lightly rolled to a finish depth of 2 ½ to 3-inches.

Because pervious asphalt is standard asphalt with reduced fines, it is similar in appearance to standard asphalt. Recent research in open-graded mixes for highway applications has led to additional improvements in pervious asphalt through the use of additives and higher-grade binders. Pervious asphalt is suitable for use in any climate where standard asphalt is appropriate.

Figure 40. Pervious asphalt parking lot at Flinn Springs County Park in El Cajon, CA.
Source: Cahill Associates

Figure 41. Close-up showing pervious asphalt pavement atop a stone infiltration/storage bed at the San Diego County Operations Center in Kearny Mesa, CA.
Source: Cahill Associates

Pervious Concrete

Pervious Portland Cement Concrete, or pervious concrete, was developed by the Florida Concrete Association and has seen the most widespread application in Florida and other southern areas. Like pervious asphalt, pervious concrete is produced by substantially reducing the number of fines in the mix in order to establish voids for drainage. Like other types of pervious pavements, pervious concrete should always be underlain by a stone bed designed for stormwater management and should never be placed directly onto a soil bed.

While pervious asphalt is very similar in appearance to standard asphalt, pervious concrete has a coarser appearance than its conventional counterpart and a clean-swept finish can not be achieved. Care must be taken during placement to avoid over-working the surface and creating an impervious layer. Pervious concrete has been proven to be an effective stormwater management BMP. Another potential advantage of pervious concrete is the option of introducing color to the mix. The industry now offers a variety of hues and tints that can allow a pervious concrete installation to better integrate with its adjacent landscape. Additional information pertaining to pervious concrete, including specifications, is available from the Florida Concrete Association and the National Ready Mix Association (see References).

Figure 42. Pervious concrete in Cerritos, CA.
Source: Bill DePoto

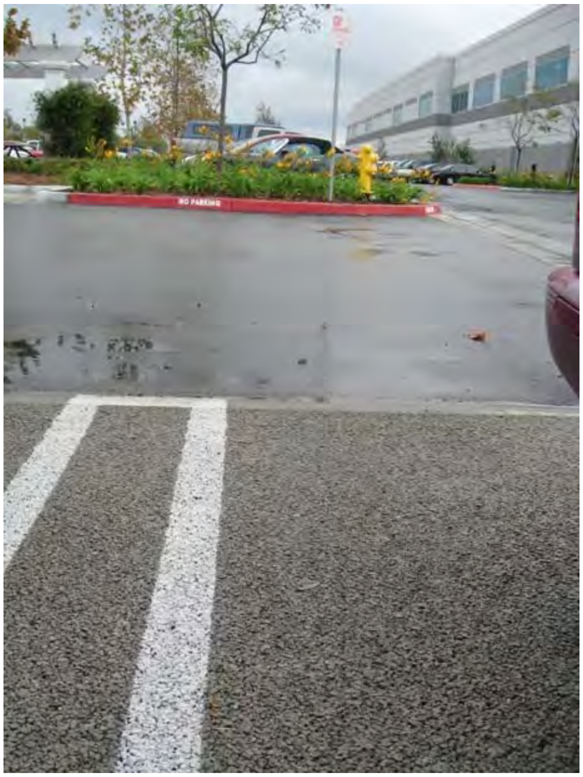

Figure 43. Pervious concrete parking areas, Haas Automation, Inc., Oxnard, CA.
Source: Lorraine Rubin

Permeable Pavers

Permeable pavers consist of interlocking units (often concrete) that provide some portion of surface area that may be filled with a pervious material such as gravel. These units are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. There are also products available that provide a fully permeable surface through the use of plastic rings/grids filled with gravel. A number of manufactured products are available, including (but not limited to): Aqua Bric (Orco Block); Turfstone; UNI Eco-stone; EP Henry ECO I Paver; Checkerblock; Netlon Gravel Pavement Systems; Permapave. Permeable pavers vary greatly in their design and resulting open area. Some designs offer relatively little open surface area where infiltration can take place. Table 25 lists the open area percentage of several commonly used paver products. Please note that this list is not exhaustive; there are many other paver products on the market.

Designers are encouraged to obtain paving system permeability data from the manufacturer of the paving stone being specified. The rates for clean systems (freshly installed) are expected to be quite high, and should be de-rated by applying a safety factor during design.

When used in parking lots or other applications involving pedestrians, ADA access standards must be considered. Options include selecting an ADA compliant block system, or paving ADA access areas with compliant, alternative surfaces such as AC or concrete.

Table 25. Open Area Percentage of Several Commonly Used Paver Products.

Paver Product	Open Area Percentage
Turfstone™	41
Checker Block®	75
Netpave® 50	85
UNI Eco-stone®	12
Acker-Stone Aqua-Via	9.3
Permapave	Varies (depends on size of stone used as aggregate)
ORCO Aqua Brick® Paving Stones	10.6
Angelus SF Rima™ Paving Stones	10

Source: The Low Impact Development Center, Inc.

Figure 44. Turfstone™ Pavers.
Source: Interlocking Paving Systems, Inc.

Figure 45. Turfstone™ Driveway.
Source: Nicolock

Figure 46. Checker Block® Shoulder.
Source: Nicolock

Figure 47. NetPave® 50.
Source: Rehbein Solutions, Inc.

Figure 48. Permapave.
Source: Permapave USA

Figure 49. Uni Eco-stone® Pavers.
Source: Interlocking Paving Systems, Inc.

Figure 50. Acker-Stone Aqua-Via.
Source: Acker-Stone Industries

Figure 51. Aqua Bric® Type 4 (ADA Compliant).
Source: ORCO Block Co., Inc., Photography by RA Hanson

Figure 52. SF Rima™ Paving Stones at the Persico Commercial Center in the City of Downey, CA.
Source: Angelus Paving Stones

As products are always being developed, the designer is encouraged to evaluate the benefits of various products with respect to the specific application. Many paver manufacturers recommend compaction of the soil and do not include a drainage/storage area, and therefore, they do not provide optimal stormwater management benefits. A system with a compacted sub-grade will not provide significant infiltration. In LID applications, pavers are used with gravel beds or uncompacted subgrades. The entire system (paver, the joint fill, and subgrade) should be tested to provide reasonable estimates of performance.

Reinforced Turf

Reinforced Turf consists of interlocking structural units that contain voids or areas for turf grass growth and are suitable for traffic loads and parking. Reinforced turf units may consist of concrete or plastic and are underlain by a stone and/or sand drainage system for stormwater management.

Reinforced Turf is excellent for applications such as fire access roads (where permitted), overflow parking, and occasional use parking (such as at religious facilities and athletic facilities). Reinforced Turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions. A number of manufactured products are available, including (but not limited to): Grasspave; Geoblock; Grassy Pave; Geoweb; Netlon Turf Pavement Systems. The designer is encouraged to evaluate and select a product suitable to the project.

Figure 53. Reinforced turf used as overflow parking area.
Source: Cahill Associates

Other
Other proprietary products are now available which are similar to pervious asphalt and concrete, but which utilize clear binders so that the beauty of the natural stone is visible, creating an aesthetically pleasing look. Some of these products are not suitable for vehicular traffic, and the material strength varies by product. The use of clear binder allows the designer the versatility of utilizing different colored aggregates to suit the application and appearance desired. Typical applications include: tree pits, walkways, plazas, and playgrounds. A number of products are available on the market today, including (but not limited to): Addapave TP, and Flexipave.

Design Guidance

A pervious pavement system consists of a pervious surface course underlain by a storage reservoir placed upon uncompacted subgrade to facilitate stormwater infiltration or upon a filter layer with subdrains. The storage reservoir consists of a stone bed of uniformly graded and clean-washed coarse aggregate, typically 1-1/2 to 2-1/2 inches in size. The pervious pavement may consist of pervious bituminous asphalt, pervious concrete, pervious pavers, or other types of pervious structural materials. A layer of nonwoven geotextile filter fabric can be used to separate the aggregate from the underlying soil, preventing the migration of fines into the bed. The porous pavement surface should be level if possible, and should not have a slope greater than 3 percent. Bed bottoms should always be level and uncompacted to allow for even and distributed stormwater infiltration. On sloped sites, beds should be constructed using a terraced design, as shown in Figure 54. Many designs incorporate a river stone/rock edge treatment or inlets which are directly tied to the bed so that the stormwater system will continue to function even if the performance of the pervious pavement surface is compromised.

Pervious pavements are adaptable to various soil conditions. In sites with less permeable soils, pervious pavement systems can be fitted with underdrains to discharge stored runoff into the storm drainage system. In sites where soils are contaminated or with high groundwater tables, the storage reservoir can be lined to prevent exfiltration entirely.

When properly designed, pervious pavement systems provide effective management of stormwater volume and peak flow rates. The storage reservoir below the pavement surface can be sized to manage both direct runoff and runoff generated by adjacent areas, such as rooftops. Because the stone bed provides storage, outlet structures can be designed to manage peak flow rates with the use of weir and orifice controls.

Many local jurisdictions are developing standard specifications for the location, sizing, configuration, and/or maintenance of LID BMPs and such requirements where they exist should be used. Where local specifications for pervious pavements do not exist, the following guidelines can be used.

Figure 54. Design subsurface infiltration beds to "step" down a slope, maintaining level bed bottoms and earthen berms between beds.
Source: Andropogon Associates

Site Factors

1. Water Table Separation: Ten (10) feet (Regional Boards and local agencies may have differing requirements.) Installations at sites with higher water tables may be lined to prevent exfiltration.
2. Bedrock Separation: Varies with site conditions (Regional Boards and local agencies may have specific requirements.)
3. Soil Permeability: Permeability of at least 0.5 in/hr is required for infiltration. Installations in less permeable soils can be fitted with underdrains.
4. Feasibility on Steep Slopes: Low**

** Infiltration beds may be placed on a mild slope (<3%) however subsurface layers should have level bottoms and be terraced along slopes.

The overall site shall be evaluated for potential pervious pavement/ infiltration areas early in the design process, as effective pervious pavement design requires consideration of grading.

Infiltration areas should be located within the immediate project area in order to control runoff at its source. Expected use and traffic demands shall also be considered in pervious pavement placement. An impervious water stop should be placed along infiltration bed edges where pervious pavement meets standard impervious pavements.

Percolation tests should be performed by a qualified professional to verify soil permeability in the locations where previous pavements are planned. If soils are found to have percolation rates less than 0.5 in/hour, pervious pavements should be fitted with underdrains and treated as filtration rather than infiltration practices. If pervious pavements are planned in close proximity to buildings or other structures, a geotechnical engineer should be consulted to evaluate the risk of creating unstable soil conditions. A thorough analysis of the soil profile and potential barriers to infiltration must be performed prior to implementing pervious pavements.

Sediment Control
Control of sediment is critical. Rigorous installation and maintenance of erosion and sediment control measures is required to prevent sediment deposition on the pavement surface or within the stone bed. The edges of the nonwoven geotextile lining may be folded over the edge of the pavement until the site is stabilized. The designer should carefully consider the site placement of pervious pavement to reduce the likelihood of sediment deposition. Surface sediment should be removed by a vacuum sweeper and should not be power-washed into the underlying bed.

Infiltration Bed
The underlying infiltration bed is comprised of clean, uniformly-graded aggregate with approximately 40 percent void space. AASHTO No.57 gravel is often used. Depending on local aggregate availability, both larger and smaller size aggregate have been used. The critical requirements are that the aggregate be uniformly-graded, clean-washed, and contain a significant void content. The depth of the bed is a function of stormwater storage requirements, site grading, and anticipated loading (in the case of pervious asphalt, see Table 26 and Table 27). Infiltration beds are typically sized to mitigate the increased runoff volume from the more frequent, small storm events.

If designed to infiltrate, the bed bottom should be compacted only to the extent necessary to provide structural stability at the direction of the geotechnical engineer. The stone bed is placed in lifts and lightly rolled according to the specifications. The thickness of the pavement system acts to distribute the traffic load, compensating for the lack of compaction of the subsoil (Ferguson, 2005).

Bed bottoms must be level or nearly level. Sloping bed bottoms will lead to areas of ponding and reduced stormwater distribution within the bed.

Table 26. Minimum Pervious Asphalt Pavement Thickness Required to Bear Structural Load on Poor Subgrade with CBR 2.

Traffic Category	Average ESAL per Day	Porous Asphalt Surface Course Thickness (in)	Aggregate Base Course Thickness (in)	Total Thickness (in)
Light (parking lots, residential streets)	1 10	4 4	6 12	10 16
Medium light (city business streets)	20 50	4.5 5	13 14	17.5 19
Heavy (highways)	1000 5000	6 7	20 22	26 29
CBR is California Bearing Ratio; ESAL is Equivalent Single Axle Load = 18,000 pounds				

Source: Ferguson, 2005

Table 27. Minimum Total Pervious Asphalt Pavement Thickness (aggregate base course + pervious asphalt surface course). Required to Bear Structural Load on Various Subgrades.

Traffic Load	Minimum Total Pavement Thickness (inches)		
	Subgrade CBR 6 to 9	Subgrade CBR 10 to 14	Subgrade CBR 15 or more
Light (ESAL 5 or less per day)	9	7	5
Medium light (1,000 vpd max., ESAL 6 to 20 per day)	11	8	6
Medium (3,000 vpd max., ESAL 21 to 75 per day)	12	9	7
vpd is vehicles per day; ESAL is 18,000 pounds			

Source: Ferguson, 2005

While most pervious pavement installations are underlain by an aggregate bed, alternative subsurface storage products may also be employed. These include a variety of proprietary, interlocking plastic units that contain much greater storage capacity than aggregate.

In areas with poorly-draining soils, infiltration beds below pervious pavement may be designed to slowly discharge to adjacent wetlands or bioretention areas. In this way, a pervious pavement installation may act as an alternative form of capture and reuse for landscape irrigation. Only in extreme cases (i.e. industrial sites with contaminated soils) will the aggregate bed need to be lined to prevent infiltration.

Figure 55. Pervious concrete parking lot with river stone edge treatment at Flinn Springs County Park, El Cajon, CA.
Source: Cahill Associates

Overflows
All systems should be designed with an overflow system. The specific design of these structures may vary, depending on factors such as rate and storage requirements, but it always must include positive overflow from the system.

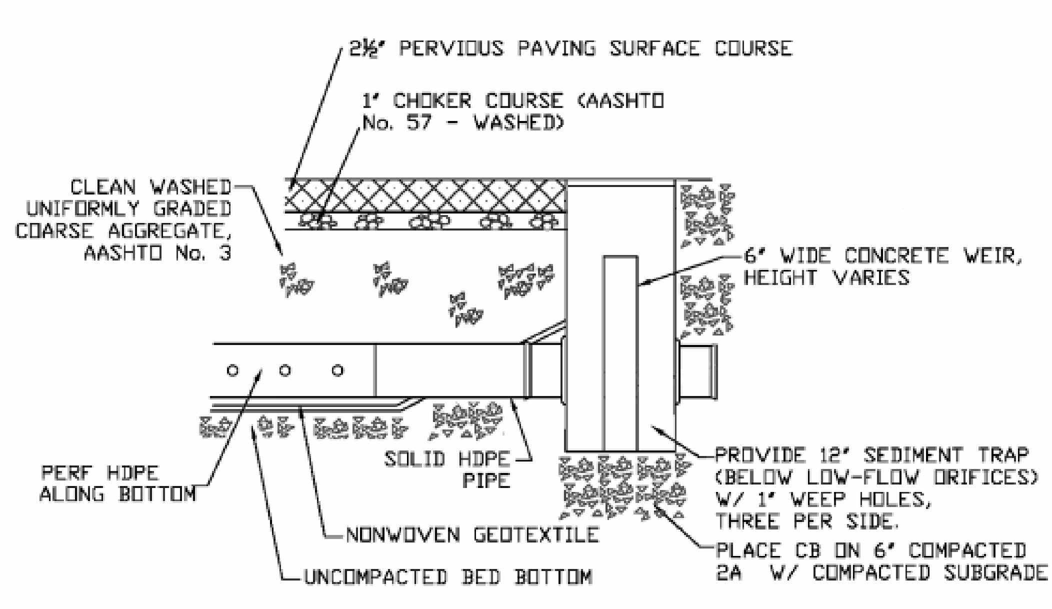

Figure 56. Example detail of an overflow device from a pervious asphalt system.
Source: Cahill Associates

Sizing Criteria
Surface area depends on storage volume requirements and permeability of the underlying native soil. Runoff volume is based on local regulatory requirements, such as a specific design storm (e.g. 2-year, 24-hour) or total runoff (85th percentile).

The permeable pavement area necessary to capture the design volume (V_{BMP}) is determined by calculating the area necessary to store the design volume at the maximum depth (b_{TH}), taking into account the available storage area within the gravel pore space. The depth of the gravel storage reservoir should not exceed 12 inches for either the infiltration or filtration designs (Riverside County, 2010). The area can be calculated using the following formula:

$$A(\mathrm{ft}^2) = \frac{V_{BMP}(ft^3)}{b_{TH}(\mathrm{in}) \times R_g / 12(in/ft)}$$

where A = BMP surface area (ft^2)
V_{BMP} = BMP design volume (ft^3)
b_{TH} = reservoir depth (in), and
R_g = gravel void ratio (usually 0.4).

This calculation assumes a level pavement surface. The storage volume for a sloped surface would be significantly reduced.

Construction Guidance

Pervious pavement is most susceptible to failure difficulties during construction, and therefore it is important that the construction be undertaken in such as way as to prevent:

- Unnecessary compaction of underlying soil

- Contamination of stone bed with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto pervious surface or into constructed bed

Staging, construction practices, and erosion and sediment control must be taken into consideration when using pervious pavements.

1. Due to the nature of construction sites, pervious pavement and other infiltration measures should be installed toward the end of the construction period, if possible. Infiltration beds under pervious pavement may be used as temporary sediment basins or traps provided that they are not excavated to within 12 inches of the designated bed bottom elevation. Once the site is stabilized and sediment storage is no longer required, the bed is excavated to its final grade and the pervious pavement system is installed.

2. If designed to infiltrate, the existing subgrade under the bed areas should be compacted to the minimum extent necessary, as determined by geotechnical analysis.

3. Where erosion of subgrade has caused accumulation of fine materials and/or surface ponding, this material shall be removed with light equipment and the underlying soils scarified to a minimum depth of 6 inches with a York rake (or equivalent) and light tractor. Fine grading shall be done by hand. Bed bottoms must be level grade.

Earthen berms (if used) between infiltration beds shall be left in place during excavation. These berms do not require compaction if proven stable during construction.

Figure 57. Earthen berms separate terraced infiltration beds.
Source: Cahill Associates

Geotextile and bed aggregate shall be placed immediately after approval of subgrade preparation. Geotextile is to be placed in accordance with manufacturer’s standards and recommendations. Adjacent strips of geotextile shall overlap a minimum of 18 inches. It shall also be secured at least 4 feet outside of the bed in order to prevent runoff or sediment from entering the storage bed. This edge strip shall remain in place until all bare soils contiguous to beds have been stabilized and vegetated. Once the site is fully stabilized, excess geotextile along bed edges can be cut back to the bed edge.

Clean (washed) uniformly-graded aggregate is placed in the bed in 8-inch lifts. Each layer shall be lightly compacted, with the construction equipment kept off the bed bottom as much as possible.

Once bed aggregate is installed to the desired grade, a +/- 1 inch layer of choker base course (AASHTO #57, or equivalent) aggregate shall be installed uniformly over the surface in order to provide an even surface for paving.

Figure 58. Open-graded, clean, coarse aggregate for infiltration beds.
Source: Cahill Associates

Install pervious pavement. Pervious concrete should be installed by an NRMCA Certified Installer (http://www.nrmca.org/certifications/pervious/). Permeable paver installers are certified by the Interlocking Concrete Pavement Institute (http://www.icpi.org/). After final pervious asphalt or concrete installation, no vehicular traffic of any kind shall be permitted on the pavement surface until cooling and hardening or curing has taken place, and in no case within the first 72 hours.

The full permeability of the pavement surface shall be tested by application of clean water over the surface, using a hose or other distribution devise. Applied water shall infiltrate directly without puddle formation or surface runoff.

Figure 59. Water on Porous Asphalt.
Source: Fishbeck, Thompson, Carr & Huber, Inc.

Maintenance Considerations

- Prevent Clogging of Pavement Surface with Sediment
  - Vacuum pavement twice per year
  - Maintain planted areas adjacent to pavement
  - Immediately clean soil deposited on pavement
  - Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface
  - Clean inlets draining to the subsurface bed twice per year

- Repairs
  - Surface should never be seal-coated
  - Inspect for pavement rutting/raveling on an annual basis (some minor ruts may occur in the pervious pavement from stationary wheel rotation)
  - Damaged areas less than 50 square feet can be patched with pervious or standard pavement
  - Larger areas should be patched with an approved pervious pavement

Properly installed and maintained pervious pavement has a lifespan comparable to impervious pavement types, and existing systems that are more than twenty years in age continue to function (Adams, 2003). Because water drains through the surface course and into the subsurface bed, freeze-thaw cycles do not tend to adversely affect pervious pavement.

The primary goal of pervious pavement maintenance is to prevent the pavement surface and/or underlying infiltration bed from becoming clogged with fine sediments. To keep the system clean throughout the year and prolong its lifespan, the pavement surface should be vacuumed twice per year with a commercial cleaning unit. Inlet structures within or draining to the infiltration beds should also be cleaned out on a biannual basis.

Planted areas adjacent to pervious pavement should be well maintained to prevent soil washout onto the pavement. If washout does occur it should be cleaned off the pavement immediately to prevent further clogging of the pores. Furthermore, if bare spots or eroded areas are observed within the planted areas, they should be replanted and/or stabilized at once. Planted areas should be inspected on a semi-annual basis. Trash and other litter that is observed during these inspections should be removed.

Superficial dirt does not necessarily clog the pavement voids. However, dirt that is ground in repeatedly by tires can lead to clogging. Therefore, vehicles should be discouraged from tracking or spilling excessive dirt onto the pavement. Furthermore, construction vehicles and hazardous materials carriers should be prohibited from entering a pervious pavement lot. Descriptive signage is recommended to maintain institutional memory of pervious pavement.

The use of pervious pavement must be carefully considered in areas where the pavement may be seal coated or paved over due to lack of awareness, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. Educational signage at pervious pavement installations may guarantee its prolonged use.

Vacuuming

Pervious pavement should be cleaned with a vacuum sweeper two times per year. Acceptable types of vacuum sweepers include the Elgin Whirlwind and the Allianz Model 650. Though much less effective than “pure” vacuum sweepers, regenerative air sweepers, such as the Tymco Model 210, Schwarze 348, Victory, and others, are sometimes used. These units contain a blower system that generates a high velocity air column, which forces the air against the pavement at an angle, creating a 'peeling' or 'knifing' effect. The high volume air blast loosens the debris from the pavement surface, then transports it across the width of the sweeping head and lifts it into the containment hopper via a suction tube. Thus, sediment and debris are loosened from the pavement and sucked into the unit. (Note: simple broom sweepers are not recommended for pervious pavement maintenance.)

If the pavement surface has become significantly clogged such that routine vacuum sweeping does not restore permeability, then a more intensive level of treatment may be required. Recent studies have proven the usefulness of washing pervious pavements with clean, low pressure water, followed by immediate vacuuming. Combinations of washing and vacuuming techniques have proved effective in cleaning both organic clogging as well as sandy clogging. Research in Florida found that a “power head cone nozzle” that “concentrated the water in a narrowly rotating cone” worked best. (Note: if the pressure of the washing nozzle is too great, contaminants may be driven further into the pervious surface.) Maintenance crews are encouraged to determine the most effective strategy of cleaning their pervious pavement installations.

For smaller installations, such as sidewalks, plazas, or small parking lots, “walk behind” vacuum units may prove most effective. Though these units can be loud and somewhat deleterious to the operator due to the lack of dust suppression, they are also relatively easy to operate and inexpensive. Examples of acceptable “walk behind” units include the Billy Goat models, the 5700 industrial-strength Scrubber by Tennant, and the sidewalk class vacuum sweepers made by Nilfisk, Advance, and Hako. If “walk behind” units are used, it is recommended that the scrub pressure be kept relatively low. The dirtiest areas may need to be power washed after scrubbing to get out the dirt that has been deeply ground in.

Restoration / Repairs

Because pervious pavement drains rapidly, potholes are extremely unlikely to occur, though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a declivity could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The declivity can also be filled with pervious mix or paver units. If an area greater than 50 SF is in need of repair, approval of patch type must be sought from either the engineer or owner. Under no circumstance is the pavement surface to ever be seal-coated. Required repair of drainage structures should be done promptly to ensure continued proper functioning of the system.

With minimal maintenance, pervious pavement can function effectively for well over 20 years. However, in the event that maintenance of the pervious pavement is neglected and it becomes clogged over time, the owner should vacuum the lot until permeability is restored. (If the permeability of the lot cannot be restored, the pavement should be removed and replaced with a new pervious mix or pervious units.) Recent research has shown that one of the most effective ways of restoring pervious pavement is applying a pressurized dose of a non-toxic detergent cleaning solution, allowing adequate soak time, and then vacuuming with a high performance unit. Once again, it is important to note that high pressure washing may drive contaminants further into the pervious surface and even into the underlying aggregate. It is therefore recommended that, prior to vacuum sweeping, a low performance pressure washer is used to get the solution to break the surface tension and reach into the pores.

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Capture and Reuse

Capture/Reuse, commonly referred to as rainwater harvesting, is a centuries old practice of collecting rainwater that has recently gained prominence as a stormwater management practice. Capture/reuse systems collect and store rainwater from impervious surfaces for later use. The collected rainwater is ideal for non-potable applications, such as landscape irrigation, toilet flushing, and vehicle washing. Capture/reuse is a multi-benefit practice because it reduces stormwater discharge volumes while simultaneously reducing the demand for potable water.

Rooftop runoff, because it often contains lower pollutant loads than surface runoff and provides accessible locations for collection, is the stormwater most often collected in capture/reuse systems. Roof downspouts are redirected to collection containers such as rain barrels, which typically range from 55 to 120 gallons, or cisterns, which can be several hundred to several thousand gallons. Rain barrels are typically installed at outdoor residential locations; cisterns can be installed in residential and nonresidential locations, either indoors or out, and above or below grade.

Capture/reuse serves to reduce the quantity of stormwater runoff by removing a volume of stormwater equal to the capacity of the collection tank. Capture/reuse can also be used as part of a treatment train by directing the overflow to a bioretention system to provide additional volume reduction and water quality treatment in instances where the quantity of runoff from a storm event exceeds the volume of the collection tank. When treatment such as filtration or disinfection is provided on capture/reuse systems it is intended to protect the collection tanks from fouling and/or to improve the quality of water for reuse applications.

Figure 60. Outdoor Cistern with Overflow Directed to Pervious Area.
Source: SEMCOG

Figure 61. Cisterns used for irrigation.
Source: Sunset Publishing Corporation

Cost

A typical commercial 55 gallon rain barrel can retail for about $80 to $120. Additional costs are incurred for the hardware necessary to attach the barrel to the drainage system. Do-it-yourself kits may cost under $30. Cistern system prices vary by size and location of installation. Cisterns for residential applications may range in size from 100 gallons to 10,000 gallons. A cistern is expected to have a lifespan of 20-50 years, depending on site specifics and materials used. Cisterns can be prefabricated plastic, concrete or metal, or they can be cast-in-place concrete. In general, storage tanks can be expected to cost about one dollar per gallon of storage.

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced potable water demand

Limitations

- Treats only rooftop runoff
- Must be monitored regularly to ensure that there is adequate storage capacity
- Regulatory obstacles may limit reuse opportunities
- If not installed correctly, may provide habitat for mosquitoes

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Water Efficiency – Credit 1 "Water Efficient Landscaping" (1 Point)
Water Efficiency – Credit 2 "Innovative Wastewater Technologies" (1 Point)
Water Efficiency – Credit 3 "Water Use Reduction" (1-2 Points)
Innovation & Design Process (1-4 Points)

Water Supply Impacts

Per capita domestic indoor water use is 70 gallons per day (gpd); however, outdoor irrigation, especially in dry climates, can increase per capita usage to 165 gpd, meaning that outdoor irrigation can account for nearly 60 percent of demand. Similarly, other non-potable uses comprise a large percentage of water demand. Domestic toilet flushing accounts for 11 percent of water demand. In office buildings, toilet flushing accounts for 25 percent of demand, while cooling systems account for 23 percent. Non-potable uses consume a significant percentage of water from municipal systems. Capture/reuse offers the opportunity to reduce the demand on the potable water supply by offering an alternative source of water. Using capture/reuse as a stormwater management technique provides the opportunity to have a positive impact on water supply by matching the quality of the water supplied to the quality required for a given demand. Due to the limited and variable rainfall, and extended dry seasons in many areas of the semi-arid southern California region, the benefits of integrating rainfall collection systems into domestic use systems must be weighed against the cost of implementing such systems. Constructing separate rainwater harvesting systems to be used solely for irrigation may be more practical economically.

Applications

Capture/reuse can be used in many applications from residential rain barrels to large-scale cisterns. Capture/reuse is appropriate for use in residential, commercial, high-density, institutional, residential, and industrial applications. The common forms of capture/reuse applications are provided below.

Potential Applications	
Residential	YES
Commercial	YES
High-density	YES
Industrial	YES
Recreational/Institutional	YES
Highway/Road	NO

Residential

Rain barrels are most commonly used in residential settings. Simple diversions of roof downspouts to rain barrels allow roof runoff to be redirected away from sewers. The collected rainwater is most often used for outdoor water uses such as landscape irrigation or vehicle washing. A 55 gallon barrel will be filled by 0.5 inches of net runoff from 176 square feet of rooftop. Rain barrels are generally not fitted with water pumps; therefore discharge areas must be located down gradient from the rain barrel. This may limit the potential for a homeowner to use captured runoff for irrigation of landscaped areas that are upslope from the roof discharge point. Flow can be improved by raising the rain barrel on blocks.

It is important to note that atmospheric deposition is a significant source of pollution in runoff (Sabin et al, 2005). Captured roof runoff should never be used for potable uses, and should not be used to irrigate vegetable gardens unless it is pretreated by filtration or settling.

Figure 62. Residential rain barrel in Los Angeles.
Source: LA Rainwater Harvesting Program

Figure 63. Large-scale residential system in Los Angeles, CA.
Source: Tree People

<u>Commercial</u>
Capture/reuse systems for commercial settings can vary in size and may consist of cisterns with several thousand gallons of storage capacity. Because non-potable uses can constitute up to 85 percent of water demand in commercial buildings, commercial applications offer a large potential to use harvested rainwater for uses such as irrigation, toilet flushing, and cooling system makeup.

Figure 64. Large cistern for vegetated roof plaza maintenance.
Source: Cahill Associates

Figure 65. Six (6) 1,000 gallon cisterns at U.S EPA headquarters provide water for irrigation
Source: U.S. EPA

Storage Beneath Structure

Stormwater can be stored under hardscaped elements (such as paths and walkways) through the use of structural plastic storage units, such as RainTank, or other alternative manufactured storage products, and can supplement onsite irrigation needs. Designing a capture-reuse system in which runoff is stored under a hardscaped structure is best used in institutional or commercial settings. This type of subsurface storage is larger and more elaborate, typically requiring pumps to connect to the irrigation system.

Figure 66. Rainstore™ unit beneath brick pavers on a vegetated rooftop plaza.
Source: Cahill Associates

Figure 67. Rainstore™ units used as the storage element underneath a brick pathway atop a vegetated rooftop plaza.
Source: Cahill Associates

Design Guidance

Site Factors

- · Water Table / Bedrock Separation: N/A
- · Soil Permeability: N/A
- · Feasibility on steeper slopes: N/A

Sizing

The sizing of capture/reuse systems is dependent upon the volume of water available for capture, comprised of the total area of the collection surface and rainfall; the associated demand for the harvested rainwater; and the space available for tank installation. In many instances the size of the collection container is a pre-determined design variable. For instance, rain barrels typically are available within a limited range of sizes; similarly, available lot or building space may determine the allowable dimensions of a cistern and thus the provided storage volume.

An analysis of precipitation and demand is required when trying to optimize the sizing of cisterns. Historical monthly or daily rainfall records should be examined to determine the amount, frequency, and seasonal variation of rainfall. Several years of data should be included to account for dry and wet years. Additionally, in Southern California it is often suggested to oversize the storage system to maximize the volume of rain captured during the rainy season. This allows some carryover in order to make water available in the dry season when little, if any, rainwater would be collected. The volume of water that can be collected from a given rain event can be calculated as:

$$V\text{ (gal)} = \text{Area of Collection Surface (ft}^2\text{)} \times \text{Rainfall (in)} / 12\text{ in/ft} \times 0.8\text{ (Capture Efficiency)} \times 7.48\text{ gal/ft}^3$$

Where captured rainwater can be practicably integrated into the sites water use supply, the specific potential end uses for the water need to be determined to provide an estimate of the daily or monthly water demands. For instance, toilet and urinal flushing impart a consistent daily demand on a water system while outdoor irrigation may be somewhat more episodic. The determined end uses will provide the daily drawdown rate. Comparing the drawdown rate to the predicted fill rate will determine proper cistern capacity. National averages for per capita residential water demand are provided below.

Table 28. Typical Domestic Daily per Capita Water Use.

Use	Gallons per Capita	% of Daily Total
Potable indoor uses		
• Showers	11.6	7.0%
• Dishwashers	1.0	0.6%
• Baths	1.2	0.8%
• Faucets	10.9	6.6%
• Other uses, leaks	11.1	6.7%
Subtotal	35.8	21.7%
Non-potable indoor uses		
• Clothes washers	15.0	9.1%
• Toilets	18.5	11.2%
Subtotal	33.5	20.3%
Outdoor uses	95.7	58.0%

Source: AWWARF, 1999

Water Quality Treatment

Efficient operation and the intended end uses will determine the level of treatment needed in a capture/reuse system. Other than simple screening, water collected in rain barrels and used for residential irrigation does not typically require treatment. Little human health risk is presented when harvested rainwater is used for other non-potable uses (e.g., water closets, urinals, hose bibbs), though such usage requires the installation of a dual plumbing system to keep potable water separated from harvested water. In these situations, screening and filtration to prevent particles and debris from traveling through the collection and plumbing system is typically sufficient. When harvested water is used for higher end contact uses, additional filtration and disinfection is required. As an example, typical water quality criteria for various end uses from the Texas Rainwater Harvesting Manual are provided in the table below. Detailed specifications and design guidance can be found through the American Rainwater Catchment Systems Association (http://www.arcsa.org).

Table 29. Minimum Water Quality Guidelines and Treatment Options for Stormwater Reuse.

Use	Minimum Water Quality Guidelines	Suggested Treatment Options
Potable indoor uses	• Total coliforms – 0 • Fecal coliforms – 0 • Protozoan cysts – 0 • Viruses – 0 • Turbidity < 1 NTU	• Pre-filtration – first flush diverter • Cartridge filtration – 3 micron sediment filter followed by 3 micron activated carbon filter • Disinfection – chlorine residual of 0.2 ppm or UV disinfection
Non-potable indoor uses	• Total coliforms < 500 cfu per 100 mL • Fecal coliforms < 100 cfu per 100 mL	• Pre-filtration – first flush diverter • Cartridge filtration – 5 micron sediment filter • Disinfection – chlorination with household bleach or UV disinfection
Outdoor uses	N/A	• Pre-filtration – first flush diverter
*cfu – colony forming units *NTU – nephelometric turbidity units		

Source: The Low Impact Development Center, Inc.

The harvesting system must not be connected to the potable water supply system at any time. High levels of caution are needed to ensure the integrity of the separation between the potable system and the harvesting system.

System Design

All components of a capture/reuse system should be designed to minimize the introduction of pollutants and to provide treatment sufficient for the intended end uses.

Tank, Collection, and Distribution

When rainwater is collected from rooftops, gutters should be equipped with leaf screens with openings no larger than 1/2 inch across their entire length, including the downspout opening. The screens prevent debris from clogging the collection system and/or fouling the harvested water. For internal downspouts, the downspout opening should be screened. A first flush diverter may be used to allow the initial portion of runoff to bypass the collection tank. If additional primary filtration is desired, roof washers may also be used. Roof washers can act as first flush diverters and also contain filter media (e.g., sand, gravel, filter fabric) to provide removal of particulates that have passed through the leaf screens.

Rain barrels and cisterns should be constructed of materials rated for potable water use. Outdoor tanks should be constructed of opaque materials or otherwise shaded or buried to protect the harvested rainwater from direct sunlight. Tank overflows should be directed away from structures and to pervious areas to allow for infiltration whenever possible. Outdoor tanks should also contain adequate screening at each opening to prevent insects from entering the tank. Rain barrels and cisterns temporarily store stormwater and when properly designed and maintained there is less potential for breeding of mosquitoes and other pests than with conventional BMPs.

For non-potable indoor uses (where local codes and ordinances allow), additional treatment can be provided following the collection tank, even though it may not be necessary for public health reasons. Additional cartridge filtration can be provided to prevent suspended particles from entering pipes.

Separate piping without direct connection to potable water piping should be provided for capture/reuse systems. Dedicated piping should be color coded and labeled as harvested rainwater, not for consumption. Faucets supplied with non-potable rainwater should contain signage identifying the water source as non-potable and not for consumption.

Cross-contamination

When make-up water is required to be provided to the capture/reuse system from the municipal system, steps should be taken to prevent cross-contamination. Cross-contamination measures for capture/reuse systems will be similar to those for reclaimed and greywater systems. The make-up supply to the cistern is the point of greatest risk for cross-contamination of the potable supply. A backflow prevention assembly on the potable water supply line, an air gap, or both must be provided to prevent collected rainwater from entering the potable supply. Contact local water system authorities to determine specific requirements. The designated dual piping system is also part of the cross-contamination prevention measures.

Construction

Cisterns are typically prefabricated, made of plastic, metal, or concrete. They can also be cast-in-place. A variety of containers are used for rain barrels. Positive outlet for overflow should be provided a few inches from the top of collection tank and should be sized to safely discharge excess volume when the tank is full. When cisterns are installed below grade, observation risers should rise at least 6 inches above grade.

Maintenance

When cisterns are used for non-potable indoor uses, a municipal inspection should occur during installation. Annual municipal inspections of the backflow prevention systems are also recommended. For a property owner, the operation and maintenance of a rainwater harvesting system is similar to a private well. Annual water quality testing is recommended when captured rainwater is provided for indoor uses. Regular inspection and replacement of treatment system components such as filters or UV lights is also recommended.

Maintenance Schedules:

Rain Barrel Maintenance

- Inspect rain barrels four times per year, and after major storm events.
- Remove debris from screens as needed.
- Replace screens, spigots, downspouts, and leaders as needed.

Cistern Maintenance

- Flush cisterns annually to remove sediment.
- For buried structures, vacuum removal of sediment is required.
- Brush the inside surfaces and thoroughly disinfect twice per year.

References and Resources

American Rainwater Catchment Systems Association: http://www.arcsa.org

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Green Roofs

Green roofs are vegetated roof systems that filter, absorb, and retain or detain the rain that falls upon them. Green roofs are comprised of a layer of soil media planted with vegetation. Extensive green roofs, defined as those systems 2 to 6 inches in thickness, are the design most often used for stormwater management. Other structural components are incorporated into green roof systems including waterproofing, synthetic insulation, and fabrics.

Intensive green roofs are less commonly used as a dedicated stormwater management practice. The soil media is greater than 6 inches thick and they can be comprised of a wide arrange of vegetation including shrubs and trees.

Rain that falls onto green roofs is returned to the atmosphere either by evaporation or transpiration by plants, which remove the water from the soil media. When the soil media becomes saturated, the excess water percolates through to the drainage layer and is discharged through the roof downspouts. Green roofs can provide high rates of rainfall retention and decrease the peak flow rate because of the temporary soil storage that occurs during discharge events.

Figure 68. Demonstration vegetated roof project at EuroAmerican Growers in Bonsall, CA.
Source: Technical Advisory Committee

Cost

The cost for green roofs will be influenced by the depth of the soil media, the number and type of additional structural components in the design, the vegetation selected, and the need for structural roof modifications. While green roofs have typically been one of the more costly LID practices, costs have continued to decrease with increasing rates of adoption. In addition, the use of green roofs can decrease the cost for stormwater conveyance systems on a site and increase the cooling efficiency of the building. Green roofs cost approximately $5 to $10 per square foot for new roof construction, but can cost up to $25 per square foot for retrofits.

Benefits

- Reduced runoff volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Habitat creation
- Enhanced site aesthetics
- Reduced building energy use

Limitations

- Captures and treats only rooftop runoff
- Not suitable for steep roofs (> 30 degrees)
- Heavier than conventional roofs, may require additional support
- Require occasional vegetation management, and may require supplemental irrigation during droughts

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1 Point)
Other: Sustainable Sites – Credit 7 “Landscape & Exterior Design to Reduce Heat Islands” (1 Point)

Water Supply Impacts

Impacts vary, and are associated with water needed for initial plant establishment and subsequent maintenance, but in general should be minor. When needed, subsurface irrigation should be used to minimize evaporative losses. Detailed guidance on the irrigation needs of landscape plantings has been published by the California Department of Water Resources (UCCE and CDWR, 2000).

Applications

Green roofs have a wide variety of applications for a number of land uses but are most common in urban/high-density, institutional, commercial, and industrial applications. Potential applications are provided below.

Potential Applications	
Residential	YES
Commercial	YES
High-density	YES
Industrial	YES
Recreational/Institutional	YES
Highway/Road	NO

Figure 69. Vista Hermosa Park Ranger Station, Los Angeles.
Source: Greenroofs.com

Figure 70. Premier Automotive Headquarters, Irvine.
Source: Roofscapes, Inc.

Design Guidance

Site Factors

- Water Table / Bedrock Separation: N/A
- Soil Permeability: N/A
- Feasibility on steeper slopes: N/A

Green roofs are most often applied to buildings with flat roofs, but roofs with slopes up to 30° can be accommodated with the use of mesh, stabilization panels, or battens. Slopes greater than 30° may also be accommodated with specialized designs. Green roofs will not cover the entire roof area because of the need to reserve space for heating ventilation and air condition (HVAC) systems and areas for roof access and maintenance. Typically 50 to 80 percent of the total roof area will be covered by the green roof.

The load carrying capacity of the roof will also influence the suitability of a green roof. The wet weight of the green roof measures the fully saturated vegetation, soil media, and membrane layers. Extensive green roof wet weight is approximately 6 to 7 pounds per square foot per inch of depth. Green roofs typically incorporate very drought-tolerant plants and utilize coarse engineered media with high permeability. A typical profile would include the following layers:

- Vegetation layer
- Engineered growth media
- Separation geotextile
- Semi-rigid plastic geocomposite drain or mat (typical mats are made from non-biodegradable fabric or plastic foam)
- Root barrier (optional)
- Waterproofing membrane

A waterproof membrane is needed to prevent water migration from the green roof to the structural roof. An optional root barrier may also be installed to prevent root damage of the waterproof membrane. Insulation, if included in the roof covering system, may be installed either above or below the primary waterproofing membrane.

Plant Selection

Plants should be selected which will create a healthy, drought-tolerant roof cover. In general, selected plants should be:

- Native or adapted species tolerant of extreme climate conditions (e.g., heat, drought, wind);
- Low-growing, with a range of growth forms (e.g., spreading evergreen shrubs or subshrubs, succulents, perennials, self-seeding annuals);
- Possessive of a shallow root system without the chance of developing a deep taproot; and
- Long lived or self-propagating, with low maintenance and fertilizer needs.

A variety of species and growth forms may be considered for a single roof project to ensure survival and plant growth. In addition, because many perennials and annuals are dormant during part or all of the rainy season, evergreen and cool-season plants should be included to help with rainfall interception and evapotranspiration during the seasons when rains typically occur.

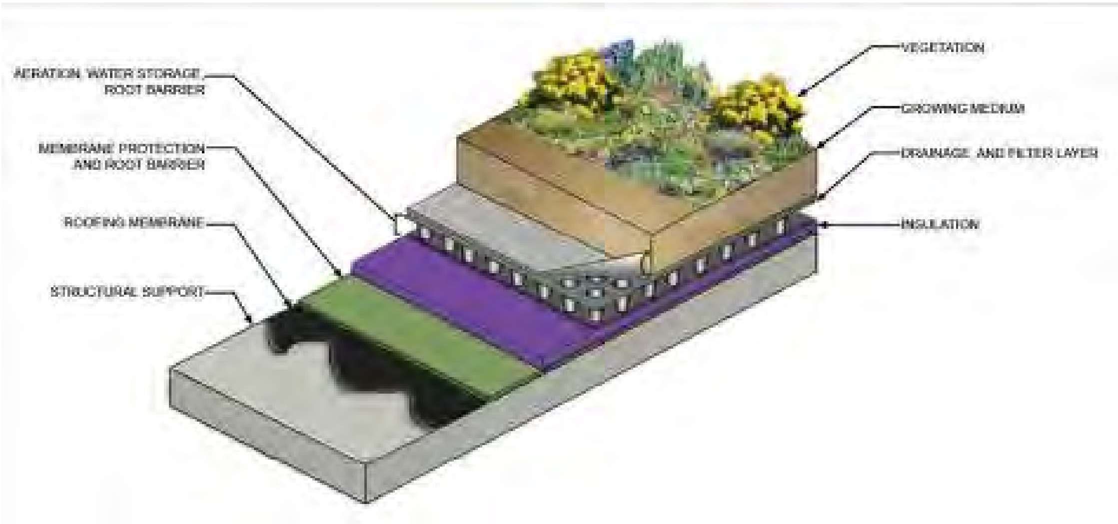

Figure 71. Green Roof Schematic.
Source: Cahill Associates

Construction Guidance

The following is a typical construction sequence. However, alterations will be necessary depending on design variations.

1. Install waterproof membrane and visually inspect. The waterproofing should be tested for water tightness by the roofing applicator.
2. Install slope stabilization measures for pitched roofs.
3. If the waterproofing materials are not root-fast, install a root-barrier layer.
4. Lay out key drainage components, including drain access chambers, internal drainage conduit, confinement border units, and isolation frames (for rooftop utilities, hatches, and penetrations).
5. Install walkways and paths (for maintenance or projects with public access).
6. Install the drainage layer. Depending on the variation type, this could be a geocomposite drain, mat, or drainage media.
7. Cover the drainage layer with the separation fabric (in some assemblies, the separation fabric is pre-bonded to a synthetic drainage layer).
8. Install sub surface irrigation capillary matting and supply lines according to design.
9. Install the growth media layer on top of the capillary matting using crane lifted supersacks.
10. Install the plant layer from cuttings, plugs, seed, or pre-grown mats, according to spacing or seeding rate specified by green roof designer.
11. Provide protection (e.g., UV-degradable erosion control netting) from wind disruptions as warranted by the project conditions and plant establishment method.
12. Overhead irrigation should be provided during the plant establishment for a period determined by the green roof designer until plants are fully established.

Maintenance Considerations

The maintenance schedule should include the following activities.

1. In the arid southwest, regular to periodic irrigation will likely be required.
2. During the plant establishment period, weeding, fertilization (if needed), and infill planting is recommended every three to four months. Thereafter, only two visits per year for inspection and light weeding should be required.
3. Drainage outlets should be inspected periodically to verify that they drain freely and are not clogged with debris.

4. The waterproof membrane should be inspected periodically for drainage or leaks. It is also possible to include a leak detection system in the green roof design.

References and Resources

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BMP Factsheets

The following factsheets cover several additional BMPs that are commonly used in LID designs. These BMPs are in widespread use, and many local sources of design guidance already exist. Therefore, the factsheets provide a brief description of the practice, its benefits and limitations, and links to more detailed information.

Downspout Disconnection

Downspout disconnection refers to the redirection of stormwater from an existing downspout to a vegetated area (e.g. a swale or planter box) or a collection system (e.g. a rain barrel or cistern). The collected water can be used for onsite landscaping. Downspout disconnections are typically used in residential, commercial, and industrial applications.

Water quality benefits are gained from disconnection practices because a percentage of the overall stormwater volume infiltrates into pervious areas or is lost through evapotranspiration. Disconnection practices decrease the total volume of stormwater discharged to receiving water bodies. Therefore, the reduction in pollutant and nutrient loading attributed to disconnection is dependent upon the reduction in stormwater volume. In addition, the impact of disconnection on stormwater volume and peak discharge is dependent upon the area to which the stormwater is directed.

Figure 72. Downspout disconnection into vegetated area.
Source: Prince George's County, MD Department of Environmental Resources

Benefits

- Reduced peak discharge rate
- Reduced runoff volume
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature

Limitations

- Runoff must not flow toward building foundations or onto adjacent private property.
- Discharge areas must be large enough to infiltrate runoff (typically 10 percent of contributing roof area)

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Design Guidance

Direct downspout disconnections away from buildings. Ensure that the ground slopes away from the discharge point. Use spashblocks, rocks, or flagstones at the end of downspouts to direct runoff and control erosion. As a rule of thumb, the discharge area should be 10 percent of the roof area draining to the downspout (Portland BES, 2010). For low permeability soils (HSG C and D), a greater discharge area may be required. In large storm events, discharge areas may be subjected to high flows, and potentially to temporary submergence. Select landscape materials that are not easily eroded or transported. Preference should be given to rock or stone groundcovers over wood mulch.

Links to Detailed Information

California Stormwater Quality Association. 2003. *Roof Runoff Controls, SD-11*. California Stormwater BMP Handbook New Development and Redevelopment. http://www.cabmphandbooks.com/Documents/Development/SD-11.pdf

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Soil Amendments

The ability of existing soils to absorb, infiltrate and remove pollutants from stormwater can be improved by the application of soil amendments. These include compost, as well as other soil conditioners and fertilizers as appropriate for specific site conditions. Soil amendments can change the physical, chemical and biological characteristics of the soil, restoring degraded soils and improving naturally poor soils. Soil amendments reduce bulk density and increase cation exchange capacity, enhancing the soil's ability to hold water, increasing infiltration rates, and improving nutrient retention and pollutant removal.

Figure 73. Soil Amending Process.
Source: U.S. EPA

Cost
Costs associated with soil amending include the amendments themselves and their application. These costs are generally on the order of $1-3 per square foot.

Benefits
- Reduced runoff volume
- Reduced peak discharge rate
- Groundwater recharge
- Reduced TSS
- Reduced pollutant loading
- Habitat creation
- Enhanced site aesthetics

Limitations
- Not recommended for slopes steeper than 3:1

Potential LEED Credits:
Primary: N/A
Other: Innovation & Design Process (1-4 Points)

Water Supply Impacts

Soil amendments increase the ability of the soil to hold water, and therefore may decrease the need for irrigation during dry periods.

Design Guidelines

Amendments can be applied by topdressing or tilling into the upper soil layers. The most appropriate amendments and application rates are determined through soil testing.

Maintenance

Soil should be planted and mulched after installation. No part of the site should have bare soil exposed. Compaction of amended soils should be avoided.

Amended soils should be inspected annually for signs of compaction, waterlogging, loss of vegetated cover, or erosion. Routine infiltration testing can be used to pinpoint potential problem areas. In areas where remediation is needed, soil samples may help to diagnose specific deficiencies in the soil. Corrective actions include application of additional amendments and mechanical aeration.

Links to Detailed Information

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Inland Empire Regional Composting Authority. *General Landscaping Information*.
http://www.ierca.org/docs/GeneralLandscape.pdf

Low Impact Development Center, Inc. *Soil Amendments*.
http://www.lid-stormwater.net/soilamend_home.htm

University of California Cooperative Extension (UCCE) and California Department of Water Resources (CDWR). 2000. *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*. Sacramento, CA: California Department of Water Resources.

Vegetated Filter Strips

Filter strips are bands of dense, permanent vegetation with a uniform slope designed to provide water quality treatment for an adjacent runoff source (i.e., impervious area) by allowing pollutant filtering and settling and stormwater infiltration. They are also commonly used as pretreatment for other BMPs.

Figure 74. Filter strip used as pretreatment for highway runoff.
Source: RBF Consulting

Benefits

- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Enhanced site aesthetics
- Reduced phosphorus (high efficiency)
- Reduced metals (medium efficiency)

Limitations

- Must be sited adjacent to imperviousness surfaces
- Requires regular inspection and maintenance to maintain sheet flow
- Relatively large footprint, may not be suitable for highly urban areas
- Must be used in conjunction with additional BMPs to provide volume storage and peak flow reduction.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Department of Transportation. 2008. *Caltrans Treatment BMP Technology Report*. April 2008, CTSW-RT-08-167.02.02.
http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-31: Vegetated Buffer Strip. http://www.cabmphandbooks.com/Documents/Development/TC-31.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.* http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Vegetated Swales

Vegetated swales are broad, shallow channels designed to convey and either filter or infiltrate stormwater runoff. The swales are vegetated along the bottom and sides of the channel and are used to reduce stormwater volume through infiltration, improve water quality through infiltration and vegetative filtering, and reduce runoff velocity by increasing flow path lengths and channel roughness.

Figure 75. A vegetated swale with curb cuts in Playa Vista, California.
Source: Keith Linker

Figure 76. A vegetated swale with curb cuts in El Monte, California.
Source: Bill DePoto

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Enhanced site aesthetics
- Reduced phosphorus (moderate efficiency)
- Reduced metals (moderate efficiency)
- Increases time of concentration, T_c

Limitations

- Not applicable for steep slopes
- Requires regular vegetation maintenance and trash removal
- Not suitable for areas with highly erodible soils
- Should not be located under trees which may drop leaves or needles, impeding flow
- Must be used in conjunction with additional BMPs to provide volume storage and peak flow reduction.

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Sustainable Sites – Credit 7 "Landscape & Exterior Design to Reduce Heat Islands" (1-2 Points)
Water Efficiency – Credit 1 "Water Efficient Landscaping" (1-2 Points)
Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Department of Transportation. 2008. *Caltrans Treatment BMP Technology Report*. April 2008, CTSW-RT-08-167.02.02.
http://www.dot.ca.gov/hq/env/stormwater/annual_report/2008/annual_report_06-07/attachments/Treatment_BMP_Technology_Rprt.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-30: Vegetated Swale.
http://www.cabmphandbooks.com/Documents/Development/TC-30.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Infiltration Basins

Infiltration basins are shallow impoundments designed to collect and infiltrate stormwater. Collected stormwater temporarily ponds on the surface of the basin, then infiltrates. Pollutant removal is accomplished by natural mechanisms within the soil including filtration, absorption and adsorption, and chemical and biological uptake. Siting is constrained by available land and the infiltration capacity of the soils.

Figure 77. Infiltration Basin.
Source: March Joint Powers Authority

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Increased groundwater recharge

Limitations

- Requires large pervious area
- Not suitable on fill sites or steep slopes
- Risk of groundwater contamination in very coarse soils
- High potential for clogging; functioning is difficult to restore
- Requires regular maintenance

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-11: Infiltration Basin. http://www.cabmphandbooks.com/Documents/Development/TC-11.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Infiltration Trenches

Infiltration trenches are narrow trenches that have been back-filled with stone. They collect runoff during a storm event, store it in the void spaces in the stone, and release it into the soil by infiltration. Pretreatment, often with filter strips, is required to prevent sediment buildup and ensure effective infiltration. Infiltration trenches can drain areas up to 10 acres. They are not recommended downstream of erodible areas, on steep slopes, or in areas where pollutant spills are likely. Infiltration trenches must be set back 10 feet from the seasonal high groundwater table, 5 feet from any impermeable soil layers or bedrock, and out of tree drip lines. Infiltration trenches can be prone to clogging with sediment and require pretreatment as well as regular observation and maintenance to ensure proper functioning.

Figure 78. Infiltration Trench.
Source: RBF Consulting

Benefits

- Reduced stormwater volume
- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Increased groundwater recharge

Limitations

- The longitudinal slope of the trench should not exceed 3 percent
- High potential for clogging; functioning is difficult to restore
- Risk of groundwater contamination in very coarse soils
- Requires regular maintenance
- Low removal of dissolved pollutants
- Some configurations may meet the definition of EPA Class V injection wells, and must be registered with EPA Region 9. Regulations vary by jurisdiction. Details are available at: http://www.epa.gov/region09/water/groundwater/uic-classv.html

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-10: Infiltration Trench. http://www.cabmphandbooks.com/Documents/Development/TC-10.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.* http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Dry Wells

A dry well is an underground storage facility used to capture and infiltrate runoff from downspouts or small impervious areas. Dry wells can be used on steep slopes, where many other BMPs cannot, provided the slope is stable and not subject to landslide risk. They have a very small footprint, and can be used in tight spaces. Dry wells are typically used in residential or other small-scale applications.

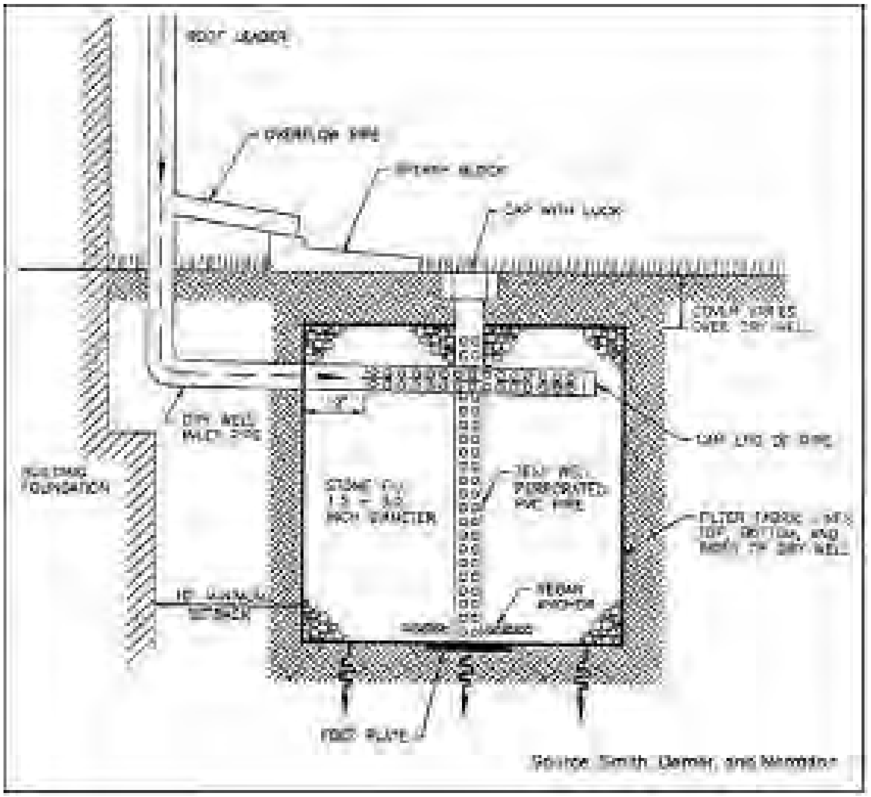

Figure 79. Schematic of a dry well.
Source: Stormwater Management for Maine, 1995. (UFC Manual).

Benefits

- Reduced peak discharge rate
- Reduced runoff volume
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature

Limitations

- Requires HSG Group A or B soils
- Not suitable for high sediment loads
- Dry wells meet the definition of EPA Class V wells, and must be registered with EPA Region 9. Regulations vary by jurisdiction. Details are available at: http://www.epa.gov/region09/water/groundwater/uic-classv.html

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: Innovation & Design Process (1-4 Points)

Links to Detailed Information

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

U.S. Department of Defense. 2004. *Unified Facilities Criteria (UFC) Low Impact Development Manual*. UFC 3-210-10. http://www.lowimpactdevelopment.org/lid%20articles/ufc_3_210_10.pdf

U.S. Environmental Protection Agency. *Underground Injection Control for Region 9 Class V Wells.*
http://www.epa.gov/region09/water/groundwater/uic-classv.html

Dry Ponds

Dry ponds, also known as extended detention basins, are designed to collect and detain a water quality volume of stormwater for a set period of time, normally 24 to 72 hours, before discharging the runoff. Dry ponds do not maintain a permanent pool, emptying completely between rain events. Water quality improvements are gained from sedimentation and peak flow attenuation.

Figure 80. Dry pond.
Source: RBF Consulting

Benefits

- Reduced TSS
- Reduced pollutant loading

Limitations

- Requires tributary area greater than 5 acres
- Outlets of detention systems may clog easily if not properly designed and maintained
- Requires large dedicated area
- Low ability to reduce runoff volume

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: N/A

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-22: Extended Detention Basin.
http://www.cabmphandbooks.com/Documents/Development/TC-22.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

Constructed Wetlands

Constructed wetlands are shallow, engineered vegetated systems designed to provide stormwater detention and pollutant removal. Natural wetlands SHOULD NOT be used to treat stormwater.

Figure 81. Dominguez Gap Wetlands, LA County.
Source: Raphael D. Mazor, Southern California Coastal Water Research Project

Benefits

- Reduced peak discharge rate
- Reduced TSS
- Reduced pollutant loading
- Reduced runoff temperature
- Habitat creation
- Enhanced site aesthetics

Limitations

- Requires year-round base flow
- Requires large footprint
- Not suitable for steep slopes
- Requires careful design, maintenance and monitoring to prevent vector infestation
- Safety concerns where there is public access
- Dense plantings may restrict access for maintenance

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-21: Constructed Wetlands. http://www.cabmphandbooks.com/Documents/Development/TC-21.pdf

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*. http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

USEPA - Guiding Principles for Constructed Wetlands
http://www.epa.gov/owow/wetlands/pdf/constructed.pdf

Media Filters

A media filter is a flow-through system designed to improve water quality from impervious drainage areas by slowly filtering runoff through a media such as sand. It consists of one or more sedimentation and filtration chambers or areas to treat runoff. Pollutant removal in media filters occurs primarily through straining and sedimentation. Treated effluent is collected by underdrain piping and discharged. Surface and underground media filters function similarly.

Types of non-vegetated Media Filters

- Bed Filters – Includes conventional Delaware and Austin sand filter designs as well as horizontal flow bed filters.
- Modular Cartridge based filters – Typically proprietary and available in a range of configurations including radial flow, upward flow and fluidized bed filters with customizable media.
- Powered filtration systems – Utilize a range of media and are often designed as parallel systems with backwash capabilities.
- Catch Basin inserts – Typically designed with shallow media beds (<2") very high hydraulic loading rates (> 10 gpm/ft^2) and very low contact time (<5 sec) at design flow rates.

Figure 82. Surface media filter.
Source: Portland BES

Benefits

- Most media filters can be located below ground and can support H20 loading. Therefore they require no dedicated site area.
- No potable water demand
- Pollutant sequestration. Pollutants are stored out of contact with the public, wildlife, groundwater, soil or vegetation.
- Spill protection
- Filter media can be customized to target specific pollutants of concern

- Modular, standardized design can reduce construction errors

Limitations

- Very low runoff volume reduction capability
- Low ability to remove dissolved pollutants
- May require confined space entry for maintenance
- May require cooperation with vendor for replacement media or cartridges
- Maintenance of underground filters is easily neglected, and can lead to system failure
- Designs that maintain permanent standing water may create vector concerns

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 "Stormwater Management" (1-2 Points)
Other: N/A

Application

Where landscape based BMPs are infeasible, especially on retrofit projects due to space limitations or pre-existing structures and grading, filtration can be provided in a modular, non-vegetated format to provide important pollutant reduction benefits.

Filter Performance and Design

The performance of any media filter is governed primarily by four factors:

- Hydraulic Loading Rate – The application rate of untreated water to the surface of the filter media usually expressed as a flow rate per filter surface area. i.e. gpm/ft^2
- Filter Media Gradation – A finer media gradation reduces hydraulic conductivity and increases the capture efficiency for fine particulate pollutants. Finer media also has a greater surface area which increases sorption rates for chemically active media. A more homogenous media gradation increases voids volume in a media bed. Finer media is more susceptible to surface clogging.
- Residence Time - Residence time is a function of media gradation, hydraulic loading rate and the media bed depth and configuration. A longer residence time generally improves pollutant removal performance.
- Media Chemical properties – Filter media can be inert (i.e. perlite) or can be selected to target specific pollutants of concern (i.e. activated carbon for trace organics). Chemically active options may be organic, mineral or synthetic or a combination of types. Media should be selected with consideration of the type and load of pollutants requiring removal.

Given the tremendous variability and the proprietary nature of many media filter designs, observed media filter performance varies widely. Sand filters following CASQA handbook guidance are generally accepted as effective stand-alone treatment systems for most common stormwater pollutants. At least three peer reviewed field monitoring protocols have been developed for the express purpose of identifying those stormwater treatment system designs that demonstrate comparable performance and that operational feasibility. Initial laboratory or bench scale performance evaluation is useful for refining filter design and operation characteristics, but in-field performance verification following one of the following protocols is essential. Media filter designs that have been accepted by the following programs may be considered for use where bioretention facilities are infeasible.

- Sacramento Stormwater Quality Partnership – "Investigation of Structural Control Measures for New Development"
- Washington State Department of Ecology – "Technology Assessment Protocol – Ecology" (TAPE), General Use Level Designation
- Technology Assessment Reciprocity Partnership (TARP) – "Protocol for Stormwater Best Management Practice Demonstrations", Final Certification

Links to Detailed Information

Caltrans, 2004. BMP Retrofit Pilot Program – Final Report. Report ID: CTSW - RT - 01 – 050. California Department of Transportation, Sacramento, CA.
http://www.dot.ca.gov/hq/env/stormwater/special/newsetup/_pdfs/new_technology/CTSW-RT-01-050.pdf

City of Austin. 2009. Environmental Criteria Manual.
http://www.amlegal.com/austin_nxt2/gateway.dll?f=templates&fn=default.htm&vid=amlegal:austin_environment

County of Los Angeles Department of Public Works. 2009. *Stormwater Best Management Practice Design and Maintenance Manual*.
http://dpw.lacounty.gov/DES/design_manuals/StormwaterBMPDesignandMaintenance.pdf

County of San Diego. 2007. *Low Impact Development Handbook.*
http://www.sdcounty.ca.gov/dplu/docs/LID-Handbook.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-40: Media Filter.
http://www.cabmphandbooks.com/Documents/Development/TC-40.pdf

Sacramento Stormwater Management Program. 1999. *Investigation of Structural Control Measures for New Development.*
http://www.sacstormwater.org/ConstructionandNewDevelopment/Manuals/SCM/SCMReport.pdf

Technology Acceptance and Reciprocity Partnership (TARP). 2001. *The Technology Acceptance Reciprocity Partnership Protocol for Stormwater Best Management Practice Demonstrations.*
http://www.mass.gov/dep/water/laws/swprotoc.pdf

Washington State Department of Ecology. 2008. *Guidance for Evaluating Emerging Stormwater Treatment Technologies: Technology Assessment Protocol – Ecology (TAPE).*
http://www.ecy.wa.gov/biblio/0210037.html

Proprietary Devices

Proprietary devices include water quality inlets, catch basin controls or stand-alone vaults that prevent sediment, oils, floatable trash, and debris from being transmitted through the collection system. Proprietary devices may be used with other BMPs as part of a stormwater treatment train. However, these controls are generally considered pretreatment devices, as they typically provide limited treatment when compared to other BMPs, and often do not provide detention or retention of stormwater runoff.

Figure 83. Catch basin insert.
Source: REM Inc.

Benefits

- Remove trash, debris, sediment, and/or oils
- Good retrofit capability

Limitations

- Provide limited water quality treatment
- Do not attenuate peak flows or volume
- Some devices permit permanent pools of standing water, which can provide a breeding area for mosquitoes
- Maintenance of underground devices is easily neglected, and can lead to system failure

Potential LEED Credits:

Primary: Sustainable Sites – Credit 6 “Stormwater Management” (1-2 Points)
Other: N/A

Links to Detailed Information

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet TC-50: Water Quality Inlet. http://www.cabmphandbooks.com/Documents/Development/TC-50.pdf

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. BMP Factsheet MP-50: Wet Vault.
http://www.cabmphandbooks.com/Documents/Development/MP-50.pdf

Sacramento Stormwater Management Program. 1999. *Investigation of Structural Control Measures for New Development.*
http://www.sacstormwater.org/ConstructionandNewDevelopment/Manuals/SCM/SCMReport.pdf

Step 5: Evaluate Design

A successful LID design must meet the goals that have been laid out at the beginning of the design process. Assessment of the level to which these goals have been met has both quantitative and qualitative elements.

LID centers on the goal of mimicking the predevelopment hydrology of a site, including volume, flow, and time of concentration of the runoff hydrograph. A successful LID design will have the following attributes:

- Runoff should be captured and treated where it is generated. Therefore, every impervious surface should be associated with a dedicated BMP or set of BMPs to capture and treat the runoff from that surface.
- No runoff should be discharged untreated, with the exception of excess runoff from events greater than the 85^{th} percentile storm event.
- Excess stormwater relative to predevelopment conditions should be captured and held onsite to the maximum extent practicable. The exact level of capture that is warranted will depend on the site's predevelopment hydrology, and the level of infiltration that can be achieved will depend on the site's soils.
- Predevelopment peak discharge rates should be maintained.
- The predevelopment time of concentration should be maintained. Flow paths should be as long as possible, flow surfaces should be roughened. This will prevent increases in the peak flow rate.
- Environmentally sensitive site features should be preserved.
- A designer should try to optimize the siting of buildings and paved areas in places that will have minimal impact on the site's hydrology. The design should avoid developing the most permeable soils, instead taking advantage of these areas for infiltration.

LID Hydrologic Analysis

The purpose of this section is to provide technical guidance on the estimation and control of stormwater runoff quality and quantity. A general overview of hydrograph methods used for designing BMPs, and a description of some of the more common computerized modeling methods and analysis is provided.

When assessing the structural BMPs that can be used to meet stormwater control objectives for a new or redevelopment project, the stormwater designer will need to adequately simulate various stormwater runoff scenarios. The hydrologic analysis includes estimating design storm characteristics (e.g., frequency, intensity, duration, and quality of runoff) with and without stormwater BMP controls. The type of calculations and models utilized in the hydrologic analyses is integral to appropriately simulating the pre- and post- design conditions and determining whether a successful design has been developed.

Background on Modeling LID

Stormwater modeling has its origin in the design of flood control facilities, which focused on protection of public property and safety. Changes in stormwater management, primarily related to environmental objectives, have necessitated that models be expanded to include a broader array of modeling capabilities. Additionally, conventional modeling focuses on the large storm events, whereas environmental objectives are often focused on the smaller events, which have the greatest influence on pollutant transport and channel geomorphology.

With the increasing use of LID as a stormwater mitigation approach, the peak flow rate and volume runoff benefits of LID need to be adequately accounted for in the selected modeling approach. There are multiple models that are capable of simulating stormwater runoff characteristics.

Commonly Used Models for LID Design

- California Stormwater BMP Handbook Approach
- Rational Method
- TR-20/TR-55
- HEC-1
- HSPF
- SWMM
- SLAMM

There have been many methodologies developed to estimate the total runoff volume, the peak flow rate of runoff, and the runoff hydrograph from land surfaces under a variety of conditions. This section describes some of the methods that are most commonly used for stormwater design. When selecting a modeling approach, match the tool to the scope, complexity, and size of the project while considering the conditions of the receiving waters and runoff conveyance system.

California Stormwater BMP Handbook Approach

Source: California Stormwater Quality Association

Storm Simulation Type: Continuous

Stormwater Analysis Capability: Volume, Flow

Description: The California Stormwater BMP Handbook Approach is based on an application of the STORM model, developed by the U.S. Army Corps of Engineers, to California. Both volume-based and flow-based BMP sizing curves are provided for representative areas throughout the state, and require only the calculation of a composite runoff coefficient for the proposed site.

Typical Use: Primarily used for site-scale sizing of water quality BMPs.

Advantages: This approach is easy to apply, and does not require the use of sophisticated models. Calculations are based on commonly available project information. The approach is often approved for use in California NPDES permits.

References:

California Stormwater Quality Association (CASQA). 2003. *California Stormwater BMP Handbook – New Development and Redevelopment*. Section 5, Treatment Control BMPs. http://www.cabmphandbooks.com/Documents/Development/Section_5.pdf

The Rational Method

Source: Kuichling, 1889

Storm Simulation Type: Single event

Storm Analysis Capability: Flow

Description: The rational formula calculates the peak flow rate as a function of the rainfall intensity (for a specific design return period and time of concentration (T_c)), the watershed area, and the runoff coefficient.

Typical Use: Estimating peak runoff rates from relatively small (200 acre) developed drainage areas. The Rational Method is commonly used to estimate runoff rates from large storm events for the design of conventional stormwater infrastructure (e.g., pipes) for flood management.

Advantages: Simple calculations that do not require intensive labor or software. Input values are readily available and can be adjusted to improve estimates.

Disadvantages: While the calculations are simple, peak runoff rate estimates are highly sensitive to estimates of the T_c. Additionally, the Rational Method is unable to accommodate for storage in the drainage area.

Recommendation: Can be used to size BMPs for water quality improvement. Manipulation of runoff coefficients can be conducted to simulate storage and infiltration processes, but considerable error may be introduced.

References:

CASQA, 2003. *California Stormwater BMP Handbook for New Development and Redevelopment*. Available online: http://www.cabmphandbooks.com/

Kuichling, E., 1889. *The Relation Between Rainfall and the Discharge of Sewers in Populous Districts*¸ Transactions ASCE 20(402):1-60.

TR-55 / TR-20

Source: The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS)

Storm Simulation Type: Single event

Description: "Technical Release 55 (TR-55) presents simplified procedures to calculate storm runoff volume, peak rate of discharge, hydrographs, and storage volumes required for floodwater reservoirs. These procedures are applicable to small watersheds, especially urbanizing watersheds, in the United States." (NRCS, 1986) TR-55 uses the runoff curve number method and unit hydrographs to convert rainfall into runoff estimates.

Typical Use: Used for both watershed/basin planning as well as project scale calculations.

Advantages: The advantage of applying TR-55 and TR-20 is the convenience of tables and input parameters included for a wide range of soil and land use conditions. TR-55 is the most widely used approach to hydrology.

Disadvantages: While simple to use, runoff estimates are highly sensitive to estimates of the Tc and curve numbers.

Recommendation: Can be effectively used to model LID BMPs for single event storms. User must be aware of uncertainty related to input parameters.

References:
NRCS, 1986. *Urban Hydrology for Small Watersheds*. Washington, DC: USDA.

NRCS – WinTR-55 Computer Model
http://www.wsi.nrcs.usda.gov/products/W2Q/H&H/Tools_Models/WinTR55.html

HEC-1

Source: U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC)

Storm Simulation Type: Single event

Stormwater Analysis Capability: Flow

Description: HEC-1 is designed to simulate the surface runoff response of a drainage basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component provides simulation of a rainfall-runoff process. The result of the modeling process is the computation of streamflow hydrographs at desired locations in the river basin.

Typical Use: Primarily used to design conventional detention basins for flood control.

Advantages: The ability to simulate system routing and storage provides some improvement over use of the Rational Method.

Disadvantages: May be complex for most users without appreciable benefit over TR-55, which is easier to use.

Recommendation: Can be used to simulate LID BMPs, but TR-55 would be a better option.

References:

USACE, HEC-1 Flood Hydrograph Package
http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1.htm

HSPF- Hydrologic Simulation Program – FORTRAN

Source: U.S. Environmental Protection Agency

Storm Simulation Type: Continuous simulation

Stormwater Analysis Capability: Water Quality and Flow

Description: The HSPF model simulates of water quantity and quality runoff from mixed land use watersheds. Using continuous simulation of rainfall-runoff processes, the model generates hydrographs, runoff flow rates, sediment yield, and pollutant washoff and transport. HSPF includes consideration of infiltration, subsurface water balance, interflow, and base flow.

Typical Use: Traditional use for conventional flood control and water quality treatment. Increasingly, models based on HSPF are being utilized to estimate emerging stormwater management practices such as LID.

Advantages: Models most processes that would concern LID BMP design. Capable of simulating a wider range of hydrologic responses through continuous simulation.

Disadvantages: HSPF is a complex model and requires a user familiar with the software. Also requires significant input data.

Recommendation: If the model is available and calibrated to the local conditions, then HSPF or an HSPF-based model would be appropriate. The LID designer should consider whether a simpler model (e.g., TR-55) would be sufficient.

References:
USEPA – Exposure Assessment Models: HSPF http://www.epa.gov/ceampubl/swater/hspf/

Storm Water Management Model (SWMM)

Source: U.S. Environmental Protection Agency

Storm Simulation Type: Single event and continuous simulations

Stormwater Analysis Capability: Water quality and flow

Description: SWMM is an urban stormwater model developed and maintained by the EPA. SWMM is applied to stormwater simulations including urban runoff, flood routing, and flooding analysis. The model provides continuous simulation of rainfall-runoff processes (peak flow, rate, duration) and associated pollutant washoff and transport. SWMM also includes flow routing capabilities for open channels and piped systems.

Typical Use: Predominantly used to design conventional stormwater facilities for flood control and conveyance. Used both at watershed- and parcel- level analysis. Some users have modified SWMM to better simulate LID practices and processes.

Advantages: SWMM provides ability to simulate water quality and flow, routing, and storage functions. Accounts for rainfall patterns and characteristics through continuous simulations. Can be modified to better meet user needs.

Disadvantages: Requires significant data input and user familiarity. Increase in variables, while providing an opportunity for more accurate simulations, can also create increased error due to the need to estimate multiple parameters.

Recommendation: Can be effectively used to model LID BMPs but user should determine whether a simpler method would be satisfactory.

References:
USEPA – Ecosystems Research Division: Stormwater Management Model (SWMM)
http://www.epa.gov/athens/wwqtsc/html/swmm.html

SLAMM (Source Loading and Management Model)

Source: PV & Associates

Storm Simulation Type: Continuous

Stormwater Analysis Capability: Water Quality

Description: SLAMM was developed to better understand the relationships between sources of runoff pollutants and runoff quality. It has been continually expanded and includes a variety of water quality control practices (infiltration, detention ponds, porous pavement, street cleaning, catch basin cleaning, and grass swales).

Typical Use: SLAMM is mostly used as a planning tool, to better understand sources of urban runoff pollutants and their control. Special emphasis has been placed on small storms, where most pollutant transport occurs.

Advantages: One of its most important features is its ability to consider many stormwater controls (affecting source areas, drainage systems, and outfalls) together, for a long series of rains. SLAMM can be effectively used in conjunction with drainage design models to incorporate the mutual benefits of water quality controls on drainage design.

Disadvantages: As a water quality model, SLAMM cannot predict stormwater runoff characteristics associated with LID.

Recommendation: Can be used if coupled with an appropriate runoff model.

References:
WinSLAMM - http://www.winslamm.com/default.html

Selecting the Appropriate Model to Evaluate Your LID Design

All of the models described in the preceding section can be utilized for evaluation of LID design. The appropriate computational methods depend on the type of information required and the size of the drainage area to be analyzed. In selecting the appropriate procedure, consider the scope and complexity of the problem, the available data, and the acceptable level of error. Consider the stormwater runoff objective (e.g., volume, peak rate, flow frequency/duration, water quality), then select the appropriate model.

Single Event versus Continuous Simulation Model

A continuous simulation model has considerable advantages over the single event-based methods. A continuous simulation model is capable of simulating a wider range of hydrologic responses than the single event models. Single event models cannot take into account storm events that may occur just before or just after the single event (the design storm) that is under consideration. Event- based modeling has a place, however, especially in the design of small projects (typically less than 200 acres), where resources are limited.

Continuous runoff models are able to simulate a continuous long term record of runoff and soil moisture conditions. Finally, single event models do not allow for estimation and analyses of flow durations, which may be necessary to determine acceptable discharges to streams.

Table 30 further describes the differences between these models.

Table 30. Commonly Used Models for LID Design.

	CA BMP Handbook	Rational Method	TR-55/TR-20	HEC-1	HSPF	SWMM	SLAMM
Simulation Type	Continuous	Single event	Single event	Single event	Continuous	Single Event/ Continuous	Continuous
Runoff Volume	Yes	No	Yes	Yes	Yes	Yes	No
Peak Discharge	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water Quality	No	No	No	No	Yes	Yes	Yes
Flow Routing	No	No	Yes	Yes	Yes	Yes	Yes
Storm Events	Small	Large	All	Large	All	All	Small
Overall Complexity	Low	Low	Moderate	Moderate	High	High	High
Appropriateness for LID	Moderate	Moderate	High	Moderate	High	High	High

Source: The Low Impact Development Center, Inc.

Section 3: Case Studies

Case Study 1: Commercial Retrofit

Retrofit existing commercial site with green roofs, permeable pavement, and bioretention.

Location: San Diego
Total Site Area: 2.81 acres

Existing Conditions
Total impervious area: 1.65 ac

- buildings: 0.39 ac
- parking: 0.99 ac
- walkways: 0.26 ac

Landscaped areas (turf): 1.16 ac

Existing soils: Gravel pit, Hydrologic Soil Group A, Infiltration rate: 13 in/hr, based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Weighted runoff coefficient: 0.54
Composite curve number: 78

Predevelopment Conditions
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook approach, the required storage volume for 85 percent capture would be 3,979 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 11,224 cubic feet.

Suggested BMPs:

1. Retrofit existing buildings with extensive green roofs. Cover 75 percent of each roof's surface, leaving room for HVAC and other equipment. This would reduce the site composite curve number to 69, and reduce the required storage volume to 5,153 cubic feet.
2. The remaining impervious area can be treated by incorporating 6,800 square feet of permeable pavement into existing parking areas. The permeable pavement would be underlain by a 1-foot-deep gravel storage bed. This is well below the 5.2-foot maximum storage depth to ensure drainage within 48 hours on this soil, providing 2,736 cubic feet of storage.

Landscaped areas cannot be drained to permeable pavement. Runoff from these areas can be captured by surrounding existing drains with small bioretention cells. Assuming a typical 1.4-foot depth of storage, based on 6 inch ponding depth and 2.5 foot media depth, 1,940 square feet of bioretention would provide an additional 2716 cubic feet of storage.

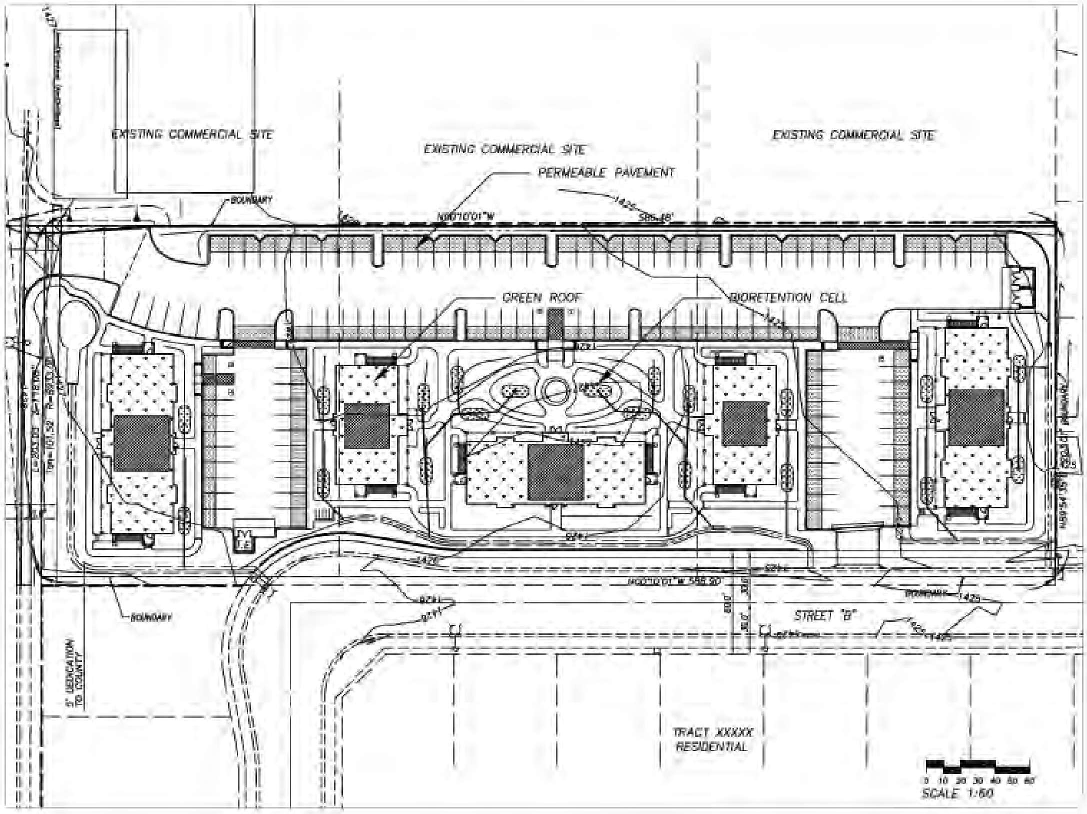

Figure 84. Retrofit of an existing commercial site.
Source: The Low Impact Development Center, Inc.

Case Study 2: Residential Retrofit

Retrofit existing residential development with permeable pavement, bioretention, and rain barrels.

Location: Ventura
Total site area: 14.7 acres

Existing Conditions
Total impervious area: 6.9 ac

- houses: 1.3 ac
- driveways: 1.1 ac
- sidewalks: 1.0 ac
- roads: 3.0 ac

Landscaped areas (turf): 7.7 ac

Existing soils: Mocho loam and Pico sandy loam, Hydrologic Soil Group B, average infiltration rate: 2.6 in/hr, based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Weighted runoff coefficient: 0.49
Composite curve number:

Predevelopment Conditions
Land cover: California sagebrush
Curve number: 35

Analysis
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85 percent capture would be 39,949 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 127,304 cubic feet.

Suggested BMPs:

1. Replace existing sidewalks with permeable pavement, underlain by a 2-foot gravel storage layer. This would provide 55,187 cubic feet of storage.
2. Retrofit each of the 57 houses in the development with two 55-gallon rain barrels. This would provide a total of 834 cubic feet of storage over the entire development.
3. Build two bioretention cells on each of the 57 lots, totaling 580 square feet per lot, assuming a 6-inch ponding depth, and 30-inch media depth. This would provide a total of 45,493 cubic feet of storage over the entire development.
4. Convert existing swale to bioretention, 10,206 square feet, assuming a 6-inch ponding depth, and a 30-inch media depth. This would provide the remaining 14,033 cubic feet of storage.

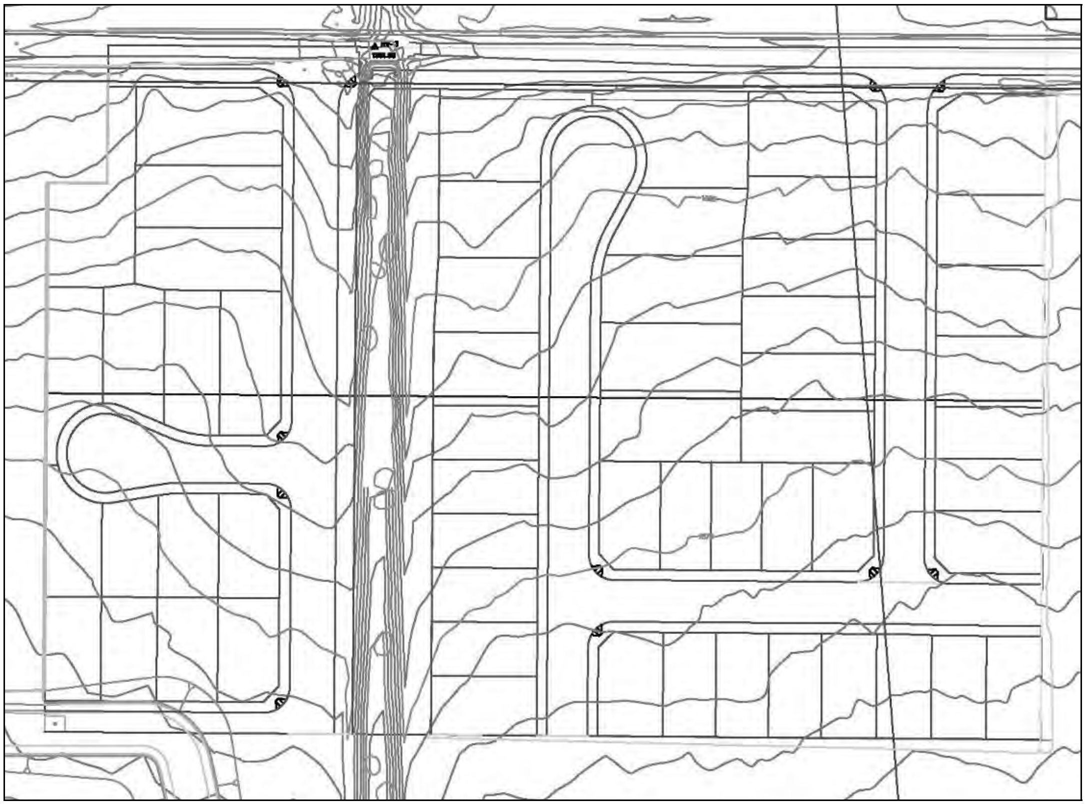

Figure 85. Existing residential subdivision.
Source: The Low Impact Development Center, Inc.

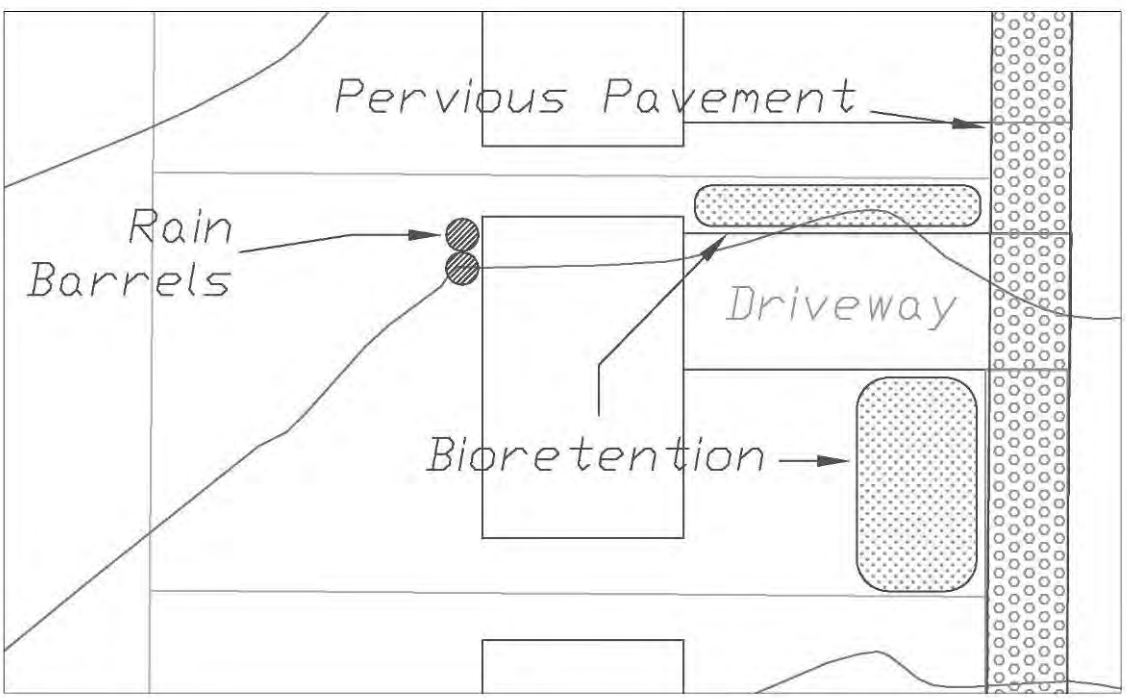

Figure 86. LID retrofits to an existing residential lot.
These retrofits are to be applied to each lot in the subdivision.
Source: The Low Impact Development Center, Inc.

Case Study 3: Commercial Design

Retrofit an existing commercial warehouse with green roof, permeable pavement, and bioretention, and reduce the impact of a planned expansion.

Location: Riverside
Total site area: 52.9 acres

Existing Conditions
Total impervious area: 21.6 ac

- Existing building: 11.8 ac
- Existing parking: 9.8 ac

Undeveloped area: 31.3 ac

Existing Hydrology: Existing ephemeral stream running through site. Depth to groundwater: high (> 2m). Site is within a braided channel and floods frequently.

Topography: Site has a steady, 2-5 percent slope running northwest to southeast. Stream runs transverse to the slope in the eastern half of the site.

Existing soils: Soboba stony loamy sand, psamments, and fluvents, Hydrologic Soil Group A, average infiltration rate: 16 in/hr. Soil is very coarse, but frequently floods. No restrictive layers. Soils data is based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Existing vegetation: California sagebrush

Ecoregion: Los Angeles Plain

Sensitive and restricted areas: There is a stream running through the site, blocking the natural area for the addition.

Existing development: existing building (513,361 sf), two parking areas (55,606 sf in front, 360,644 sf loading area behind building)

Contamination: no known contamination issues

Landslide Potential: low

Proposed Addition
Warehouse addition: 146,711 sf
Parking lot: 50,687 sf
Loading area: parking for 210 tractor trailers

Design Approach
Design addition using LID Site Design Strategies to minimize hydrologic disturbance.

- Maximize Natural Infiltration Capacity
- Preserve Existing Drainage Patterns
- Protect Existing Vegetation and Sensitive Areas

Avoid development within riparian corridor. Place new building and parking areas to the east of the stream, with a bridge connecting the two areas.

- Minimize Impervious Area

Reduce the size of the tractor trailer parking area by creating a two-story parking structure.

- Disconnect Impervious Areas and Downspouts

Separate front parking area from building. Isolate roof runoff from loading area.

Weighted runoff coefficient: 0.52
Composite curve number, developed site: 75
Composite curve number, predevelopment (before ALL development): 35

Analysis
Using the California Stormwater BMP Handbook Approach, the required storage volume for 85 percent capture would be 67,153 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 193,785 cubic feet.

Suggested BMPs:
1. Retrofit existing building with extensive green roof. Cover 75 percent of roof's surface, leaving room for HVAC and other equipment. This would reduce the site composite curve number to 69, and reduce the required storage volume to 84,421 cubic feet.
2. Harvest rainwater from the roof of the new building, stored in cisterns under the building. This would provide 38,023 cubic feet of storage.
3. Install pervious pavement with 6-inch gravel storage layer in front parking lots. This would provide 21,572 cubic feet of storage.
4. Surround perimeter of existing and proposed loading areas with bioretention:
    a. 10 feet x 1,350 ft, 6 inch ponding depth, 30-inch media for existing loading area – 18,562 cubic feet.
    b. 10 feet x 743 ft, 6 inch ponding depth, 30-inch media for proposed loading area/ truck parking – 10,220 cubic feet.

Bioretention has an excellent capacity to trap and remove any oil, grease or other pollutants resulting from high truck traffic in these areas.

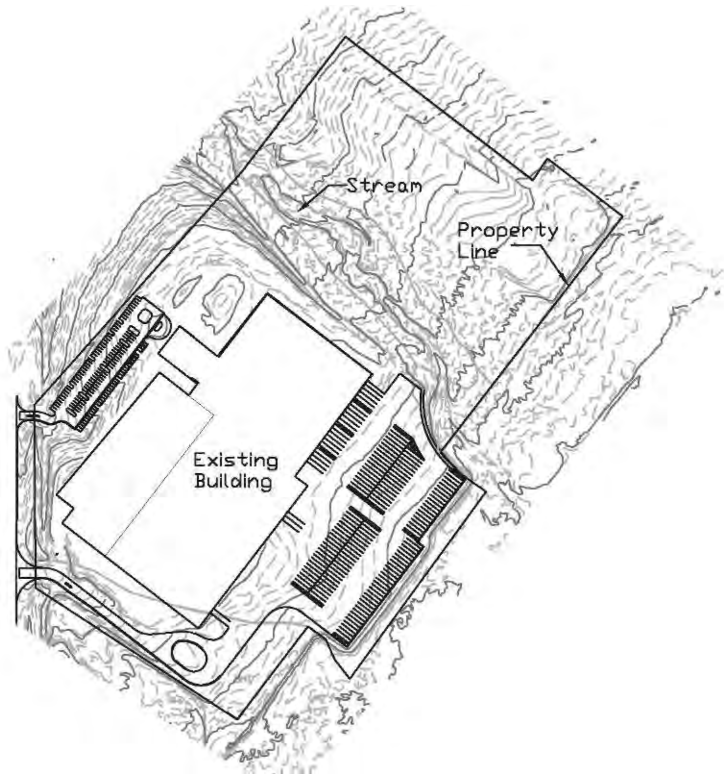

Figure 87. Existing commercial development.
Source: The Low Impact Development Center, Inc.

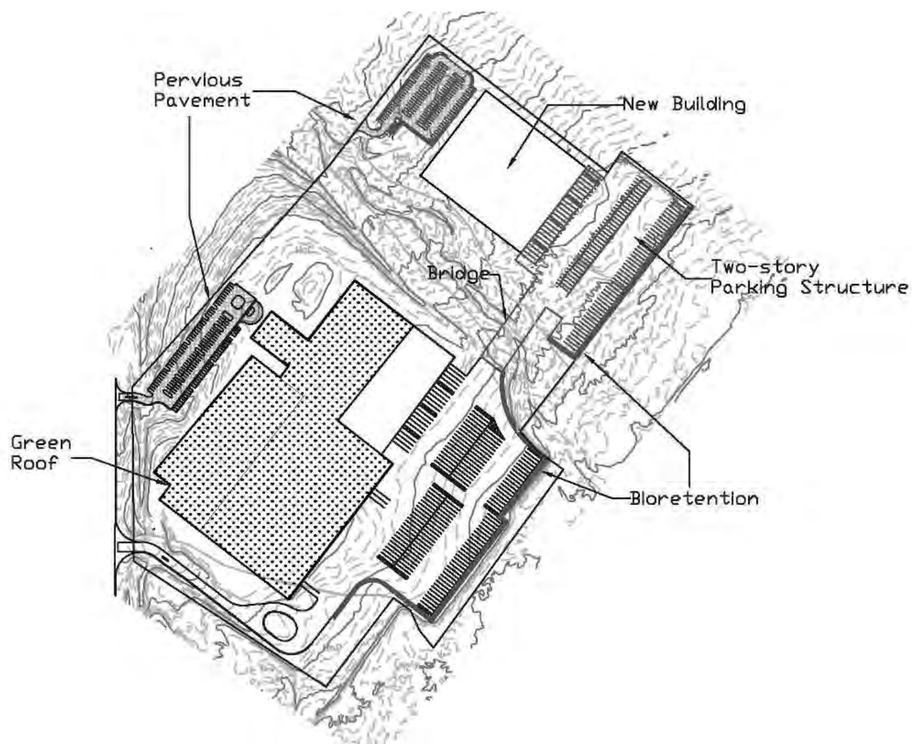

Figure 88. Proposed retrofits and addition to existing commercial development.
Source: The Low Impact Development Center, Inc.

Case Study 4: Residential Development

Design a 118-lot residential subdivision on an undeveloped parcel.

Location: Riverside
Total site area: 44.4 acres

Existing Conditions

Existing Hydrology: No waterbodies are present onsite. Depth to groundwater: high (> 2m).

Topography: Site is sloped from west to east. The northwestern quadrant slopes steeply to the south and east (5-8 percent slopes). A smaller hill is present in the southeast corner, sloping north and west. The low area between these hills slopes gently from west to east, with a slope of 1-2 percent.

Existing soils:

- 60% Cortina gravelly coarse sandy loam, 2-5% slopes, HSG A
- 34% Arbuckle gravelly loam, 8-15% slopes, HSG B
- 3% Ysidora gravelly very fine sandy loam, 8-25% slopes, eroded, HSG C

No restrictive layers. Soils data is based on NRCS Web Soil Survey (http://websoilsurvey.nrcs.usda.gov). Soil profiles and infiltration rates should be measured in the field prior to finalization of design.

Existing vegetation: California sagebrush

Ecoregion: Los Angeles Plain

Sensitive and restricted areas: The slope on the northwestern side of the site is fairly steep, with poorly draining, eroded soils, and should therefore be avoided.

Existing development: none

Contamination: no known contamination issues

Landslide Potential: low

Proposed Development

Design Approach

Design subdivision using LID Site Design Strategies to minimize hydrologic disturbance.

- Maximize Natural Infiltration Capacity

- Preserve Existing Drainage Patterns

Development is focused on level ground to avoid disturbance of natural drainage patterns

- Protect Existing Vegetation and Sensitive Areas

Avoid developing on steep, eroded slopes

- Minimize Impervious Area

The subdivision is designed with small lots concentrated on one part of the site. Lots are centered around a large communal park to provide recreational opportunities. Minimal road widths are used (40 feet, including sidewalks on one side).

- Disconnect Impervious Areas and Downspouts

Roof downspouts are connected to rain barrels. Driveways use permeable pavement to avoid discharge onto roads. Sidewalks are fitted with permeable pavement to capture street runoff.

Weighted runoff coefficient:
Composite curve number, predevelopment: 36
Composite curve number, developed site: 51

<u>Analysis</u>
Using the California Stormwater BMP Handbook approach, the required storage volume for 85 percent capture would be 59,653 cubic feet.

Using the TR-55 approach, the required storage volume to restore predevelopment hydrologic performance for the 10-year, 24 hour storm would be 21,121 cubic feet.

Suggested BMPs:

1. Install one 55-gallon rain barrel at each of the 115 houses in the development. This would provide a total of 841 cubic feet of storage.
2. Install pervious pavement with 1-foot gravel storage layer in driveways. This would provide a total of 11,500 cubic feet of storage over the entire development.
3. Install pervious pavement with 1-foot gravel storage layer on sidewalks. This would provide 11,193 cubic feet of storage.

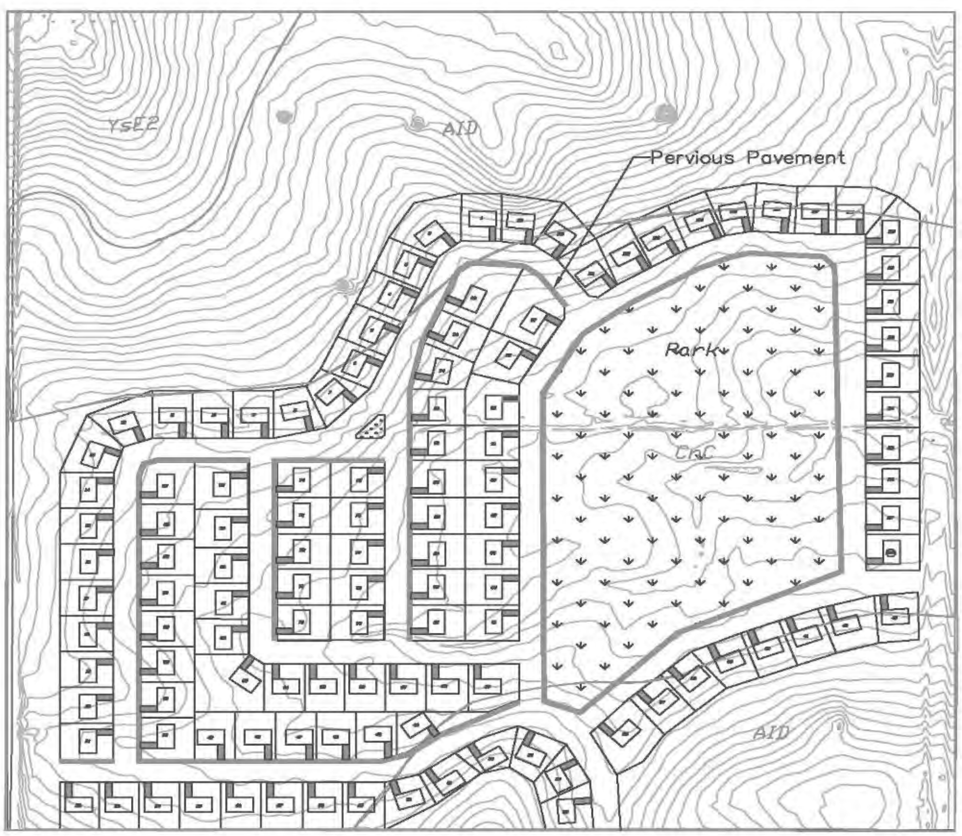

Figure 89. Residential subdivision design.
Source: The Low Impact Development Center, Inc.

Appendix A: Lists of Plants Suitable for Southern California

The plant lists included in this manual are intended to serve as a general guide for identifying plants likely to be suitable for use in LID. The lists a and associated references are not exhaustive, and are not a substitute for the planting recommendations of a qualified landscape professional with knowledge of LID and following a site and design specific evaluation.

Table 31. Master Plant List.

Master Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Acalypha californica	California Copperleaf	evergreen shrub		✓	✓	✓	chaparral, scrub	✓	✓		✓✓				✓		
*Achillea millefoilum **	Yarrow	herbaceous perennial	1-24	✓	✓	✓	Many	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	✓
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	14-16, 18-24	✓	✓	✓	Chaparral	✓	✓	✓	✓✓			✓	✓		✓
Aesculus californica	California Buckeye	deciduous tree	4-10,12,14-24	✓	✓	✓	Woodland	✓	✓	✓	✓✓			✓	✓		✓
Agave deserti	Desert Century Plant	succulent	12-24	✓	✓	✓	Scrub	✓		✓	✓✓			✓	✓		✓
Agave shawii	Shaw's Century Plant	succulent		✓	✓		css	✓		✓	✓✓			✓	✓		✓
Ambrosia chamissonis	Sand Bur	sprawling perennial		✓			dunes	✓			✓✓						✓
Ambrosia pumila	San Diego Ambrosia	groundcover		✓	✓		dunes	✓	✓		✓✓	✓					✓
Amorpha fruticosa	False Indigobush	Deciduous shrub		✓	✓	✓	riparian	✓	✓	✓	✓		✓	✓	✓	✓	✓
Antigonon leptopus	San Miguel Coral Vine	climbing vine	12, 13, 18-24	✓	✓		chaparral, scrub	✓	✓			✓	✓				✓
Arbutus menziesii	Madrone	broadleaf evergreen tree	15-17, 19-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓	✓	✓		✓
Arctostaphylos catalinae	Catalina Manzanita	broadleaf evergreen tree/shrub		✓	✓	✓	chaparral	✓	✓	✓	✓✓			✓	✓		✓
Arctostaphylos densiflora 'Howard McMinn'	McMinn Manzanita	broadleaf evergreen shrub	7-9, 14-21	✓	✓	✓	chaparral	✓	✓	✓	✓✓			✓	✓		✓
Arctostaphylos edmundsii 'Carmel Sur'	Carmel Sur Manzanita	groundcover	6-9, 14-24	✓	✓	✓	ocean bluffs	✓	✓	✓	✓	✓		✓	✓		✓
Arctostaphylos glauca	Bigberry Manzanita	broadleaf evergreen shrub		✓	✓	✓	chaparral	✓	✓	✓	✓✓			✓	✓		✓

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Arctostaphylos 'Lester Rowntree'	Lester Rowntree Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		
Arctostaphylos uva-ursi 'Point Reyes'	Point Reyes Bearberry	groundcover	1-9, 14-24	✓		✓	woodland	✓	✓	✓	✓				✓		
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓	✓	✓
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		✓
Artemisia californica 'Canyon Gray'	Canyon Gray Sagebrush	groundcover	1-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Artemisia ludoviciana	Silver Wormwood	creeping perennial				✓	scrub	✓			✓				✓		✓
Artemisia pycnocephala	Beach Sagewort	herbaceous perennial	1-24	✓		✓	css, dune	✓	✓		✓	✓					✓
Atriplex lentiformis ssp. Breweri	Quail Bush	everg. or decid. shrub	1-24	✓	✓	✓	scrub	✓			✓✓				✓		
Baileya multiradiata	Desert Marigold	perennial	7-14, 18, 19		✓	✓	scrub, grassland	✓			✓✓	✓					✓
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	1-3, 7-23	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓	✓	✓
Baileya multiradiata	Desert Marigold	perennial	7-14, 18, 19		✓	✓	scrub, grassland	✓			✓✓	✓					✓
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	1-3, 7-23	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓	✓	✓
Baccharis pilularis ssp. consanguinea	Coyote Bush	woody perennial	5-11, 14-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓			✓		✓
Brahea armata	Blue Hesper Palm	palm tree	10, 12-17, 19-24	✓	✓	✓	scrub	✓			✓	✓			✓		
Brahea edulis	Guadalupe Palm	palm tree	12-24	✓	✓		woodland	✓	✓		✓	✓			✓		
Calycanthus occidentalis	Spice Bush	decid shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓		✓	✓	
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Calocedrus decurrens	Incense Cedar	evergreen tree	2-12, 14-24	✓	✓	✓	forest	✓	✓		✓	✓			✓		
Camissonia (Oenothera) cheiranthifolia *	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓✓	✓			✓		✓
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓	✓	✓	
Carex praegracilis	California Field Sedge	creeping perennial		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Ceanothus arboreus	Island Ceanothus	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓			✓	✓			✓		
Ceanothus crassifolius	Hoaryleaf Ceanothus	broadleaf evergreen shrub		✓	✓		chaparral	✓			✓✓				✓		
Ceanothus greggii ssp. Perplexans	Cupleaf Lilac	broadleaf evergreen shrub			✓	✓	chaparral	✓			✓✓				✓		
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓		✓	✓	
Ceanothus griseus horizontalis 'Yankee Point'	Carmel Creeper	groundcover	5-9, 14-17, 19-24	✓	✓		css, forest	✓	✓		✓	✓			✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓✓				✓		
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓	✓	
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓✓				✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chaparral, woodland	✓			✓✓				✓		
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓	✓	
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓✓				✓		
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓	✓	
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓✓				✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chaparral, woodland	✓			✓✓				✓		

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓	✓	
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Dendromecon harfordii	Channel Island Bush Poppy	evergreen shrub	7-9, 14-24	✓	✓		chaparral	✓			✓✓				✓		
Dendromecon rigida	Bush Poppy	evergreen shrub	4-12, 14-24		✓	✓	chaparral	✓			✓✓				✓		
Deschampsia caespitosa *	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓		✓	✓	
Dichelostemma capitatum	Wild Hyacinth	Bulb	1-24	✓		✓	many	✓			✓✓				✓		✓
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune; marsh	✓	✓			✓	✓	✓	✓	✓	
Dudleya hassei	Catalina Live-forever	Succulent		✓		✓	css	✓	✓	✓	✓✓				✓		✓
Dudleya pulverulenta	Chalk Dudleya	Succulent		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		✓
Eleocharis montevidensis	Spike Rush	grass-like perennial		✓	✓	✓	many	✓	✓	✓				✓		✓	
Encelia californica	Coast Sunflower	evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓✓				✓		
Encelia farinose	Incienso	evergreen subshrub		✓	✓	✓	chaparral, scrub	✓			✓✓				✓		
Epilobium californicum	California Fuchsia	herb perennial		✓	✓	✓	many	✓	✓		✓✓				✓		✓
Epilobium canum	Hoary California Fuchsia	herb perennial		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		✓
Eriogonum arborescens	Santa Cruz Island Buckwheat	evergreen shrub	14-24	✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub/herb perennial	12-24	✓	✓		css	✓			✓✓				✓		✓
Eriogonum fasciculatum	California Buckwheat	woody perennial	8, 9, 12-24	✓	✓	✓	many	✓	✓		✓✓				✓		

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Eriogonum fasciculatum 'Dana Point'	Dana Point Buckwheat	groundcover	8, 9, 12-24	✓	✓		css	✓	✓		✓✓				✓		
Eriogonum grande var. rubescens	Red Buckwheat	evergreen subshrub	14-24	✓			beach/dune; css	✓	✓		✓	✓			✓		
Eriogonum parvifolium	Coastal Buckwheat	evergreen subshrub		✓			beach/dune; css	✓	✓		✓✓				✓		
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓		✓		✓
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓✓				✓		✓
Euphorbia misera	Cliff Spurge	shrub		✓		✓	scrub	✓			✓						✓
Fallugia paradoxa	Apache Plume	semi-decid shrub	2-23	✓	✓	✓	scrub, woodland	✓			✓✓				✓		
Fragaria californica *	Woodland Strawberry	groundcover		✓	✓	✓	chap, forest		✓	✓		✓	✓		✓		
Fraxinus dipetala	California Ash	deciduous tree	7-24	✓	✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Fremontodendron californicum	California Flannelbush; Fremontia	evergreen shrub	7-24	✓	✓	✓	chaparral, forest	✓			✓✓				✓		
Galvezia speciosa	Island Bush Snapdragon	evergreen shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Grindelia stricta	Gum Plant	evergreen herb. perenn.		✓	✓		css, chap, beach	✓	✓		✓	✓			✓		
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓✓				✓		✓
Heteromeles arbutifolia	Toyon	broadleaf evergreen tree/shrub	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓			✓	✓	
Hyptis emoryi	Desert Lavender	semi-ever shrub		✓	✓	✓	scrub	✓	✓		✓✓				✓		
Iris douglasiana *	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓			✓	✓	

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓✓				✓		✓
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓✓				✓	✓	✓
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓✓	✓	✓	✓	✓	✓	
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓✓	✓			✓		✓
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergreen shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓	✓			✓	✓	
Leymus triticoides 'Grey Dawn' *	Grey Dawn Creeping Wild Rye	creeping perennial grass		✓	✓	✓	css, chaparral, woodland	✓	✓	✓	✓	✓	✓			✓	
Linum lewisii *	Blue Flax	herbaceous perennial		✓	✓	✓	many	✓	✓	✓	✓	✓	✓	✓	✓		
Lonicera subspicata	Chaparral Honeysuckle	deciduous vine/shrub		✓	✓		chaparral	✓	✓		✓✓				✓		
Lotus scoparius	Deerweed	herbaceous perennial		✓	✓		chaparral	✓	✓		✓✓				✓		
Lyonothamnus floribundus ssp. Asplenifolius	Fern-leaved Catalina Ironwood	broadleaf evergreen tree	15-17, 19-24	✓	✓		chap., woodland	✓			✓✓				✓		
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓✓	✓			✓	✓	
Malacothamnus fasciculatus	Chaparral Mallow	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Malosma laurina (Rhus laurina)	Laurel Sumac	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Mimulus cardinalis	Scarlet Monkeyflower	herbaceous perennial	4-24	✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap., grassland	✓			✓	✓			✓		✓
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓✓				✓	✓	

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓	✓			✓	✓		✓	✓	
Nasella pulchra *	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓✓				✓		✓
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓✓				✓		✓
Ornithostaphylos oppositifolia	Baja Bird Bush	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Pinus coulteri	Coulter Pine	evergreen tree		✓	✓	✓	woodland, forest	✓			✓				✓		
Pinus sabiniana	Foothill Pine	evergreen conifer		✓	✓	✓	woodland	✓			✓✓				✓		
Pinus torreyana	Torrey Pine	evergreen conifer		✓	✓		woodland	✓			✓✓				✓		
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓✓	✓	✓		✓	✓	
Polypodium californicum	California Polypody	summer-dormant fern		✓	✓	✓	css, chaparral, woodland		✓	✓			✓	✓		✓	
Populus fremontii	Fremont Cottonwood	deciduous tree	7-24	✓	✓	✓	riparian	✓			✓	✓	✓		✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergreen tree/shrub	7-9, 12-24	✓	✓	✓	chap, woodland	✓	✓		✓✓				✓		
Quercus agrifolia	Coast Live Oak	broadleaf evergreen tree	7-9, 14-24	✓	✓		chap, woodland	✓			✓✓				✓		
Quercus chrysolepis	Canyon Live Oak	broadleaf evergreen tree	3-11, 14-24	✓	✓	✓	woodland	✓	✓		✓	✓			✓		
Quercus engelmannii	Engelmann Oak	broadleaf evergreen tree	7-9, 14-21	✓	✓		grassland, woodland	✓			✓✓				✓		
Quercus kelloggii	Black Oak	deciduous tree	5-9, 14-21	✓	✓	✓	woodland, forest	✓			✓	✓			✓		
Quercus lobata	Valley Oak	deciduous tree	4-9, 12-24	✓	✓	✓	grassland, woodland	✓			✓	✓			✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap, woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓	✓	
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓✓	✓			✓	✓	
Romneya coulteri	Matilija Poppy	clumping semi-evergreen perennial	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumping semi-evergreen perennial		✓	✓	✓	css, chaparral	✓			✓✓				✓		
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓		✓	✓	
Salix lucida ssp. Lasiandra	Lance-leaf Willow	deciduous tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Salvia apiana	White Sage	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓✓				✓		✓
Salvia clevelandii	Cleveland Sage	evergreen shrub	8, 9, 12-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓✓	✓			✓		✓

Master Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓		✓	✓	
Symphoricarpos mollis	Creeping Snowberry	groundcover	4-24	✓	✓		chap., woodland		✓	✓	✓	✓			✓		
Trichostema lanatum	Woolly Blue Curls	evergreen shrub	14-24	✓	✓		chaparral	✓			✓✓				✓		
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓✓	✓			✓	✓	
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chaparral, woodland	✓	✓	✓		✓	✓	✓	✓	✓	
Washingtonia filifera	California Fan Palm	palm tree	8-24		✓	✓	desert oasis	✓	✓				✓		✓		
Yucca schidigera	Mohave Yucca	succulent	10-24	✓	✓	✓	scrub	✓			✓✓				✓		
Yucca whipplei	Our Lord's Candle	succulent	2-24	✓	✓	✓	css, chap., scrub	✓	✓		✓✓				✓		

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).

[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.

[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.

[4] H = high (full sun); M = medium (partial shade); L = low (full shade)

[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)

* Can be used in a native meadow planting as a lawn substitute, for example: *Achillea millefolium, Camissonia cheiranthifolia, Deschampsia caespitosa, Fragaria californica, Iris douglasiana, Leymus triticoides 'Gray Dawn', Linum Lewisii, Muhlenbergia rigens, Nasella pulchra, Salvia sonomensis, Sisyrhynchium bellum*

** Several Sedum species may be used for vegetated roofs, including: *S. clavatum, S. hakonense, S. lineare, S. nussbaumerianum, S. repestre, S. spathulifolium*

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Table 32. General Plant List.

General Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Trees																	
Aesculus californica	California Buckeye	deciduous tree	4-10, 12, 14-24	✓	✓	✓	woodland	✓	✓		✓✓				✓		
Arbutus menziesii	Madrone	broadleaf evergreen tree	15-17, 19-24	✓	✓		woodland, forest	✓	✓			✓	✓		✓		
Arctostaphylos catalinae	Catalina Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓✓				✓		
Arctostaphylos 'Lester Rowntree'	Lester Rowntree Manzanita	broadleaf evergreen tree/shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Brahea armata	Blue Hesper Palm	palm tree	10, 12-17, 19-24	✓	✓	✓	scrub	✓			✓	✓			✓		
Brahea edulis	Guadalupe Palm	palm tree	12-24	✓	✓		woodland	✓	✓		✓	✓			✓		
Calocedrus decurrens	Incense Cedar	evergreen tree	2-12, 14-24	✓	✓	✓	forest	✓	✓		✓	✓			✓		
Ceanothus arboreus	Island Ceanothus	broadleaf evergreen tree/shrub		✓	✓		css, chaparral	✓			✓	✓			✓		
Cercidium floridum	Blue Palo Verde	deciduous tree	10-14, 18-20	✓	✓	✓	scrub	✓			✓✓				✓		
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓		✓		
Cupressus forbesii	Tecate Cypress	evergreen conifer	8-14, 18-20	✓	✓	✓	chaparral, forest	✓			✓				✓		
Fraxinus dipetala	California Ash	deciduous tree	7-24	✓	✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Lyonothamnus floribundus ssp. asplenifolius	Fern-leaved Catalina Ironwood	broadleaf evergreen tree	15-17, 19-24	✓	✓		chap., woodland	✓			✓✓				✓		
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub	4-9, 14-24	✓	✓		css, chaparral	✓	✓			✓	✓		✓		
Pinus coulteri	Coulter Pine	evergreen tree		✓	✓	✓	woodland, forest	✓			✓				✓		
Pinus sabiniana	Foothill Pine	evergreen conifer		✓	✓	✓	woodland	✓			✓✓				✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Pinus torreyana	Torrey Pine	evergreen conifer		✓	✓		woodland	✓			✓✓				✓		
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓✓	✓	✓		✓		
Populus fremontii	Fremont Cottonwood	deciduous tree	7-24	✓	✓	✓	riparian	✓			✓	✓	✓		✓		
Quercus agrifolia	Coast Live Oak	broadleaf evergreen tree	7-9, 14-24	✓	✓		chap., woodland	✓			✓✓				✓		
Quercus chrysolepis	Canyon Live Oak	broadleaf evergreen tree	3-11, 14-24	✓	✓	✓	woodland	✓	✓		✓	✓			✓		
Quercus engelmannii	Engelmann Oak	broadleaf evergreen tree	7-9, 12-24	✓	✓		grassland, woodland	✓			✓✓				✓		
Quercus kelloggii	Black Oak	deciduous tree	5-9, 14-21	✓	✓	✓	woodland, forest	✓			✓	✓			✓		
Quercus lobata	Valley Oak	deciduous tree	4-9, 12-24	✓	✓	✓	grassland, woodland	✓			✓	✓			✓		
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓✓	✓			✓		
Washingtonia filifera	California Fan Palm	palm tree	8-24		✓	✓	desert oasis	✓	✓				✓		✓		
Shrubs																	
Acalypha californica	California Copperleaf	evergreen shrub		✓	✓	✓	chaparral, scrub	✓	✓		✓✓				✓		
Arctostaphylos densiflora 'Howard McMinn'	McMinn Manzanita	broadleaf evergreen shrub	7-9, 14-21	✓	✓		chaparral	✓	✓		✓✓				✓		
Arctostaphylos glauca	Bigberry Manzanita	broadleaf evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Arctostaphylos manzanita	Common Manzanita	evergreen shrub		✓	✓	✓	chaparral, forest, woodland	✓	✓		✓✓				✓		
Arctostaphylos otayensis	Otay Manzanita	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Arctostaphylos refugioensis	Refugio Manzanita	evergreen shrub		✓	✓		chaparral	✓	✓		✓				✓		
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Atriplex lentiformis ssp. Breweri	Quail Bush	evergreen or deciduous shrub	7-14, 18, 19	✓	✓	✓	scrub	✓			✓✓				✓		
Calycanthus occidentalis	Spice Bush	deciduous shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓		✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Ceanothus crassifolius	Hoaryleaf Ceanothus	broadleaf evergreen shrub		✓	✓		chaparral	✓			✓✓				✓		
Ceanothus greggii ssp. Perplexans	Cupleaf Lilac	broadleaf evergreen shrub			✓	✓	chaparral	✓			✓✓				✓		
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓		✓		
Ceanothus impressus	Santa Barbara Ceanothus	evergreen shrub		✓			chaparral	✓	✓		✓✓				✓		
Ceanothus megacarpus	Big Pod Ceanothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceonothus verrucosus	Wartystem Ceonothus	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ceanothus 'Concha'	Concha Ceanothus	evergreen shrub		✓	✓		chaparral	✓			✓	✓			✓		
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	evergreen shrub	5-9, 14-24	✓	✓		css, chaparral	✓			✓	✓			✓		
Cercis occidentalis	Western Redbud	deciduous shrub/tree	2-24	✓	✓	✓	chaparral, woodland	✓	✓		✓	✓			✓		
Cercocarpus betuloides	Western Mountain Mahogany	evergreen shrub/tree	6-24	✓	✓	✓	chap., woodland	✓			✓✓				✓		
Cneoridium dumosum	Bushrue	evergreen shrub		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Dendromecon harfordii	Channel Island Bush Poppy	evergreen shrub	7-9, 14-24	✓	✓		chaparral	✓			✓✓				✓		
Dendromecon rigida	Bush Poppy	evergreen shrub	4-12, 14-24		✓	✓	chaparral	✓			✓✓				✓		
Encelia californica	Coast Sunflower	evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓✓				✓		
Encelia farinose	Incienso	evergreen subshrub		✓	✓	✓	chap, scrub	✓			✓✓				✓		
Eriogonum arborescens	Santa Cruz Island Buckwheat	evergreen shrub	14-24	✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Eriogonum fasciculatum	California Buckwheat	woody perennial	8, 9, 12-24	✓		✓	many	✓	✓		✓✓				✓		
Eriogonum grande var. rubescens	Red Buckwheat	evergreen subshrub	14-24	✓			beach/dune, css	✓	✓		✓	✓			✓		
Eriogonum parvifolium	Coastal Buckwheat	evergreen subshrub		✓			beach/dune, css	✓	✓		✓✓				✓		
Fallugia paradoxa	Apache Plume	semi-deciduous shrub	2-23	✓	✓	✓	scrub, woodland	✓			✓✓				✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Fremontodendron californicum	California Flannelbush	evergreen shrub	7-24	✓	✓	✓	chap, forest	✓			✓✓				✓		
Galvezia speciosa	Island Bush Snapdragon	evergreen shrub	14-24	✓	✓		css	✓	✓			✓			✓		
Heteromeles arbutifolia	Toyon	broadleaf evergreen tree/shrub	5-9, 14-24	✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Hyptis emoryi	Desert Lavender	semi-evergreen shrub		✓	✓	✓	scrub	✓	✓		✓✓				✓		
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓✓				✓		
Iva hayesiana	Hayes Iva	evergreen shrub	10-13	✓	✓	✓	css, marsh	✓	✓		✓✓				✓		
Justicia californica	Chuparosa	semi-deciduous shrub		✓	✓	✓	scrub	✓	✓		✓	✓	✓		✓		
Keckiella antirrhinoides	Yellow Bush Penstemon	semi-evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Lepechinia fragrans	Fragrant Pitcher Sage	semi-evergreen shrub		✓	✓		chaparral	✓	✓		✓	✓			✓		
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓✓	✓			✓		
Malacothamnus fasciculatus	Chaparral Mallow	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Malosma laurina (Rhus laurina)	Laurel Sumac	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Ornithostaphylos oppositifolia	Baja Bird Bush	evergreen shrub		✓	✓	✓	chaparral	✓	✓		✓✓				✓		
Prunus ilicifolia ssp. Ilicifolia	Hollyleaf Cherry	broadleaf evergreen tree/shrub	7-9, 12-24	✓	✓	✓	chap., woodland	✓	✓		✓✓				✓		
Rhamnus californica	Coffeeberry	evergreen shrub	4-9, 14-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus californica 'Eve Case'	Coffeeberry	evergreen shrub	4-24	✓	✓		chap., woodland	✓	✓		✓	✓			✓		
Rhamnus crocea	Redberry	evergreen shrub	14-21	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Rhamnus ilicifolia	Hollyleaf Redberry	evergreen shrub	7-16, 18-21	✓	✓	✓	chaparral, woodland, forest	✓	✓		✓✓				✓		
Rhus integrifolia	Lemonadeberry	evergreen shrub	8, 9, 14-17, 19-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Rhus ovata	Sugar Bush	evergreen shrub	9-12, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Ribes aureum var. gracillimum	Golden Currant	semi-deciduous shrub	1-24		✓	✓	chap., woodland	✓	✓		✓✓	✓			✓		
Ribes malvaceum 'Dancing Tassels'	Dancing Tassels Currant	deciduous shrub	6-9, 14-21	✓	✓	✓	chap., woodland	✓	✓	✓	✓	✓			✓		
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8,9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓		✓		
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8,9, 14-24	✓	✓	✓	css	✓	✓	✓	✓✓	✓			✓		
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓		✓		
Salvia apiana	White Sage	evergreen shrub		✓	✓		css, chaparral	✓			✓✓				✓		
Salvia clevelandii	Cleveland Sage	evergreen shrub	8,9, 12-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Salvia leucophylla	Purple Sage	semi-evergreen shrub	8, 9, 14-17	✓	✓		css, chap	✓			✓✓	✓			✓		
Salvia mellifera 'Tera Seca'	Tera Seca Sage	semi-evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓	✓			✓		
Sambucus mexicana	Mexican Elderberry	deciduous shrub/tree	1-24	✓	✓	✓	css, chaparral, woodland	✓	✓				✓	✓	✓		
Simmondsia chinensis	Jojoba	evergreen shrub	7-24	✓	✓	✓	scrub	✓			✓✓				✓		
Trichostema lanatum	Woolly Blue Curls	evergreen shrub	14-24	✓	✓		chaparral	✓			✓✓				✓		
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum *	Yarrow	herbaceous perennial	1-24	✓	✓	✓	many	✓	✓	✓	✓✓	✓	✓	✓	✓		
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	14-16, 18-24	✓	✓		chaparral	✓	✓		✓✓				✓		
Agave deserti	Desert Century Plant	succulent	12-24	✓	✓	✓	scrub	✓			✓✓				✓		
Agave shawii	Shaw's Century Plant	succulent		✓	✓		css	✓			✓✓				✓		
Arctostaphylos edmundsii 'Carmel Sur'	Carmel Sur Manzanita	groundcover	6-9, 14-24	✓	✓		ocean bluffs	✓	✓			✓			✓		
Arctostaphylos hookeri 'Monterey Carpet'	Monterey Carpet Manzanita	groundcover		✓	✓		woodland		✓		✓	✓			✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Arctostaphylos uva-ursi 'Point Reyes'	Point Reyes Bearberry	groundcover	1-9, 14-24	✓		✓	woodland	✓	✓	✓	✓				✓		
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	groundcover	7-9, 14-24	✓	✓		chaparral	✓	✓		✓	✓			✓		
Aristolochia californica	California Dutchman's Pipe	deciduous vine		✓	✓	✓	woodland		✓	✓	✓	✓	✓		✓		
Artemisia californica 'Canyon Gray'	Canyon Gray Sagebrush	groundcover	1-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Artemisia ludoviciana	Silver Wormwood	creeping perennial	1-24			✓	scrub	✓			✓				✓		
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓	✓			✓		
Baccharis pilularis ssp. consanguinea	Coyote Bush	woody perennial	5-11, 14-24	✓	✓		css, chaparral	✓	✓		✓✓				✓		
Baccharis 'Centennial'	Centennial Desert Broom	groundcover	10-13		✓	✓	scrub	✓	✓		✓✓				✓		
Calystegia macrostegia 'Anacapa Pink'	Island Morning-glory	evergreen vine		✓	✓		css, chaparral	✓	✓			✓			✓		
Camissonia (Oenothera) cheiranthifolia *	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓✓	✓			✓		
Ceanothus griseus horizontalis 'Yankee Point'	Carmel Creeper	groundcover	5-9,14-17, 19-24	✓	✓		css, forest	✓	✓		✓	✓			✓		
Ceanothus hearstiorum	Heart Ceanothus	groundcover		✓			css, forest	✓	✓		✓	✓			✓		
Ceanothus maritimus	Maritime Ceanothus	groundcover		✓			css	✓	✓		✓	✓			✓		
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover		✓	✓		css, forest	✓	✓			✓	✓		✓		
Dichelostemma capitatum	Wild Hyacinth	bulb	1-24	✓		✓	many	✓			✓✓				✓		
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune, marsh	✓	✓			✓	✓	✓	✓		
Dudleya hassei	Catalina Live-forever	succulent		✓		✓	css	✓	✓	✓	✓✓				✓		
Dudleya pulverulenta	Chalk Dudleya	succulent		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Epilobium californicum	California Fuchsia	herbaceous perennial		✓	✓	✓	many	✓	✓		✓✓				✓		
Epilobium canum	Hoary California Fuchsia	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub/ herbaceous perennial	12-24	✓	✓		css	✓			✓✓				✓		
Eriogonum fasciculatum 'Dana Point'	Dana Point Buckwheat	groundcover	8, 9, 12-24	✓	✓		css	✓	✓		✓✓				✓		
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓		✓		
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓✓				✓		
Fragaria californica *	Woodland Strawberry	groundcover		✓	✓	✓	chaparral, forest		✓	✓		✓	✓		✓		
Grindelia stricta	Gum Plant	evergr. herb. perennial		✓	✓		css, chap, beach	✓	✓		✓	✓			✓		
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓✓				✓		
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓			✓		
Iris douglasiana *	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓			✓		
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓✓	✓			✓		
Linum lewisii *	Blue Flax	herbaceous perennial		✓	✓	✓	many	✓	✓	✓	✓	✓	✓	✓	✓		
Lonicera subspicata	Chaparral Honeysuckle	deciduous vine/shrub		✓	✓		chaparral	✓	✓		✓✓				✓		
Lotus scoparius	Deerweed	herbaceous perennial		✓	✓		chaparral	✓	✓		✓✓				✓		
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap, grassland	✓			✓	✓			✓		
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓✓				✓		
Romneya coulteri	Matilija Poppy	clumping semi-everg perennial	4-12, 14-24	✓	✓		css, chaparral	✓	✓		✓				✓		
Romneya trichocalyx	Hairy Matilija Poppy	clumping semi-everg perennial		✓	✓	✓	css, chaparral	✓			✓✓				✓		
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓✓				✓		

General Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓✓	✓			✓		
Salvia sonomensis *	Creeping Sage	perennial	7-9, 14-24	✓	✓	✓	chap., woodland	✓	✓		✓				✓		
Salvia spathacea	Hummingbird Sage	perennial		✓	✓		many		✓	✓	✓✓				✓		
Satureja douglasii	Yerba Buena	evergr. herb. perennial	4-9, 14-24	✓	✓		chap., woodland		✓	✓	✓	✓	✓		✓		
Sisyrhynchium bellum *	Blue-eyed Grass	perennial	4-24	✓	✓	✓	many	✓	✓		✓✓				✓		
Sphaeralcea ambigua	Desert Mallow	woody perennial			✓	✓	scrub	✓	✓		✓				✓		
Symphoricarpos mollis	Creeping Snowberry	groundcover	4-24	✓	✓		chap, woodland		✓	✓	✓	✓			✓		
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chap, woodland	✓	✓	✓		✓	✓	✓	✓		
Yucca schidigera	Mohave Yucca	succulent	10-24	✓	✓	✓	scrub	✓			✓✓				✓		
Yucca whipplei	Our Lord's Candle	succulent	2-24	✓	✓	✓	css, chap, scrub	✓	✓		✓✓				✓		
Grasses and Grass-like Plants															✓		
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓✓				✓		
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓			✓		
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓	✓		
Deschampsia caespitosa *	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓		✓		
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓✓	✓	✓	✓	✓		
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓	✓			✓		
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓✓				✓		
Nasella pulchra *	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓✓				✓		
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓		✓		

General Plant List (Cont.)	

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).
[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.
[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.
[4] H = high (full sun); M = medium (partial shade); L = low (full shade)
[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)
* Can be used in a native meadow planting as a lawn substitute, for example: *Achillea millefolium, Camissonia cheiranthifolia, Deschampsia caespitosa, Fragaria californica, Iris douglasiana, Leymus triticoides 'Gray Dawn', Linum Lewisii, Muhlenbergia rigens, Nasella pulchra, Salvia sonomensis, Sisyrhynchium bellum*

Table 33. Bioretention Plant List.

Bioretention Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Trees																	
Chilopsis linearis	Desert Willow	deciduous tree/shrub	7-14, 18-23	✓	✓	✓	riparian, scrub	✓			✓	✓	✓			✓	
Myrica californica	Pacific Wax Myrtle	broadleaf evergreen tree/shrub	4-9, 14-24	✓	✓		css, chaparral	✓	✓			✓	✓			✓	
Platanus racemosa	California Sycamore	deciduous tree	4-24	✓	✓		riparian	✓			✓✓	✓	✓			✓	
Salix lucida ssp. lasiandra	Lance-leaf Willow	deciduous tree		✓	✓	✓	many	✓	✓				✓	✓		✓	
Umbellularia californica	California Bay Laurel	broadleaf evergreen tree	4-10, 12-24	✓	✓	✓	woodland, forest	✓	✓		✓✓	✓				✓	
Shrubs																	
Amorpha fruticosa	False Indigobush	deciduous shrub		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Calycanthus occidentalis	Spice Bush	deciduous shrub	4-9, 14-24	✓	✓	✓	woodland, forest	✓	✓			✓	✓			✓	
Ceonothus griseus 'Santa Ana'	Santa Ana Ceonothus	evergreen shrub		✓			chaparral	✓	✓			✓	✓			✓	
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓✓					✓	
Justicia californica	Chuparosa	semi-decid shrub	10-13	✓	✓	✓	scrub	✓	✓		✓	✓	✓			✓	
Mahonia nevinii	Nevin's Barberry	evergreen shrub	8-24	✓	✓	✓	css, chaparral	✓			✓✓	✓				✓	
Ribes speciosum	Fuchsia Flowering Gooseberry	deciduous shrub	8, 9, 14-24	✓	✓	✓	chap., woodland		✓	✓		✓	✓			✓	
Ribes viburnifolium	Catalina Perfume	evergreen shrub	8, 9, 14-24	✓	✓	✓	css	✓	✓	✓	✓✓	✓				✓	
Rosa californica	California Wild Rose	semi-deciduous shrub		✓	✓	✓	riparian, woodland	✓	✓	✓		✓	✓			✓	
Sambucus mexicana	Mexican Elderberry	deciduous shrub/tree	1-24	✓	✓	✓	css, chaparral, woodland	✓	✓				✓	✓		✓	

Bioretention Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum	Yarrow	herbaceous perennial	1-24	✓	✓	✓	riparian	✓	✓	✓			✓			✓	
Artemisia douglasiana	Mugwort	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓	✓				✓	
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓		css, forest	✓	✓			✓	✓			✓	
Ceanothus 'Anchor Bay'	Anchor Bay Ceanothus	groundcover														✓	
Huechera maxima	Island Alum Root	evergreen perennial		✓		✓	css, chaparral		✓	✓	✓	✓				✓	
Iris douglasiana	Douglas Iris	herbaceous perennial	4-9, 14-24	✓	✓	✓	grassland, forest	✓	✓	✓	✓	✓				✓	
Mimulus cardinalis	Scarlet Monkeyflower	herbaceous perennial	4-24	✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Polypodium californicum	California Polypody	summer-dormant fern		✓	✓	✓	css, chaparral, woodland		✓	✓			✓	✓		✓	
Satureja douglasii	Yerba Buena	evergr. herb. perennial	4-9, 14-24	✓	✓		chap., woodland		✓	✓	✓	✓	✓			✓	
Venegasia carpesioides	Canyon Sunflower	semi-evergreen subshrub		✓	✓	✓	css, chaparral, woodland	✓	✓	✓		✓	✓	✓		✓	
Grasses and Grass-like Plants																	
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓✓					✓	
Carex pansa	California Meadow Sedge	creeping perennial		✓		✓	bluffs, strand	✓	✓	✓			✓	✓		✓	
Carex praegracilis	California Field Sedge	creeping perennial		✓	✓	✓	riparian	✓	✓	✓			✓	✓		✓	
Deschampsia caespitosa	Tufted Hairgrass	perennial bunchgrass	1-24	✓	✓	✓	woodland, forest	✓	✓	✓	✓	✓	✓			✓	
Distichlis spicata	Salt Grass	creeping perennial		✓		✓	beach/dune, marsh	✓	✓			✓	✓	✓		✓	
Eleocharis montevidensis	Spike Rush	grass-like perennial		✓	✓	✓	many	✓	✓	✓				✓		✓	

Bioretention Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Juncus patens	California Gray Rush	perennial rush	8-24	✓	✓	✓	riparian	✓	✓	✓	✓✓	✓	✓	✓		✓	
Leymus condensatus 'Canyon Prince'	Canyon Prince Wild Rye	bunchgrass		✓	✓	✓	css, chaparral, woodland	✓	✓		✓	✓				✓	
Leymus triticoides 'Grey Dawn'	Grey Dawn Creeping Wild Rye	creeping perennial grass		✓	✓	✓	css, chaparral, woodland	✓	✓	✓	✓	✓	✓			✓	
Muhlenbergia rigens *	Deergrass	bunchgrass	4-24	✓	✓	✓	many	✓	✓		✓✓					✓	
Scirpus cenuus	Low Bulrush	grass-like perennial		✓	✓		marsh	✓	✓	✓			✓	✓		✓	
Sporobolus airoides	Alkali dropseed	perennial bunchgrass	1-24	✓	✓	✓	many	✓			✓	✓	✓			✓	

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).
[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.
[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.
[4] H = high (full sun); M = medium (partial shade); L = low (full shade)
[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)

Table 34. Vegetated Roof Plant List.

Vegetated Roof Plant List				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Shrubs																	
Euphorbia misera	Cliff Spurge	shrub		✓		✓	scrub	✓			✓						
Iva hayesiana	Hayes Iva	evergreen shrub		✓	✓	✓	css, marsh	✓	✓		✓✓						
Groundcovers, Vines, Succulents, Perennials, Annuals																	
Achillea millefoilum	Yarrow	herbaceous perennial	1-24	✓	✓	✓	many	✓	✓	✓	✓✓	✓	✓	✓			
Adenostoma fasciculatum 'Nicolas'	Prostrate Chamise	groundcover	4-16, 18-24	✓	✓		chaparral	✓	✓		✓✓						
Ambrosia chamissonis	Sand Bur	sprawling perennial		✓			dunes	✓			✓✓						
Ambrosia pumila	San Diego Ambrosia	groundcover		✓	✓		dunes	✓	✓		✓✓	✓					
Antigonon leptopus	San Miguel Coral Vine	climbing vine	12, 13, 18-24	✓	✓		chap, scrub	✓	✓			✓	✓				
Artemisia californica	California Sagebrush	evergreen subshrub	1-24	✓	✓		css, chaparral	✓	✓		✓✓						
Artemisia ludoviciana	Silver Wormwood	creeping perennial	1-24			✓	scrub	✓			✓						
Artemisia pycnocephala	Beach Sagewort	herbaceous perennial	1-24	✓		✓	css, dune	✓	✓		✓	✓					
Baileya multiradiata	Desert Marigold	perennial			✓	✓	scrub, grassland	✓			✓✓	✓					
Baccharis pilularis 'Pigeon Point' or 'Twin Peaks'	Dwarf Coyote Bush	groundcover	5-11, 14-24	✓	✓	✓	css, chaparral	✓	✓		✓	✓					
Camissonia (Oenothera) cheiranthifolia	Beach Evening Primrose	herbaceous perennial		✓			beach/dune	✓	✓		✓✓	✓					
Dichelostemma capitatum	Wild Hyacinth	bulb		✓		✓	many	✓			✓✓						
Dudleya hassei	Catalina Live-forever	succulent		✓		✓	css	✓	✓	✓	✓✓						
Dudleya pulverulenta	Chalk Dudleya	succulent		✓	✓	✓	css, chaparral	✓	✓		✓✓						
Epilobium californicum	California Fuchsia	herbaceous perennial		✓	✓	✓	many	✓	✓		✓✓						

Vegetated Roof Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Epilobium canum	Hoary California Fuchsia	herbaceous perennial		✓	✓	✓	css, chaparral	✓	✓		✓✓						
Eriogonum crocatum	Saffron Buckwheat	evergreen subshrub/ herbaceous perennial	12-24	✓	✓		css	✓			✓✓						
Eriophyllum confertiflorum	Golden Yarrow	herbaceous subshrub		✓	✓		many	✓	✓			✓	✓				
Eschscholzia californica	California Poppy	annual	1-24	✓	✓	✓	scrub	✓			✓✓						
Helianthemum scoparium	Sun Rose	herbaceous subshrub		✓	✓	✓	css, forest	✓	✓		✓✓						
Isocoma menziesii var. menziesii	Menzies' Goldenbush	evergreen subshrub		✓			css, beach/dune	✓	✓		✓✓						
Lasthenia californica	California Goldfields	annual		✓	✓		css, woodland	✓	✓		✓✓	✓					
Mirabilis californica	Wishbone Bush	perennial		✓		✓	chap., grassland	✓			✓	✓					
Opuntia littoralis	Coastal Prickly Pear	low-growing cactus		✓	✓		css, chaparral	✓			✓✓						
Salvia cedrosensis	Cedros Island Sage	perennial		✓			scrub	✓	✓		✓✓						
Salvia greggii	Autumn Sage	woody perennial	8-24		✓	✓	grassland, woodland	✓	✓		✓✓	✓					
Salvia mellifera 'Tera Seca'	Tera Seca Sage	semi-evergreen subshrub		✓	✓		css, chaparral	✓	✓		✓	✓					
Salvia sonomensis	Creeping Sage	perennial	7-9, 14-24	✓	✓	✓	chap., woodland	✓	✓		✓						
*Sedum sp. ***	Sedum	succulent		✓	✓	✓		✓			✓✓	✓					
Sisyrhynchium bellum	Blue-eyed Grass	perennial	4-24	✓	✓	✓	many	✓	✓		✓✓						
Sphaeralcea ambigua	Desert Mallow	woody perennial			✓	✓	scrub	✓	✓		✓						
Grasses and Grass-like Plants																	
Aristida purpurea	Purple Three-Awn	bunchgrass		✓	✓	✓	css, chaparral	✓	✓		✓✓						
Bouteloua curtipendula	Side-oats Grama	bunchgrass		✓	✓	✓	scrub, woodland	✓			✓	✓					

Vegetated Roof Plant List (Cont.)				Region[2]				Light Level[4]			Moisture[5]				Uses		
Latin Name[1]	Common Name	Form	Sunset Zone	Coastal	Intermediate	Inland	Native Community[3]	H	M	L	VL	L	M	H	General	Bioretention	Roof
Nasella pulchra	Purple Needlegrass	bunchgrass		✓	✓	✓	css, chap, woodland	✓	✓		✓✓						

[1] References: *California Native Plants for the Garden*. Carol Bornstein, David Fross, & Bart O'Brien. Cachuma Press (2005). *California Native Trees & Shrubs*. Lee W. Lenz & John Dourley. Rancho Santa Ana Botanic Garden (1981). *Plants of El Camino Real*. Tree of Life Nursery (2004). *Western Garden Book*. Kathleen Norris Brenzel, ed. Sunset Publishing (2007).
[2] Indicates region that species may be grown in, based on horticultural references. Verify the cold-hardiness of desired species, especially for higher elevations. Coastal region includes Sunset *Western Garden Book* zones 22 and 24; Intermediate region includes Sunset zones 3, 20, 21, and 23; Inland region includes Sunset zones 2, 18, and 19.
[3] Note that some native plants may not be permitted in certain fire fuel management areas, or are only permitted under specific planting and management conditions. Consult with appropriate county fire authority as to the applicability of a proposed plant species list.
[4] H = high (full sun); M = medium (partial shade); L = low (full shade)
[5] Refers to summer water needed after establishment. VL = very low (summer water every 4 weeks; two check marks indicates that species may acclimate to seasonal rainfall, especially if planted in its native region and conditions); L = low (summer water every 4 weeks); M = medium (summer water every 2-3 weeks); H = high (summer water every week; some species may require constant moisture)
** Several Sedum species may be used for vegetated roofs, including: *S. clavatum, S. hakonense, S. lineare, S. nussbaumerianum, S. repestre, S. spathulifolium*

Appendix B: California Planning and Regulatory Framework for LID

Introduction

Low Impact Development is a relatively new practice in California. As such, LID is still being integrated into the California planning process. Very few general plans have water or water resources elements, and even fewer specifically address LID and hydromodification. Since the general plan is the foundation of the California planning process, and LID is not well addressed in general plans, LID is also inconsistently addressed in subsequent steps in the planning process.

When LID is addressed in the planning process, it is frequently incorporated at the site planning stage, which is too late in the process to make the kinds of impacts that are possible.

Currently, the State Water Resources Control Boards and California Regional Water Quality Control Boards are driving the use of LID measures in new development. The US Environmental Protection Agency, which has published several documents on both low impact development and smart growth as stormwater best management practices, also encourages LID.

NOTE: The following information is current as of the publishing of this document. Please contact the appropriate regulatory agency for the most up-to-date information.

LID in NPDES Stormwater Permits

Municipal Permits

Since the adoption of the San Diego County Municipal Separate Storm Sewer Systems (MS4) Permit in 2007, municipal permits within the region have contained specific LID and hydromodification requirements. The LID terminology is new, but the underpinnings of LID in MS4 permits in Southern California have existed for some time. The major emphasis of the LID requirements in municipal permits is on reduction of impervious area in order to facilitate infiltration and reduce urban runoff. New MS4 permits include LID requirements that apply to specified categories of new development and redevelopment projects. The Permittees are tasked with the responsibility of developing design and maintenance criteria and establishing minimum standards for the use of LID practices. They are also required to develop manuals or technical guidance for municipal employees and private sector practitioners involved with the implementation of LID practices.

San Diego County MS4 Permit

San Diego County's current MS4 Permit was adopted in 2007 (RWQCB Order No. R9-2007-01, NPDES Permit No. CAS0108758). The permit was the first in the region to contain specific LID requirements. Priority Development Projects are required, where feasible, to:

a) Conserve natural areas, including existing trees, other vegetation, and soils.
b) Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety and a walkable environment for pedestrians are not compromised.
c) Minimize the impervious footprint of the project.
d) Minimize soil compaction.
e) Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)
f) Minimize directly connected impervious areas and promote infiltration.

g) Drain a portion of impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge, where feasible.
h) Properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, taking into consideration the pervious areas' soil conditions, slope, and other pertinent factors.
i) Construct a portion of walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials, where site and soil conditions permit.

In addition, Priority Development Projects are required to maintain predevelopment flow rates and durations for a range of storms designated by the County.

Orange County MS4 Permits

Orange County has two separate NPDES Permits, which are administered by the Santa Ana and San Diego Regional Water Quality Control Boards. The current Santa Ana Region Permit was renewed in 2009 (RWQCB Order No. R8-2009-0030, NPDES Permit No. CAS618030). The San Diego Region Permit was also renewed in 2009 (RWQCB Order No. R9-2009-002, NPDES Permit No. CAS0108740).

Santa Ana Region: The permit requires priority development projects to ascertain the impact of the development on the site's hydrologic regime, and attempt to maintain or replicate the pre-development hydrologic regime through the use of design techniques that create a functionally equivalent post-development hydrologic regime. This is accomplished through site preservation techniques and the use of integrated and distributed micro-scale storm water infiltration, retention, detention, evapotranspiration, filtration and treatment systems as close as feasible to the source of runoff. LID site design principles must be followed to reduce runoff to a level consistent with the maximum extent practicable (MEP) standard. Priority development projects are required to infiltrate, harvest and re-use, evapotranspire, or bio-treat the 85th percentile storm event. Biotreatment systems may only be used if infiltration, evapotranspiration, and reuse are infeasible.

The Permittees are required to minimize the short and long-term impacts on receiving water quality from new developments and significant re-developments, including submittal of a Water Quality Management Plan (WQMP), emphasizing implementation of LID principles and addressing hydrologic conditions of concern, prior to issuance of any grading or building permits or recordation of any subdivision maps. The WQMPs are required to include BMPs for source control, pollution prevention, site design, LID implementation and structural treatment control BMPs.

San Diego Region: The permit requires the following LID BMPs to be implemented at all Development Projects where applicable and feasible:

a) Conserve natural areas, including existing trees, other vegetation, and soils.
b) Construct streets, sidewalks, or parking lot aisles to the minimum widths necessary, provided that public safety is not compromised.
c) Minimize the impervious footprint of the project.
d) Minimize soil compaction to landscaped areas.
e) Minimize disturbances to natural drainages (e.g., natural swales, topographic depressions, etc.)
f) Disconnect impervious surfaces through distributed pervious areas.

Priority Development Projects are required to implement LID BMPs which will collectively minimize directly connected impervious areas, limit loss of existing infiltration capacity, and protect areas that provide important water quality benefits necessary to maintain riparian and aquatic biota, and/or are particularly susceptible to erosion and sediment loss.

The following LID BMPs must be implemented at all Priority Development Projects where technically feasible as required below:

(i) Maintain or restore natural storage reservoirs and drainage corridors (including depressions, areas of permeable soils, swales, and ephemeral and intermittent streams.
(ii) Projects with landscaped or other pervious areas must, where feasible, drain runoff from impervious areas (rooftops, parking lots, sidewalks, walkways, patios, etc) into pervious areas prior to discharge to the MS4. The amount of runoff from impervious areas that is to drain to pervious areas shall not exceed the total capacity of the project's pervious areas to infiltrate or treat runoff, taking into consideration the pervious areas' geologic and soil conditions, slope, and other pertinent factors.
(iii) Projects with landscaped or other pervious areas must, where feasible, properly design and construct the pervious areas to effectively receive and infiltrate or treat runoff from impervious areas, prior to discharge to the MS4. Soil compaction for these areas shall be minimized. The amount of the impervious areas that are to drain to pervious areas must be based upon the total size, soil conditions, slope, and other pertinent factors.
(iv) Projects with low traffic areas and appropriate soil conditions must construct walkways, trails, overflow parking lots, alleys, or other low-traffic areas with permeable surfaces, such as pervious concrete, porous asphalt, unit pavers, and granular materials.

LID BMPs are required to capture and retain the volume of runoff produced from a 24-hour 85th percentile storm event, if technically feasible. LID biofiltration BMPs may be used to treat any volume that cannot be retained onsite. Conventional BMPs may only be used if LID BMPs are infeasible.

The Hydromodification Management Plan (HMP) shall be incorporated into the local Sewer System Management Plan (SSMP) and implemented by each Co-permittee so that estimated post-project runoff discharge rates and durations shall not exceed pre-development discharge rates and durations. Where the proposed project is located on an already developed site, the pre-project discharge rate and duration shall be that of the pre-developed, naturally occurring condition.

Riverside County MS4 Permit

The current Riverside County MS4 Permit was adopted in 2010 (RWQCB Order No. R8-2010-0033, NPDES Permit No. CAS618033). Priority development projects are required to infiltrate, harvest and use, evapotranspire, or bio-treat the 85th percentile storm event. Preference is given to retention through infiltration, harvest and use, and/or evapotranspiration. If these techniques cannot feasibly treat the entire design storm volume, then bio-treatment BMPs can be used. The permit requires new development and redevelopment projects disturbing more than one acre to maintain pre-development site hydrology (including runoff volume, velocity, duration, time of concentration) to the maximum extent practicable for the 2-year return frequency storm.

San Bernardino County MS4 Permit

The current San Bernardino County MS4 Permit was adopted in 2010 (RWQCB Order No. R8-2010-0036, NPDES Permit No. CAS618036). Priority development projects are required to infiltrate, harvest and use, evapotranspire, or bio-treat the 85th percentile storm event. Preference is given to retention through infiltration, harvest and use, and/or evapotranspiration. If these techniques cannot feasibly treat the entire design storm volume, then bio-treatment BMPs can be used. The permit requires new development and redevelopment projects disturbing more than one acre to maintain pre-development site hydrology (including runoff volume, velocity, duration, time of concentration) to the maximum extent practicable for the 2-year return frequency storm.

Ventura County MS4 Permit

Ventura County's current MS4 Permit was adopted in 2000, and is currently under revision (RWQCB Order No. R4-2009-0057, NPDES Permit No. CAS004002). The proposed permit establishes a 5 percent limit on effective impervious area (EIA) for new development and redevelopment, and requires that the design storm runoff volume from 95 percent of the impervious area be retained by infiltration, evapotranspiration, or reuse. EIA is the portion of surface area that is hydrologically connected via sheet flow over a hardened conveyance or impervious surface without intervening medium to mitigate stormwater from the design storm. On infill projects where 5 percent is not technically feasible, the project must reduce percent EIA to as close to 5 percent as feasible and no more than 30 percent of the total project area. The EIA difference may be made up through off-site mitigation. Off-site mitigation is required for the volume of stormwater from the design storm that that cannot be retained on-site within the 5 percent EIA limitations. Any design storm volume runoff from the impervious area of the site needs to be treated for stormwater quality.

Treatment BMPs must be selected in the following order of preference: Infiltration BMPs, BMPs that store and reuse stormwater, BMPs that incorporate vegetation and integrate multiple uses, BMPs that percolate runoff through engineered soils and allow it to slowly discharge downstream, and proprietary treatment control BMPs that are based on LID. Bioretention with an underdrain (biotreatment) is considered a treatment BMP and can be used only after the design storm volume has been retained and the water used on site.

A Technical Guidance Manual (TGM) was developed in 2002 for the previous permit to explain how to design and implement a variety of specific LID and Best Management Practices (BMPs) for the treatment of storm water utilizing source control, site design and structural treatment control. The 2002 TGM will be updated for the new permit requirements to provide cost effective strategies to successfully meet the latest storm water quality improvement goals. The new TGM will also provide alternative compliance measures where LID is infeasible or limited.

Los Angeles County MS4 Permit

Los Angeles County's current MS4 Permit was issued in 2001 and amended in 2006, 2007, and 2009 (RWQCB Order No. R4-2001-182, NPDES Permit No. CAS004001). A new permit is currently under development. There are no specific LID requirements in the current permit. The current LA County MS4 Permit requires that post-construction treatment control BMPs incorporate, at a minimum, one of the following design standards:

1. Volumetric Treatment Control BMP (Any of the four methods would be acceptable)
    a. 85th percentile 24-hour runoff event, or
    b. Volume of runoff produced from a 0.75 inch storm event, or
    c. Volume of annual runoff based on unit basin storage to achieve 80 percent volume treatment, or
    d. Volume of runoff from a historical-record based reference 24-hour rainfall for treatment that achieves the same reduction in pollutant loads achieved by the 85th percentile 24-hour runoff event.
2. Flow Based Treatment Control BMP (Any of the three methods would be acceptable)
    a. Flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity, or
    b. The flow of runoff produced from a rain event equal to at least two times the 85th percentile hourly rainfall intensity for Los Angeles County, or
    c. The flow from runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

The current Los Angeles County MS4 Permit does not require any LID measures. However, the Los Angeles County Department of Public Works proactively developed an LID manual for both private and public projects. As of January 2009, such projects within unincorporated LA County are required to implement LID measures (County of Los Angeles, 2009). The LID manual requires infiltration of ∆V, the increase of the runoff volume at parcel level (if possible). If parcel level LID is not possible, then the developer can apply for a regional LID solution. Currently, Los Angeles County is developing another LID Manual for infrastructure projects such as highways and drainage projects.

Phase II Municipal Permits

The SWRCB adopted a statewide General Phase II MS4 Permit in April 2003 (SWRCB Order No. 2003-0005-DWQ). The general permit covers small MS4s that are not directly regulated by the Phase I permits. Phase II communities are required to develop stormwater management programs that reduce the discharge of pollutants to the maximum extent practicable (MEP) and protect water quality. The Permittees are required to address stormwater runoff from new development and redevelopment projects that disturb more than one acre by developing and implementing control strategies, which can include a combination of structural and non-structural BMPs.

General Construction Permits

As of July 2010, all discharges related to construction activity will be required to obtain coverage under the statewide Construction General Permit (SWRCB Order No. 2009-0009-DWQ). The new permit establishes statewide post-construction runoff standards and requires the maintenance of a site's predevelopment hydrology in order to control hydromodification.

The regulatory approach of the permit is one of effluent limitation and hydrograph control. The pre-development site hydrology must be evaluated and approximated using structural and non-structural controls so that there is no increase in the volume of runoff that leaves the site and no decrease in the time of concentration.

Incorporating LID into the Planning Process

Incorporating LID into General Plans

Although California has a variety of regional plans, including Regional Blueprints adopted by Councils of Governments, the cornerstone of the California planning process is the general plan. According to Thomas Kent, in his text The Urban General Plan (1964), a general plan is "the official statement of a municipal legislative body which sets forth its major policies concerning desirable future physical development." The general plan process is defined by Government Code Sections 65000-66037, which delegate most local land use decisions to individual cities and counties across the state. Each county and incorporated city is required to adopt "a comprehensive long term general plan for physical development."

General plans include development goals and policies and lay the foundation for land use decisions made by planning commissions, city councils, or boards of supervisors. General plans must contain text sections and maps or diagrams illustrating the general distribution of land uses, circulation systems, open space, environmental hazard areas, and other policy statements that can be illustrated. The Government Code specifies that general plans must contain seven mandatory elements or components: circulation, conservation, housing, land use, noise, open-space, and safety. Local governments may also voluntarily adopt other elements addressing topics of local interest. Cities and counties could adopt an optional water element in their general plans, but few have done so. Instead, water has most often been partially addressed in either the mandatory conservation element or in optional natural resources or public facilities elements. Water is frequently addressed only in terms of water supply and/or water conservation.

Possible Approaches to Incorporate LID into General Plans

There are several viable methods of incorporating LID into general plans. One approach would involve amending existing general plan elements to incorporate LID principles, goals, and policies. Since water is most often addressed in the required conservation element, appropriate principles, goals, and policies could be added to this element. In a January 2008, report prepared for the Ocean Protection Council, entitled **"State and Local Policies Encouraging or Requiring Low Impact Development in California,"** The report recommends that a state LID statute should provide language for incorporating low impact development into the mandatory land use and conservation elements of general plans. In addition, since the land use element is the focus of local land use decisions, language on low impact development should also be added to the element. When water is addressed in another element, such as an optional natural resources or water element, LID language should be added to that element.

A second approach would be to develop a new water element. Not many such optional elements have been adopted in California; however, the 2003 edition of the State of California General Plan Guidelines contains a detailed discussion of optional water elements. OPR stated,

> *"Given the importance of water to the state's future, a community would be well served to create a separate water element, in conjunction with the appropriate water supply and resource agencies, in which each aspect of the hydrologic cycle is integrated into a single chapter of the general plan. With recent law that requires land use decisions to be linked to water availability, a water element takes on increased importance."*

An optional element, such as a water element, can be amended at any time, which is important since LID is an evolving practice. To assist local governments in developing water elements, the Local Government Commission included a model water element as appendix to its July 2006 publication, *The Ahwahnee Water Principles, A Blueprint for Regional Sustainability*.

The model water element proposed by the Local Government Commission (LGC) includes sample policies grouped into three sections: 1) Watershed protection and management; 2) Protecting and improving water quality; and 3) Managing supply and demand of water resources. The model element was designed to provide a policy framework to address the links between water and land use. It builds upon the Ahwahnee Water Principles.

Addressing LID through Specific Plans

A specific plan is a flexible tool for systematically implementing general plans. Specific plans must be consistent with Section 65450-65457 of the Government Code. These provisions require that specific plans be consistent with the general plans of the jurisdictions that adopt them. The range of issues addressed and the area covered by specific plans is left to the discretion of the decision-making body of the city or county adopting the plan. Once a specific plan is adopted, all zoning regulations, all public works projects, and all subsequent subdivision and development must be consistent with the specific plan.

Section 65451 of the Government Code specifies the structure of a specific plan. The information that is to be presented by text and diagram includes the distribution, location and extent of land uses within the area covered by the plan. Specific plans also include:

> *"(2) The proposed distribution, location, and extent and intensity of major components of public and private transportation, sewage, water, drainage, solid waste disposal, energy, and other essential facilities proposed to be located*

within the area covered by the plan and needed to support the land uses described in the plan.

In addition, the specific plans contain:

"(3) The Standards and criteria by which development will proceed, and standards for the conservation, development, and utilization of natural resources, where applicable," and

"(4) A program of implementation measures including regulations, programs, public works projects, and financing measures necessary to carry out paragraphs (1), (2), and (3).

Since specific plans are flexible and scalable by design, they can be used in different ways to implement LID. If adopted by resolution, a specific plan is a policy document. If adopted by ordinance, a specific plan would be a regulatory document. An overlay specific plan could be adopted either by resolution or ordinance to address only the LID issue. Alternatively, a specific plan could be adopted to address the comprehensive development or redevelopment of a defined area and include LID requirements among the standards and implementation measures applicable to the area.

An example specific plan is being prepared for a portion of the City of San Bernardino as part of the Inland Empire Sustainable Watershed Program (IESWP), a Proposition 50 grant project funded through the CalFed Watershed Program of the California Department of Water Resources. This project, **"The Model Specific Plan for Watershed Sustainability"** was designed to "develop a guide for how urban planners can use land use design to create LID-friendly specific plans that implement LID at a community scale. This approach leverages the efficiency and opportunity of scale to streamline the MS4 storm water runoff permit compliance process.

The IESWP is a capacity building program to increase participation in watershed planning and management in the upper Santa Ana River watershed. It targets land use planners and decision-makers, the development community, and residents by providing products, resources, and forums that encourage the incorporation of watershed and low impact development approaches into the planning and development process.

Addressing LID through Conditions of Approval

One method of addressing LID as early as possible in the planning process and of tracking implementation of LID practices would be to develop and apply both standard and non-standard conditions of approval. Most jurisdictions apply conditions of approval to the approval of development projects. These conditions often relate to a broad range of topics, including grading, drainage, landscaping, and water quality. Conditions of approval normally state what is to be done, who is to do it, when it is to be done, and who is responsible for determining compliance. Conditions are applied to discretionary planning permits and subdivision maps at different levels in the approval process and may be repeated at subsequent levels of approval when they would be informative to applicants or municipal staff.

Many jurisdictions have developed water quality conditions of approval. Such conditions often relate to pollution prevention during construction and planning for the installation of post-construction structural and non-structural water quality control measures.

New conditions of approval requiring consideration of, and planning for, implementation of low impact development measures could be added to the lists of conditions of approval. LID conditions of approval should be applied as early as possible in the project approval process and repeated at subsequent levels of approval to ensure compliance, timely implementation, and long-term maintenance.

LID and Municipal Codes and Ordinances

LID and Municipal Codes

Municipal codes can relate to low impact development in several ways. Cities and counties can adopt separate LID ordinances to require the use of LID principles in development projects and provide standards for the use of LID. An LID ordinance can specify when LID implementation plans are due and can specify compliance with criteria and standards in a manual or guidance document that can be updated as new information becomes available and as experience with implementation and maintenance of LID measures is gained.

Municipal codes may contain barriers to LID implementation. The magnitude of the barriers in existing ordinances will vary with the purpose of implementing LID measures. If the primary purpose for implementing LID measures is to reduce runoff to improve water quality or to improve flood control, the barrier in existing ordinances may be less difficult to overcome than if the purpose is to achieve a broad watershed protection and enhancement goal.

Many types of codes and ordinances can influence the implementation of LID. Different codes may impact LID differently at different scales. At the site scale, building codes, landscape codes, parking codes, and zoning ordinances can influence site coverage, building dimension, parking requirements and landscaping. Parking codes have received special attention because vehicle parking is a major component of the built environment. These issues are discussed in detail in the January 2008 Tetra Tech analysis of **"State and Local Policies Encouraging or Requiring Low Impact Development in California**" and in an analysis of watershed-based planning strategies completed for Ventura County by the Local Government Commission.

New Ordinances to Facilitate LID

One direct way to use city and county codes to facilitate LID is to adopt specific LID ordinances to require the use of LID principles in development projects. This approach has been followed by the County of Los Angeles, which added a chapter to the Title 12 Environmental Protection of the Los Angeles County Code. This chapter is entitled Low Impact Development (LID) Standards; its stated purpose is to require the use of LID principles in development projects. The chapter states, *"LID builds on conventional design strategies by utilizing every softscape and hardscape surface in the development to perform a beneficial hydrologic function by retaining, detaining, storing, changing the timing of, or filtering stormwater and urban runoff."* The ordinance requires that comprehensive LID plans that demonstrate compliance with an LID Standards Manual be submitted for review and approval by the Department of Public Works. It also specifies that urban and stormwater runoff quantity and quality control standards will be established in the LID Standards Manual that is to be updated and maintained by the Department of Public Works. For subdivisions, the LID plans must be approved prior to tentative map approval. For all other development, an LID plan must be approved prior to issuance of a grading permit or, where a grading permit is not required, prior to issuance of a building permit.

The Subdivision and Planning Zoning Titles of the Los Angeles County Code were amended to add reference to the Low Impact Development Title. In addition, the County adopted ordinances for green building and drought-tolerant landscaping. All three ordinances apply to all administrative and all discretionary projects.

Changes to Los Angeles Municipal Code

The City of Los Angeles amended Chapter VI Article 4.4 Section 64.72 of the Los Angeles Municipal Code in January 2010 to incorporate LID. The code was amended to "expand the applicability of the existing Standard Urban Stormwater Mitigation Plan (SUSMP) requirements by providing stormwater and rainwater LID strategies for planning, and construction of development and redevelopment projects that require building permits" (LA DPW, 2010).

The City's LID ordinance requires that stormwater runoff from development and redevelopment projects be managed to the maximum extent feasible through onsite infiltration, evapotranspiration, capture and reuse, and biofiltration or bioretention BMPs.

Including LID in Stormwater Ordinances

County of Contra Costa

LID can be included in new stormwater management ordinances or amended into existing ordinances. One example of this is the model developed by the Contra Costa County Clean Water Program (CCCCWP) for adoption by its member municipalities. This ordinance was adopted individually by the County of Contra Costa and the 19 cities and towns in the County after the San Francisco Bay Regional Water Quality Control Board added provision C.3 to the County's 1999 area-wide municipal NPDES permit in 2003. This provision is similar to the SUSMP provisions in other MS4 permits. The permittees began to implement provision C.3 in 2005.

This ordinance is a comprehensive stormwater management and discharge control ordinance. It incorporates LID by requiring that:

> *"Every application for a development project, including but not limited to a rezoning, tentative map, parcel map, conditional use permit, variance, site development permit, design review, or building permit that is subject to the development runoff requirements in the City's NPDES permit shall be accompanied by a stormwater control plan that meets the criteria in the most recent version of the Contra Costa Clean Water Program Stormwater C.3. Guidebook."*

The Guidebook contains step-by-step guidance for preparing the required Stormwater Control Plans. It also includes design procedures and calculation procedures, as well as guidance for the operation and maintenance of stormwater facilities.

Originally, the Stormwater Control Plan requirement applied, with some exceptions, to all developments that created one acre or more of impervious surface, including street and road projects and projects on previously developed sites that result in the addition or replacement of a combined total of one acre or more of impervious surface. Effective August 15, 2006, it applies, again with some exceptions, to all projects that create 10,000 square feet or more of impervious surface.

The Contra Costa County Clean Water Program created an LID approach to implementing the Regional Water Board's requirements for applicable new developments to:

- Design the site to minimize imperviousness, detain runoff, and infiltrate runoff where feasible;
- Cover or control sources of stormwater pollutants;
- Treat runoff prior to discharge from the site;

- Ensure runoff does not exceed pre-project peaks and durations; and
- Maintain treatment and flow-control facilities.

Removing Barriers to LID in Current Codes

Removing barriers to LID in existing codes, including zoning codes, is likely to be a time consuming process and vary from jurisdiction to jurisdiction. Perceived barriers to implementation of LID measures are often the result of the needs and experience of multiple departments within a municipality. These departments have promoted standards to facilitate achieving a variety of goals and responsibilities. Not all perceived barriers will need to be removed from existing codes. It may be easier, at least initially, to use overlay zones or specific plans to facilitate implementation of LID practices in both new development and redevelopment projects. As more experience is gained with implementation of LID, standards could be modified in consultation with the departments that promoted the standards that are perceived by stormwater managers to be barriers to LID.

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Appendix C: LID, LEED, and the Sustainable Sites Initiative

LID practices can not only accomplish stormwater management goals but can also aid in obtaining LEED (Leadership in Energy and Environmental Design) certification. There are currently nine LEED Green Building Rating Systems, all of which are voluntary, consensus-based, and market-driven (U.S. Green Building Council, 2009). The systems are categorized by development type, and internally divided into credit categories. The credit name, number, and LEED point-worth are provided, as well as the credit's intent, requirements, options, and in some cases, potential strategies. A minimum of 40 points are needed for LEED certification. Two rating systems most relevant to LID are for new construction and neighborhood development.

The LEED for New Construction Rating System is designed to guide high-performance commercial and institutional projects, including office buildings, high-rise residential buildings, government buildings, recreational facilities, manufacturing plants, and laboratories of all sizes (U.S. Green Building, 2009). The intent is to promote healthful, durable, affordable, and environmentally sound practices in building design and construction (U.S. Green Building Council, 2009). Credit categories relating to LID include: Sustainable Sites, Water Efficiency, and Materials and Resources. Table C-1 provides examples of LEED credits that LID can be used to address.

Table 35. LEED for New Construction Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP
Sustainable Sites	5.1	Site Development, Protect or Restore Habitat	1	Appropriate native plant selection, protect sensitive areas
	5.2	Site Development, Maximize Open Space	1	Minimize construction footprint
	6.1	Stormwater Design, Quantity Control	1	Multiple LID BMPs
	6.2	Stormwater Design, Quality Control	1	Multiple LID BMPs
	7.1	Heat Island Effect, Non-roof	1	Shade from trees, light colored pervious paving
	7.2	Heat Island Effect, Roof	1	Vegetated roof
Water Efficiency	1.1	Water Efficient Landscaping, Reduce by 50%	2	Rain barrels, cisterns, select appropriate plant species
	1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	4	Soil amendments, capture/reuse
	2.1	Innovative Wastewater Technologies, Reduce potable by 50%	2	Capture/reuse
	3.1	Water Use Reduction, 30% Reduction	2	Capture/reuse
	3.2	Water Use Reduction, 35% Reduction	3	Capture/reuse
	3.3	Water Use Reduction, 40% Reduction	4	Capture/reuse
	3.1	Material Reuse, 5%	1	Multiple LID BMPs
Materials & Resources	3.2	Material Reuse, 10%	1	Multiple LID BMPs
	4.1	Recycled Content, 10%	1	Multiple LID BMPs
	4.2	Recycled Content, 20%	1	Multiple LID BMPs
	5.1	Regional Materials, 10%	1	Multiple LID BMPs
	5.2	Regional Materials, 20%	1	Multiple LID BMPs
		Total Possible Points:	22	

Source: The Low Impact Development Center, Inc.

The LEED for Neighborhood Development Rating System integrates the principles of smart growth, urbanism, and green building to bring buildings together into a neighborhood, and relate the neighborhood to its larger region and landscape (Congress of New Urbanism et al, 2009). These standards have been assembled through collaboration among the Congress of New Urbanism, the U. S. Green Building Council, and the Natural Resources Defense Council. The partnership created the rating system to encourage developers to revitalize existing urban areas, reduce land consumption, reduce automobile dependence, promote pedestrian activity, improve air quality, decrease polluted stormwater runoff, and build more livable, sustainable, communities for people of all income levels (Congress of New Urbanism et al, 2009). Credit categories relating to LID include: Smart Location & Linkage and Green Construction & Technology. The table below provides examples of LEED credits that LID can be used to address.

Table 36. LEED for Neighborhood Development Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Smart Location & Linkage	8.1	Steep Slope Protection	1	Vegetated swales, native plants
	9.1	Site Design for Habitat or Wetland Conservation	1	Native plants, infiltration basins, dry ponds, constructed wetlands
	10.1	Restoration of Habitat or Wetlands	1	Restore vegetation
	11.1	Conservation Management of Habitat or Wetlands	1	Preserve existing vegetation and sensitive areas
Neighbor-hood Patter & Design	1.1	Compact Development	1-7	Minimize impervious areas
	6.1	Reduced Parking Footprint	2	Decrease size of parking spaces, pervious pavement
	7.1	Walkable Streets	4-8	Planting trees, curb bump-outs
	12.1	Access to Open Spaces	1	Minimize impervious areas
	13.1	Access to Active Spaces	1	Minimize impervious areas
	15.1	Community Outreach and Involvement	1	Informative signs on public LID structures, meetings

Source: The Low Impact Development Center, Inc.

Table C-2 (Cont.): LEED for Neighborhood Development Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Green Construction & Technology	1.1	LEED Certified Green Buildings	1-3	Green roofs, cisterns, landscaping
	2.1	Energy Efficiency in Buildings	1-3	Green roofs, cisterns, landscaping
	3.1	Reduced Water Use	1-3	Cisterns, rain barrels
	6.1	Minimize Site Disturbance Through Site Design	1	Native vegetation preservation
	7.1	Minimize Site Disturbance Through Site Design	1	Minimizing construction footprint
	9.1	Stormwater Management	1-5	Vegetated swales
	10.1	Heat Island Reduction, Non-Roof	1	Shade from native trees, light colored pervious paving
	10.2	Heat island Reduction, Roof	1	Vegetated roof
		Total Possible Points:	40	

Source: The Low Impact Development Center, Inc.

The above tables display just some of the options for achieving LEED credit points through LID. There are many other points available under these systems as well as through the other seven rating systems that may be applicable to a given project. Some credit categories have prerequisites that must be met before credit certification can be achieved. The U.S. Green Building Council provides information about all of the LEED rating systems, listing all prerequisites, possible credits, and points.

The Green Building Certification Institute administers LEED certification for all commercial and industrial projects. The certification process begins with a determination of whether LEED is right for a project. The project must then be registered, signifying intent to develop a building which meets LEED certification requirements. Resources will be provided at this time that will assist with the application for certification. Application preparation will require a specific set of documents, depending on the desired credit or certification. Once all materials are assembled, the designated LEED Project Administrator is eligible to submit the application online.

Sustainable Sites Initiative

The Sustainable Sites Initiative, a partnership of the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and the United States Botanic Garden, has established Sustainable Sites Initiative Guidelines to certify sustainable landscapes. The Guidelines are modeled after the LEED program, and offer certification based on the use of prerequisites and credits for specific sustainable design practices. The Initiative is currently in its pilot phase. Ratings are based on a 250 point system. Projects can be awarded one to five stars, based on the number of credits earned. A minimum of 100 credits must be earned in order to be awarded one star. In addition to earning credits, projects must follow several prerequisites in order to qualify as sustainable sites. Up to 127 of these credits can be earned by following the LID Site Design Process described in this manual.

Table 37. Sustainable Sites Initiative Prerequisite and Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Site Selection	Prerequisite 1.2	Protect floodplain functions		Protect sensitive areas
	Prerequisite 1.3	Preserve wetlands		Protect sensitive areas
	Prerequisite 1.4	Preserve threatened or endangered species and their habitats		Protect sensitive areas
	Credit 1.5	Select brownfields or greyfields for redevelopment	5-10	LID can be used on these sites
	Credit 1.6	Select sites within existing communities	6	LID can be used for redevelopment
	Credit 1.7	Select sites that encourage non-motorized transportation and use of public transit	5	LID can be used for redevelopment
Pre-Design Assessment and Planning	Prerequisite 2.1	Conduct a pre-design site assessment and explore opportunities for site sustainability		LID site assessment process
	Prerequisite 2.2	Use an integrated site development process		LID site planning strategies
Site Design – Water	Prerequisite 3.1	Reduce potable water use for landscape irrigation by 50 percent from established baseline		Plant adapted vegetation Capture/reuse
	Credit 3.2	Reduce potable water use for landscape irrigation by 75 percent or more from established baseline	2-5	Plant adapted vegetation Capture/reuse
	Credit 3.3	Protect and restore riparian, wetland, and shoreline buffers	3-8	Protect sensitive areas
	Credit 3.5	Manage stormwater on site	5-10	Multiple LID BMPs
	Credit 3.6	Protect and enhance on-site water resources and receiving water quality	3-9	Multiple LID BMPs
	Credit 3.7	Design rainwater/stormwater features to provide a landscape amenity	1-3	Multiple LID BMPs
	Credit 3.8	Maintain water features to conserve water and other resources	1-4	Multiple LID BMPs

Source: The Low Impact Development Center, Inc.

Table C-3 (Cont.): Sustainable Sites Initiative Prerequisite and Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Site Design – Soil and Vegetation	Prerequisite 4.2	Use appropriate, non-invasive plants		Revegetate disturbed areas
	Prerequisite 4.3	Create a soil management plan		Amend soils
	Credit 4.4	Minimize soil disturbance in design and construction	6	Minimize impervious areas Minimize construction footprint
	Credit 4.5	Preserve all vegetation designated as special status	5	Protect existing vegetation
	Credit 4.6	Preserve or restore appropriate plant biomass on site	3-8	Protect existing vegetation Revegetate disturbed areas
	Credit 4.7	Use native plants	1-4	Revegetate disturbed areas
Site Design – Soil and Vegetation	Credit 4.8	Preserve plant communities native to the ecoregion	2-6	Protect existing vegetation
	Credit 4.9	Restore plant communities native to the ecoregion	1-5	Revegetate disturbed areas
	Credit 4.10	Use vegetation to minimize building heating requirements	2-4	Vegetated roofs
	Credit 4.11	Use vegetation to minimize building cooling requirements	2-5	Vegetated roofs
	Credit 4.12	Reduce urban heat island effects	3-5	Minimize impervious areas Vegetated roofs Light-colored pervious pavement

Source: The Low Impact Development Center, Inc.

Table C-3 (Cont.): Sustainable Sites Initiative Prerequisite and Credit Options.

Category	Credit Number	Credit Name	Points Possible	Possible LID BMP/Strategy
Site Design – Materials Selection	Credit 5.2	Maintain on-site structures, hardscape, and landscape amenities	1-4	Minimize impervious areas
Site Design – Human Health and Well-Being	Credit 6.7	Provide views of vegetation and quiet outdoor spaces for mental restoration	3-4	Multiple LID BMPs
	Credit 6.8	Provide outdoor spaces for social interaction	3	Vegetated roofs
Monitoring and Innovation	Credit 9.2	Innovation in site design	8	LID Site Design Process
		Total Possible Points:	127	

Source: The Low Impact Development Center, Inc.

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1

Identification of Significant Factors Affecting Stormwater Quality Using the NSQD

Alexander Maestre, Robert Pitt

1 Introduction

The normal approach to classify urban sites for estimating stormwater characteristics is based on land use. This approach is generally accepted because it is related to the activity in the watershed, plus many site features are generally consistent within each land use. Two drainage areas with the same size, percentage of imperviousness, ground slope, sampling methods, and stormwater controls will produce different stormwater concentrations if the main activity in one watershed is an automobile manufacturing facility (industrial land use) while the other is a shopping center (commercial land use) for example. There will likely be higher concentrations of metals at the industrial site due to the manufacturing processes, while the commercial site may have higher concentrations of PAHs (polycyclic aromatic hydrocarbons) due to the frequency and numbers of customer automobiles entering and leaving the parking lots.

Previous studies indicated that there are significant differences in stormwater constituents for different land use categories (Pitt et al. 2004). This is supported for other databases like NURP (EPA 1983), CDM (Smullen and Cave, 2002) and USGS (Driver et al., 1985). The main question to be addressed in this chapter is if there is a different classification method that better describes stormwater quality, possibly by also considering such factors as geographical area (EPA Rain Zone), season, percentage of imperviousness, watershed area, type of conveyance, controls in the watershed, sampling method, and type of sample compositing, and possible interactions between these factors.

This chapter presents several approaches to explain the variability of stormwater quality by considering these additional factors. Maestre (2005b) has shown that ignoring the non-detected observations can adversely affect the mean, median and standard deviations of the dataset, and the resulting statistical test results. Therefore, the calculations presented in this chapter used the censored observations using the Cohen's maximum likelihood method.

2 Main Factors Affecting Stormwater Quality

The EPA Rain Zone (geographical location), percentage of imperviousness, land use, type of conveyance, controls in the watershed, sample analysis method, and type of sampling procedures were selected as potential influencing factors affecting stormwater quality for the preliminary analyses. Data from sites having single land uses will be used in the basic analyses. Data from the mixed land use sites could be used for verification. The first step was to inventory the total number of events in each of the possible combinations of these factors. The EPA Rain Zone, land use, type of conveyance, type of controls present in the watershed, sampling methods and type of compositing procedures are discrete variables, while percentage of imperviousness is a continuous variable. The total counts and percentage for each discrete variable option is shown in Table 1.

Table 1 Numbers and percentage of samples by discrete site variable category

LAND USE	TOTAL EVENTS	PERCENTAGE
Residential	1042	27.68
Mixed Residential	611	16.23
Commercial	527	14.00
Mixed Commercial	324	8.61
Industrial	566	15.03
Mixed Industrial	249	6.61
Institutional	18	0.48
Open Space	49	1.30
Mixed Open Space	168	4.46
Freeways	185	4.91
Mixed Freeways	26	0.69

EPA RAIN ZONE	TOTAL EVENTS	PERCENTAGE
1	69	1.83
2	2000	53.12
3	266	7.07
4	212	5.63
5	485	12.88
6	356	9.46
7	229	6.08
8	24	0.64
9	124	3.29

TYPE OF CONTROL	TOTAL EVENTS	PERCENTAGE
Channel Weirs (CW)	30	0.80
Dry Pond (DP)	50	1.33
Detention Storage (enlarged pipe) (DS)	17	0.45
Wet Pond at Outfall (WP)	113	3.00
WP in Watershed (WP_W)	182	4.83
WP in Series at Outfall (WP_S)	42	1.12
None	3331	88.47

SAMPLE ANALYSIS	TOTAL EVENTS	PERCENTAGE
Composite (not specified)	718	19.07
Flow Composite	2752	73.09
Time Composite	295	7.84

TYPE OF CONVEYANCE	TOTAL EVENTS	PERCENTAGE
Curb and gutter	2454	65.18
Grass swale	344	9.14
Not specified	967	25.68

SAMPLER	TOTAL EVENTS	PERCENTAGE
Automatic	3055	81.14
Manual	393	10.44
Not specified	317	8.42

About 80 percent of the samples were collected using automatic samplers. It was observed that manual sampling can result in lower TSS concentrations compared to automatic sampling procedures. This may occur, for example, if the manual sampling team arrives after the start of runoff and therefore misses the first flush (if it exists for the site), resulting in reduced event mean concentrations. For those sites using automatic samplers, about 73% of the events were collected using flow-composite samplers, 8% were collected using time-composite samplers, and about 19% did not have any designation available. Flow-composite samples are considered more accurate than time-composite samples when obtaining data for event-mean concentrations, unless very large numbers of subsamples are obtained (Roa-Espinosa and Bannerman, 1995).

Almost 66% of the events were collected at sites drained with conventional curbs and gutters, 9% were collected at sites having roadside grass swales, and it was not possible to determine the drainage system for about 25% of the samples. Grass swales can reduce the concentrations of suspended solids and metals, especially during low flows. They can also infiltrate large quantities of the stormwater, reducing pollutant mass discharges, runoff volume, and peak flows.

2.1 Effects of Stormwater Controls on Stormwater Quality

It is hoped that stormwater controls located in a watershed, or at an outfall, would result in significant reductions in stormwater pollutant concentrations. Figure 1 shows the effects on effluent TSS concentrations when using various controls in residential area watersheds in EPA Rain Zone 2

(Maryland, Virginia, North Carolina, Tennessee and Kentucky), the area having large enough numbers of samples for an effective statistical analysis. The controls noted for these locations included:

1. Channel weir: a flow measurement weir in an open channel that forms a small pool (a very small wet pond).
2. Dry pond (DP): a dry detention pond that drains completely between each storm event.
3. Wet pond (WP): a wet detention pond that retains water between events, forming a small lake or pond. If the pond is in the watershed but not at the outfall, this will be considered a wet pond inside of the watershed (WPW), which would only treat a fraction of the total stormwater from the site
4. Detention storage (DS): Oversize pipes with small outlet orifices, usually under parking lots.

The stormwater monitoring was conducted at the outfalls of the drainage areas, after the stormwater controls. Wet ponds are seen to reduce the TSS concentration in the stormwater more than the other controls (about 78%) compared to the "no control" median value. Detention storage units and dry ponds also reduced the TSS concentrations, but to a smaller extent (about 60% and 37% respectively). Only one site (located in Virginia Beach) had a channel weir control, but that site did not reduce the observed TSS concentrations compared to the "no control" category.

The effectiveness of the stormwater controls was evaluated for each constituent separately. The effects of sample analysis method, sampler instrument, and type of conveyance were also examined. The first step was to identify the suitable subsets that could be examined, based on suitable numbers of samples in each category. The following four land uses and EPA Rain Zones had suitable numbers of sites having controls that could be examined: residential, commercial and industrial in EPA Rain Zone 2 and industrial in EPA Rain Zone 3. For each group, one-way ANOVA analyses were used to identify if there were any differences in the concentrations of 13 constituents (after log-transformations and substitutions for non-detectable values) for those sites that included different controls. Dunnet's method was also used to compare sites with each specific stormwater control type to sites without stormwater controls, using a family error rate of 5%. Table 2 shows the results for these analyses for each of these groups.

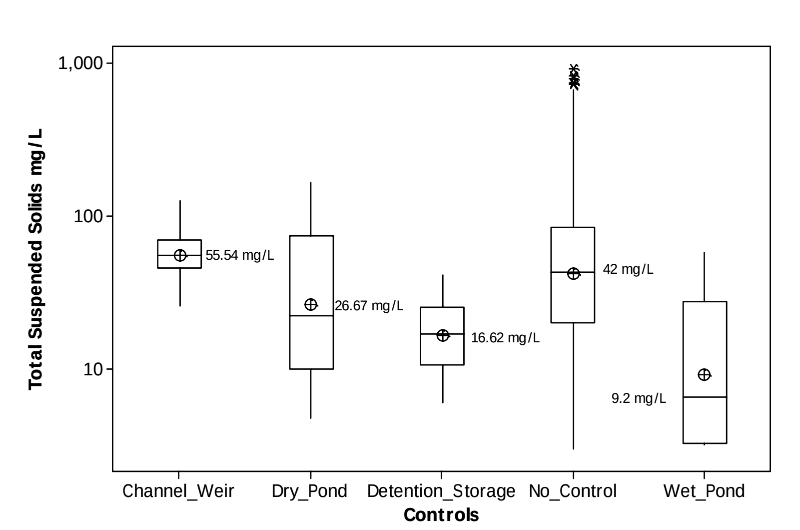

Figure 1. TSS distribution by controls in residential areas and EPA Rain Zone 2 (the cross circles indicate the average concentrations, while the median concentrations are written next to the median bar in the box diagrams)

Table 2 shows that there are no significant differences between sites with or without wet ponds for all constituents having observations in industrial land uses in EPA Rain Zone 3. Nitrite-nitrate, total phosphorus, total copper and total zinc were significantly lower in concentrations at sites located in EPA Rain Zone 2, having wet ponds before the outfall, compared to sites without stormwater controls. Wet ponds did not reduce the TKN concentrations in any of the four groups. Significant reductions in TSS concentrations were also observed for sites having wet ponds in residential and commercial land uses, but not in industrial land uses.

Dry ponds were only available for evaluation in the residential land use category in EPA Rain Zone 2. No significant differences were found for TSS or nitrite-nitrate for sites having dry ponds. However, significant reductions of BOD5, TKN, total phosphorus, total copper, total lead and total zinc were noted.

Some communities have installed detention-storage facilities (enlarged pipes) under parking lots to reduce runoff flow rates. More than 400 of these underground pipes are located in Arlington, Virginia, for example. A significant reduction in the TSS, BOD5, COD, total lead, and total zinc concentrations were observed at sites with these underground devices. On the other hand, these controls did not indicate a significant difference in the concentrations of nutrients (ammonia, nitrite-nitrate, TKN, dissolved phosphorus and total phosphorus), compared to comparable sites not having stormwater controls. A conflicting situation was observed in EPA Rain Zone 2 for total zinc for sites having underground enlarged pipes; zinc concentrations at residential land uses were significantly higher, while zinc concentration at commercial areas were significantly lower, compared to sites with no stormwater controls. It is possible that the sites having elevated zinc concentrations used galvanized metal enlarged pipe systems.

2.2 Sampling Method Effects on Stormwater Concentrations

The use of manual or automatic sampling is a factor that is sometimes mentioned as having a possible effect on the quality of the collected samples. Manual sampling is usually preferred when the number of samples is small and when there are not available resources for the purchase, installation, operation, and maintenance of automatic samplers. Manual sampling may also be required when the constituents being sampled require specific handling (such as for bacteria, oil and grease, and volatile organic compounds) (ASCE/EPA, 2002). Automatic samplers are recommended for larger sampling programs, when better representations of the flows are needed, and especially when site access is difficult or unsafe. In most cases, where a substantial number of samples are to be collected and when composite sampling is desired, automatic sampling can be much less expensive. Automatic samples also improve repeatability by reducing additional variability induced by the personnel from sample to sample (Bailey, 1993). Most importantly, automatic samplers can be much more reliable compared to manual sampling, especially when the goal of a monitoring project is to obtain data for as many of the events that occur as possible, and sampling must start near the beginning of the rainfall (Burton and Pitt, 2002).

One-way ANOVA analyses were used to identify any statistical differences between the two groups. Dunnet’s test was used to compare manual sampling against automatic sampling. Table 3 shows the results from the ANOVA analyses.

Table 2 One-Way ANOVA Results by Control Type

	Residential Land Use, EPA Rain Zone 2						Commercial Land Use, EPA Rain Zone 2					Industrial EPA Rain Zone 2			Residential EPA Rain Zone 3		
Constituent	No Control	Weir	DP	DS	WP	p-value[a]	No Control	DS	WP	WPW	p-value	No Control	WP	p-value	No Control	WP	p-value
Hardness mg/L	30.77 (61) [b]	-	-	44.38 (7,=)	66.45 (10,>)	***0.024***	58.97 (35)	58.17 (8,=)	71.80 (11,=)	47.11 (9,=)	0.717	-	-	None	-	-	None
Oil and Grease mg/L	2.38 (202)	2.50 (3,=)	2.68 (3,=)	2.19 (9,=)	2.50 (13,=)	0.999	4.20 (100)	1.84 (8,=)	2.84 (17,=)	3.36 (13,=)	0.082	3.85 (81)	1.43 (37,<)	***0***	-	-	None
TDS mg/L	62.42 (424)	112.80 (29.>)	58.88 (3,=)	98.45 (8,=)	120.39 (12,>)	***0***	74.89 (174)	100.69 (8,=)	89.99 (26,=)	71.12 (13,=)	0.477	-	-	None	69.53 (44)	49.84 (25,=)	0.112
TSS mg/L	40.10 (559)	55.54 (29,=)	26.67 (21,=)	14.46 (9,<)	9.25 (12,<)	***0***	48.13 (244)	19.54 (8,<)	19.47 (26,<)	16.85 (13,<)	***0***	51.96 (205)	48.05 (29,=)	0.693	48.35 (44)	70.40 (25,=)	0.281
BOD mg/L	11.07 (533)	6.16 (29,<)	3.44 (21,<)	3.66 (9,<)	3.10 (21,<)	***0***	14.66 (241)	4.44 (8,<)	7.06 (26,<)	5.41 (12,<)	***0***	10.63 (200)	9.30 (29)	0.466	6.41 (44)	5.14 (23,=)	0.221
COD mg/L	56.91 (418)	49.02 (29,=)	33.45 (3,=)	22.17 (9,<)	24.58 (12,<)	***0***	73.62 (174)	27.18 (8,<)	35.99 (26,<)	23.88 (13,<)	***0***	-	-	None	37 (44)	43.06 (25,=)	0.395
Ammonia mg/L	0.24 (409)	0.05 (29,<)	0.41 (3,=)	0.40 (9,=)	0.07 (12,<)	***0***	0.39 (174)	0.30 (8,=)	0.13 (26,<)	0.16 (13,<)	***0***	-	-	None	0.12 (3)	0.03 (25,=)	0.165
NO_2 + NO_3 mg/L	0.54 (546)	0.05 (29,<)	0.59 (21,=)	0.98 (9,=)	0.28 (12,<)	***0***	0.60 (242)	1.18 (8,=)	0.48 (26,=)	0.22 (13,<)	***0***	0.61 (197)	0.30 (29,<)	***0***	0.57 (30)	0.40 (25,=)	0.193
TKN mg/L	1.34 (549)	1.49 (29,=)	0.79 (21,<)	1.38 (9,=)	1.04 (12,=)	***0.012***	1.59 (241)	1.04 (8,=)	1.19 (26,=)	1.03 (13,=)	0.057	1.22 (198)	0.98 (29,=)	0.166	1.18 (43)	1.12 (25,=)	0.807
Dissolved Phosphorus mg/L	0.14 (404)	0.04 (29,<)	0.15 (3,=)	0.11 (8,=)	0.03 (12.<)	***0***	0.11 (161)	0.09 (7,=)	0.05 (25,=)	0.03 (13,=)	***0***	-	-	None	0.07 (39)	0.06 (25,=)	0.191
Total Phosphorus mg/L	0.30 (550)	0.23 (29,=)	0.12 (21,<)	0.15 (9,<)	0.07 (12, <)	***0***	0.25 (238)	0.16 (8,=)	0.13 (26,<)	0.08 (13,<)	***0***	0.23 (200)	0.09 (29,<)	***0***	0.16 (43)	0.19 (25,=)	0.438
Total Copper µg/L	11.01 (403)	2.69 (3,<)	6.16 (21,<)	20,75 (9,>)	3.13 (4,<)	***0***	17.53 (194)	14.14 (8,=)	5.57 (6,<)	6.00 (4,<)	***0***	16.00 (150)	7.38 (29,<)	***0***	16.66 (38)	12.58 (25,=)	0.106
Total Lead µg/L	7.73 (364)	6.41 (3,<)	1.50 (21,<)	1.16 (9,<)	1.00 (4,<)	***0***	16.41 (194)	1.61 (8,<)	4.90 (7,<)	2.49 (4,<)	***0***	11.16 (142)	8.66 (29,=)	0.353	8.49 (31)	6.73 (25,=)	0.454
Total Zinc µg/L	67.56 (405)	4.11 (3,<)	29.63 (21,<)	103.25 (9,>)	10.44 (4,<)	***0***	188.02 (197)	82.57 (8,<)	44.26 (7,<)	39.68 (4,<)	***0***	180.01 (157)	60.44 (29,<)	***0***	143.28 (38)	156.93 (25,=)	0.608

Note. a. The bold, italicized probability values indicate "statistically significant" findings at the 0.05 level, or better. b. Sample size and result from Dunnet test comparing if sites with control produces larger concentrations ">", smaller concentrations "<" or not statistically difference "=" than sites without control at a family error of 5%."None" indicates no samples were collected for this constituent in the group.

Table 3 One-Way ANOVA Results by Type of Sampler by Land Use and EPA Rain Zone

	Residential, EPA Rain Z. 2			Commercial, EPA Rain Z. 2			Industrial EPA Rain Zone 2		
Constituent	Automatic	Manual	p-value	Automatic	Manual	p-value	Automatic	Manual	p-value
Hardness mg/L	51.9 (23)	22.4 (28,<)	***0***	97.86 (23)	22.34 (12,<)	***0***	-	-	None
Oil and Grease mg/L	-	-	None	4.75 (70)	2.30 (19,<)	***0.009***	3.68 (62)	4.10 (14,=)	0.723
TDS mg/L	65.4 (318)	50 (66,<)	***0.004***	76.36 (123)	60.80 (18,=)	0.25	73.2 (128)	100 (100,=)	0.362
TSS mg/L	45.5 (420)	19.2 (78,<)	***0***	52.29 (179)	20.55 (24,<)	***0***	51.45 (171)	62.82 (19,=)	0.402
BOD mg/L	11.3 (396)	9.8 (78,=)	0.162	14.86 (178)	11.70 (23,=)	0.189	9.65 (166)	13.47 (19,=)	0.112
COD mg/L	62.2 (312)	36.4 (66,<)	***0***	79.74 (123)	44.02 (18,<)	***0.003***	55.02 (127)	67.68 (10,=)	0.371
Ammonia mg/L	0.229 (310)	0.233 (66,=)	0.909	0.359 (123)	0.433 (18,=)	0.569	0.243 (122)	1.54 (10,>)	0
NO_2 + NO_3 mg/L	0.51 (410)	0.66 (75,>)	***0.005***	0.55 (178)	0.75 (23,=)	0.137	0.558 (163)	0.904 (19,>)	***0.021***
TKN mg/L	1.40 (410)	1.16 (78,<)	***0.048***	1.63 (177)	1.21 (24,=)	0.117	1.135 (164)	1.944 (19,>)	***0.008***
Dissolved Phosphorus mg/L	0.136 (302)	0.120 (63,=)	0.308	0.097 (113)	0.115 (17,=)	0.554	0.091 (109)	0.086 (10,=)	0.870
Total Phosphorus mg/L	0.325 (416)	0.230 (73,<)	***0***	0.261 (176)	0.157 (23,<)	***0.003***	0.214 (166)	0.315 (19,=)	0.056
Total Copper µg/L	11.57 (256)	8.80 (77,<)	***0.025***	20.27 (127)	11.80 (23,<)	***0.001***	15.66 (108)	14.97 (22,=)	0.797
Total Lead µg/L	9.74 (247)	4.14 (71,<)	***0***	17.62 (130)	13.66 (20,=)	0.422	11.27 (109)	10.83 (16,=)	0.908
Total Zinc µg/L	73.71 (256)	53.22 (76,<)	***0.02***	208 (130)	168 (23,=)	0.404	156 (115)	233 (22,>)	***0.028***

Note. Refer to note Table 2. Comparisons with automatic sampling.

Residential, commercial and industrial sites located in EPA Rain Zone 2 were used to evaluate any significant differences between the two sampling methods. It was observed that BOD5 and dissolved phosphorus measurements are not affected by differences in sampling methods used in residential, commercial or industrial areas in EPA Rain Zone 2. In residential and commercial land uses, TSS and COD concentrations obtained using automatic samplers were almost twice the concentrations obtained when using manual sampling methods. Median total phosphorus concentrations were about 50% higher using automatic samplers, while no effects were noted for other nutrients.

Figure 2 contains box and whisker plots comparing automatic versus manual sampling methods in residential land uses in EPA Rain Zone 2. TSS, total copper and total zinc have lower concentrations using manual sampling compared with automatic sampling (p-values 0, 0.025 and 0.02 respectively). The opposite pattern was observed for nitrate-nitrate, manual sampling shows higher concentrations than samples collected with automatic samples (p-value: 0.005).

In industrial land uses, the pattern was found to be opposite. Ammonia, nitrate-nitrite, TKN and total zinc indicated higher concentrations when using manual sampling methods compared to using automatic samplers. Concentrations for these constituents were almost twice as high when using manual sampling, except for ammonia that was almost six times higher when manual sampling was used compared to automatic sampling methods. These elevated concentrations were observed in industrial sites located in Fairfax County Virginia, Howard County Maryland and the city of Charlotte in North Carolina. Sites with controls were not included in the previous analyses.

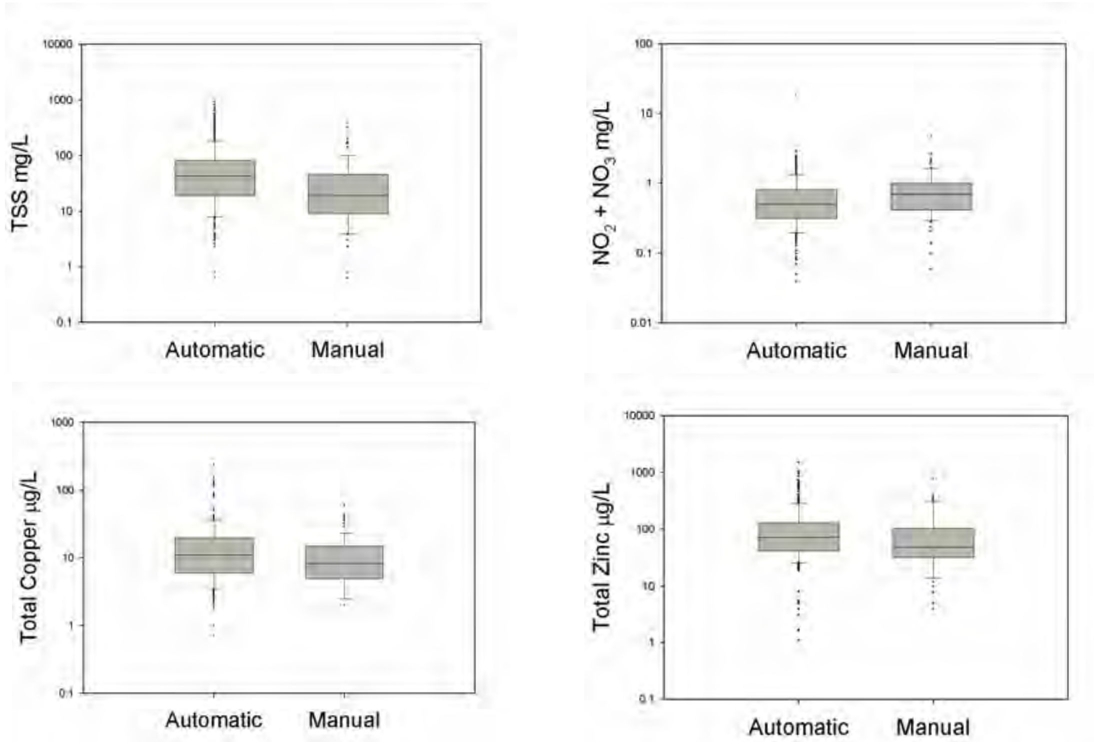

Figure 2. Comparison of reported concentrations in residential land use and EPA Rain Zone 2 for automatic vs. manual sampling methods

2.2 Sampling Method Effects on Stormwater Concentrations

Time and flow-weighted composite options were also evaluated in residential, commercial, and industrial land uses in EPA Rain Zone 2 and in industrial land uses in EPA Rain Zone 3. With time-compositing, individual subsamples are combined for even time increments. As an example, automatic samplers can be programmed to collect a subsample every 15 minutes for deposit into a large composite bottle. An automatic sampler can also collect discrete subsamples at even time increments, keeping each sample in a separate smaller sample bottle. After the sampled event, these samples can be manually combined as a composite. With flow-weighted sampling, an automatic sampler can be programmed to deposit a subsample into a large composite bottle for each set increment of flow.

The Wisconsin Department of Natural Resources conducted a through evaluation of alternative sampling modes for stormwater sampling to determine the average pollutant concentrations for individual events (Roa-Espinosa and Bannerman 1995). Four sampling modes were compared at outfalls at five industrial sites, including: flow-weighted composite sampling, time-discrete sampling, time-composite sampling, and “first-flush” sampling during the first 30 minutes of runoff. Based on many attributes, they concluded that time-composite sampling at outfalls is the best method due to simplicity, low cost, and good comparisons to flow-weighted composite sampling (assumed to be the most accurate). The time-composite sampling cost was about ¼ of the cost of the time discrete and flow-weighted sampling schemes, for example (but was about three times the cost of the first-flush sampling only). The accuracy and reproducibility of the composite samples were all good, while these attributes for the first-flush samples were poor. Burton and Pitt (2001) stress that it is important to ensure that acceptable time-weighted composite sampling include many sub-samples. Any sampling scheme is very inaccurate if too few samples are collected. Samples need to be collected to represent the extreme conditions during the event, and the total storm duration. Experimental design methods can be used to determine the minimum number of subsamples needed considering likely variations. It is more common to now include the use of "continuous" water quality probes at sampling locations, with in-situ observations obtained every few minutes. Unfortunately, these details were not available for the NSQD sampling sites; some sites may have had too few subsamples to represent the storm conditions, while others may have had sufficient numbers of subsamples. Also, most of the NSQD samples only represented the first 3 hours of runoff events. If events were longer, the later storm periods were likely not represented. These issues are discussed more in the next subsection.

One-way ANOVA tests were used to evaluate the presence of significant differences between these two composite sampling schemes. Dunnet's comparison test was used to evaluate if concentrations associated with time-compositing were larger or lower than concentrations associated with flow- compositing. Table 4 shows the results of these tests.

Table 4 shows that no significant differences were observed for BOD5 concentrations using either of the compositing schemes for any of the four categories. A similar result was observed for COD except for commercial land uses in EPA Rain Zone 2, where not enough samples were collected to detect a significant difference. TSS and total lead median concentrations in EPA Rain Zone 2 were two to five times higher in concentration when time-compositing was used instead of flow-compositing.

Nutrients in EPA Rain Zone 2 collected in residential, commercial and industrial areas showed no significant differences using either compositing method. The only exceptions were for ammonia in residential and commercial land use areas and total phosphorus in residential areas where time-composite samples had higher concentrations. Metals were higher when time-compositing was used in residential and commercial land use areas. No differences were observed in industrial land use areas, except for lead. Figure 3 shows box plots for TSS using both methods.

Table 4 One-Way ANOVA Results by Sample Compositing Scheme

	Residential, EPA Rain Z. 2			Commercial, EPA Rain Z. 2			Industrial EPA Rain Zone 2		
Constituent	Flow Composite	Time Composite	p-value	Flow Composite	Time Composite	p-value	Flow Composite	Time Composite	p-value
TDS mg/L	64.02 (351)	76.90 (14,=)	0.229	-	-	None	68.5 (101)	132.9 (9,=)	0.076
TSS mg/L	36.08 (398)	90.30 (80,>)	***0***	38.18 (163)	135.6 (30,>)	***0***	44.2 (116)	84.6 (40,>)	***0***
BOD mg/L	11.04 (379)	10.75 (78,=)	0.785	13.43 (162)	14.56 (30,=)	0.563	9.67 (112)	9.94 (39,=)	0.861
COD mg/L	56.28 (348)	47.93 (14,=)	0.416	-	-	Few	53.93 (100)	63.04 (9,=)	0.519
Ammonia mg/L	0.24 (345)	0.62 (14,>)	***0***	-	-	Few	0.25 (96)	1.11 (9,>)	***0***
NO_2 + NO_3 mg/L	0.52 (388)	0.60 (80,=)	0.097	0.583 (163)	0.567 (30,=)	0.875	0.547 (109)	0.614 (39,=)	0.488
TKN mg/L	1.30 (391)	1.46 (80,=)	0.215	1.47 (163)	1.36 (30,=)	0.637	1.06 (109)	1.13 (40,=)	0.672
Dissolved Phosphorus mg/L	0.139 (334)	0.132 (14,=)	0.832	-	-	Few	0.087 (82)	0.074 (9,=)	0.601
Total Phosphorus mg/L	0.292 (392)	0.426 (80,>)	***0***	0.242 (161)	0.194 (30,=)	0.118	0.208 (111)	0.242 (40,=)	0.338
Total Copper µg/L	9.99 (228)	16.89 (85,>)	***0***	14.91 (115)	36.34 (30,>)	***0***	15.75 (72)	21.27 (40,=)	0.070
Total Lead µg/L	5.94 (222)	19.62 (85,>)	***0***	11.96 (115)	52.23 (30,>)	***0***	9.34 (66)	22.23 (40,>)	***0.001***
Total Zinc µg/L	50.77 (227)	142 (85,>)	***0***	156 (115)	408 (30,>)	***0***	189.7 (72)	186.8 (40,=)	0.930

Note. Refer to note Table 2. Comparisons with flow compositing sampling.

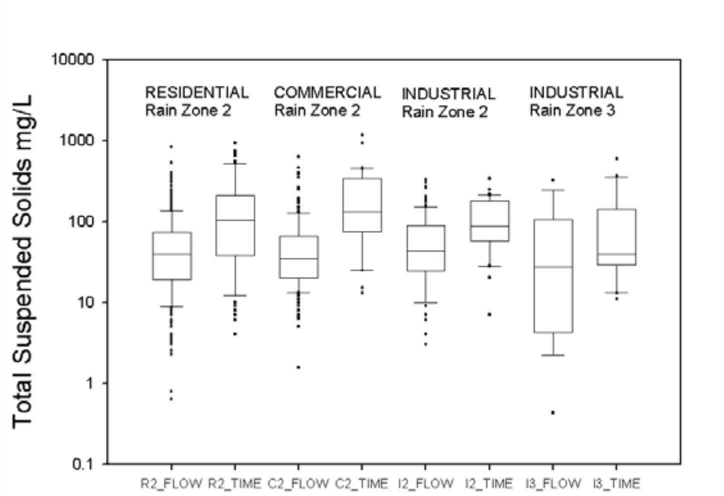

Figure 3. Comparisons between time- and flow-composite options for TSS

2.4 Sampling Period During Runoff Event and Selection of Events to Sample

Another potential factor that may affect stormwater quality is the sampling period during the runoff event. Automatic samplers can initiate sampling very close to the beginning of flow, while manual sampling usually requires travel time and other delays before sampling can be started. It is also possible for automatic samplers to represent the complete storm, if of very long duration, as long as proper sampler setup programming is performed (Burton and Pitt 2001). However, automatic samplers are not capable of sampling bed load material, and are less effective in sampling larger particles (>500 µm) than typically suspended solids. Manual sampling, if able to collect a sample from a cascading flow, can collect from the complete particle size distribution.

The NPDES stormwater sampling protocols only required collecting composite samples over the first three hours of the event instead of during the whole event. Truncating the sampling before the runoff event ended may have adversely affected the measured stormwater quality.

Selecting a small subset of the annual events can also bias the monitoring results. In most stormwater research projects, the goal is to sample and analyze as many events as possible during the monitoring period. As a minimum, about 30 samples are usually desired in order to adequately determine the stormwater characteristics with an error level of about 25% (assuming 95% confidence and 80% power) (Burton and Pitt 2001). With only three events per year required per land use for the NPDES stormwater permits, the accuracy of the calculated EMC is questionable until many years have passed. Also, the three storms need to be randomly selected from the complete set of rains in order to be most statistically representative.

Flagstaff Street, in Prince George MD, had the most events collected for any site in the NSQD. They collected 28 events during two years of sampling (1998 and 1999). A statistical test was made choosing 6 events (three for each year) from this set, creating 5,600 different possibilities. Figure 4 shows the histogram of these possibilities. The median TSS of the 28 events was 170 mg/L, with a 95% confidence interval between 119 and 232 mg/L. Only 60% of the 5,600 possibilities were inside this confidence interval. Almost half (40%) of the possibilities for the observed EMC would therefore be outside the 95% confidence interval for the true median concentration if only three events were available for two years. As the number of samples increase, there will be a reduction in the bias of the EMC estimates. In Southern California, Leecaster (2002) determined that ten years of collecting three samples per year was required in order to reduce the error to 10% (Leecaster, 2002).

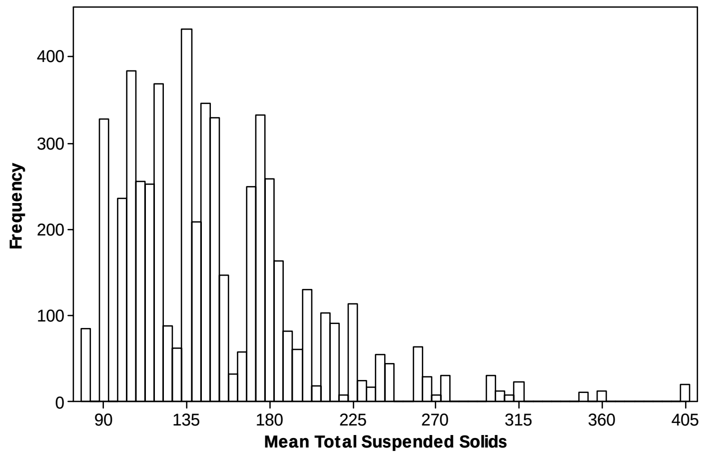

Figure 4. Histogram of possible TSS concentrations in Flagstaff Street based on collecting three samples per year for two years (the measured median TSS concentration was 170 mg/L)

2.5 Type of Conveyance

Almost all of the samples in the NSQD were collected using automatic samplers and flow compositing. Statistical tests investigating the effects of the type of conveyance only used information from flow-weighted composited samples to reduce potential errors associated with other sampling schemes, as discussed above. Grass swales are considered to be effective stormwater controls compared to conventional curb and gutter stormwater collection systems. Grass swales are commonly found in residential areas with low levels of imperviousness, especially in low density residential areas. NSQD data from residential and mixed residential sites in Virginia, Georgia, and Texas were used to compare stormwater concentrations in areas drained by grass swales and by concrete curbs and gutters.

Historical swale performance tests usually focused on pollutant mass discharges and not concentrations. Swales normally infiltrate significant amounts of the flowing water, resulting in large mass discharge decreases. Most swales operate with relatively deep water, and any “filtering” benefits of the grass (and hence concentration reductions) are usually minimal. Very shallow flows in swales do have particulate pollutant concentration reductions, but these are rarely observed during moderate to large flows (Nara and Pitt 2005).

One-way ANOVA analyses were used to identify any significant differences in stormwater pollutant concentrations between watersheds drained with grass swales or with curbs and gutters. Dunnett’s test was used to determine if grass swales produced different concentrations than curbs and gutters. Table 5 shows the results

Total lead and total phosphorus did not have any significant differences in concentrations when comparing the two conveyance systems in both land use areas. Total copper concentrations from residential land uses in EPA Rain Zones 2 and 3 were lower when grass swale was used instead of curbs and gutters. No copper concentrations differences were observed at industrial land uses having different conveyance systems.

Figure 5 shows box and whisker plots for TSS in industrial land uses, EPA Rain Zones 2 and 3 and residential areas in EPA Rain Zone 2. The median concentrations in industrial land uses were smaller in locations where curbs and gutters were used compared to sites having grass swales. The statistical tests did not identify a significant difference between the median concentrations in residential areas in EPA Rain Zone 3 (the residential boxes have much more overlap than for the industrial sites).

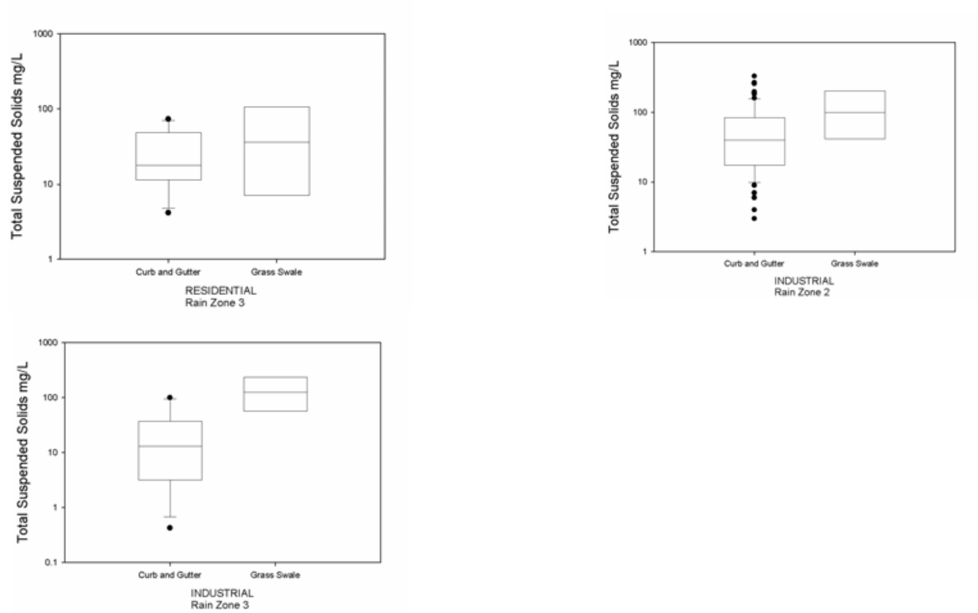

Figure 5. TSS concentration by type of conveyance (Significant differences were observed in industrial land uses)

2.6 Concentration Effects Associated with Varying Amounts of Impervious Cover

The reported values for imperviousness do not reflect the amount of pavement and roofs that are not directly connected to the drainage system. Directly connected impervious areas (DCIA) are also referred to as effective impervious areas (EIA). For example, imagine a park with a single paved basketball court surrounded by turf; the area of the court will be counted as part of the total impervious area, but would not be considered as part of the effective impervious area. The runoff from the paved court would likely be totally infiltrated by the grass and will be not discharged to the drainage system. In this case, even if we have a value for "total imperviousness," the "effective percentage of imperviousness" is zero.

It is therefore difficult to compare database concentrations with the imperviousness values due to these potential uncertainties in the actual effective imperviousness. Figure 6 is an example plot of the percent imperviousness values of different land uses for COD. Each vertical set of observations represent a single monitoring location (all of the events at a single location have the same percent imperviousness). The variation of COD at any one monitoring location is seen to vary greatly, typically by about an order of magnitude. These large variations will make trends difficult to identify. All of the lowest percentage imperviousness sites are open space land uses, while all of the highest percentage imperiousness sites are freeway and commercial land uses. This plot shows no apparent trend in concentration that can be explained by imperviousness. However, it is very likely that a significant and important trend does exist between percent effective imperviousness and pollutant mass that is discharged. While the relationship between imperviousness and concentration is not clear, the relationship between effective imperviousness and total runoff volume is much clearer and more obvious as the non-paved areas can infiltrate much water.

One important feature in the percentage of imperviousness is that most of the residential sites have low levels of imperviousness, while commercial and industrial sites usually have high percentages of imperviousness. Figure 7 shows the mean TSS concentration for residential, commercial and industrial land uses in the database. Only four of the residential watershed has percentage of imperviousness values larger than 60%. Two commercial sites have less than 60% imperviousness, with the remaining commercial sites above this value. Analyses concerning the effects of impervious cover on stormwater concentrations for each land use separately are difficult as there are limited ranges of impervious cover within each land use category.

Table 5 One-Way ANOVA Results by Type of Conveyance

	Residential, EPA Rain Zone 2			Industrial, EPA Rain Zone 2			Residential, EPA Rain Zone 3			Industrial, EPA Rain Zone 3		
Constituent	Curb and Gutter	Grass Swale	p-value	Curb and Gutter	Grass Swale	p-value	Curb and Gutter	Grass Swale	p-value	Curb and Gutter	Grass Swale	p-value
Oil and Grease mg/L	3.11 (59)	2.95 (7,=)	0.824	-	-	None	-	-	None	-	-	None
TDS mg/L	-	-	None	45.5 (67)	184 (77,>)	***0***	94.06 (11)	47.84 (6,<)	***0.049***	76.74 (10)	131.6 (6,=)	0.134
TSS mg/L	-	-	None	37.62 (69)	97.70 (7,>)	***0.023***	19.2 (12)	29.6 (6,=)	0.425	9.68 (10)	91.2 (6,>)	***0.014***
BOD mg/L	-	-	None	6.84 (67)	39.98 (5,>)	***0***	7.56 (11)	6.63 (5,=)	0.749	4.68 (10)	6.61 (6,=)	0.461
COD mg/L	-	-	None	50.16 (66)	85.64 (7,>)	***0.035***	29.36 (11)	67.27 (5,>)	***0.027***	29.40 (10)	41.26 (6,=)	0.446
Ammonia mg/L	-	-	None	0.223 (61)	0.285 (7,=)	0.492	-	-	None	-	-	None
$NO_2 + NO_3$ mg/L	-	-	None	-	-	None	-	-	None	-	-	None
TKN mg/L	-	-	None	-	-	None	1.22 (11)	0.94 (6,<)	0.170	0.515 (9)	0.885 (6,=)	0.299
Dissolved Phosphorus mg/L	-	-	None	0.07 (50)	0.23 (4,>)	***0.012***	0.07 (8)	0.04 (6,=)	0.324	0.046 (5)	0.027 (6,=)	***0.077***
Total Phosphorus mg/L	-	-	None	0.174 (64)	0.232 (7,=)	0.468	0.22 (12)	0.14 (6,=)	0.319	0.138 (9)	0.202 (6,=)	0.460
Total Copper µg/L	10.67 (82)	3.11 (7,<)	***0***	13 (20)	12.36 (7,=)	0.905	19 (11)	5 (6,<)	***0.007***	8.57 (9)	22.32 (6,=)	0.098
Total Lead µg/L	11.7 (77)	5.67 (7,=)	***0***	-	-	None	12.9 (9)	4.20 (6,=)	0.154	4.86 (4)	15.5 (6,=)	0.157
Total Zinc µg/L	59.46 (82)	17.85 (7,<)	***0***	225.7 (20)	188.4 (7,=)	0.447	49.5 (11)	43 (6,=)	0.781	72.86 (9)	198.9 (6,>)	***0.007***

Note. a. The bold, italicized probability values indicate "statistically significant" findings at the 0.05 level, or better. b. Sample size and result from Dunnet test comparing if sites with grass swales produces larger concentrations ">", smaller concentrations "<" or not statistically difference "=" than sites with curb and gutters at a family error of 5%."None" indicates no samples were collected for this constituent in the group.

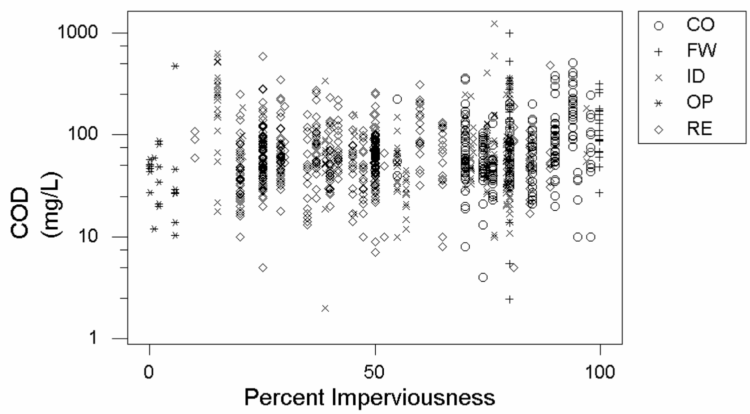

Figure 6. Plot of COD concentrations against watershed area percent imperviousness values for different land uses (CO: commercial; FW: freeway; ID: industrial; OP: open space; and RE: residential)

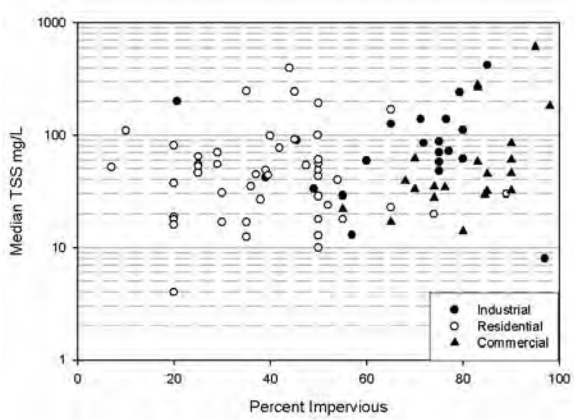

Figure 7. TSS concentrations by impervious cover and single land use

Regression analyses were used to identify possible relationships between constituent concentrations and the percentage of imperviousness for residential land use data. Table 6 shows the results from these regression analyses. Residential land uses in EPA Rain Zone 2 were examined during these analyses. Median concentrations from sites using automatic, flow-weighted samplers, and not having any controls and with curb and gutter conveyance systems were selected for analyses. Data from the site KYLOTSR3 was not used during these analyses because sewage disposal facilities were located in the test watershed. Solids and heavy metal median concentrations were higher at this location than for the remaining residential sites in the same Rain Zone.

Only nitrate-nitrite indicated a significant regression relationship between percentage of imperviousness and constituent concentration for these sites, as shown in Figure 8. In this case, the slope was negative, indicating a reduction in the concentration as the level of imperviousness increased. One possible explanation is that the nutrients are associated with landscaped areas and the use of fertilizers which all decrease with increasing impervious areas. This does not indicate that the total mass of nitrate-nitrite will be reduced. The load of this constituent depends on the total runoff volume that is discharged during the event. As the percentage of imperviousness increases, the runoff volume also increases due to lack of infiltration. Even if the concentration is shown to decrease, the total mass discharge may still increase with increasing amounts of pavement or roofs. There was not enough evidence to indicate a relationship between concentration and percentage of imperviousness for the other 11 constituents examined.

Table 6 Regression of Median Concentrations by Percentage of Impervious in Residential land Use, EPA Rain Zone 2

CONSTITUENT	N	CONSTANT COEFFICIENT	P-VALUE	IMPERVIOUS COEFFICIENT	P-VALUE	R^2 Adjusted	RESULT
TDS mg/L	10	71.94	0.002	-0.386	0.446	0	Not Significant
TSS mg/L	10	74.44	0.002	-0.715	0.172	0.121	Not Significant
BOD5 mg/L	10	8.74	0.117	0.076	0.619	0	Not Significant
COD mg/L	10	53.94	0.027	0.332	0.578	0	Not Significant
Ammonia mg/L	10	0.319	0.052	-0.002	0.639	0	Not Significant
NO3-NO2 mg/L	9	0.756	0	-0.009	0.013	0.556	Not Significant
TKN mg/L	9	1.817	0.003	-0.016	0.247	0.069	Not Significant
DP mg/L	10	0.237	0.033	-0.003	0.349	0	Not Significant
TP mg/L	10	0.561	0.002	-0.006	0.13	0.171	Not Significant
Cu µg/L	11	16.51	0.005	-0.140	0.225	0.065	Not Significant
Pb µg/L	11	46.64	0.336	-0.337	0.767	0	Not Significant
Zn µg/L	11	98.13	0.027	-0.572	0.542	0	Not Significant

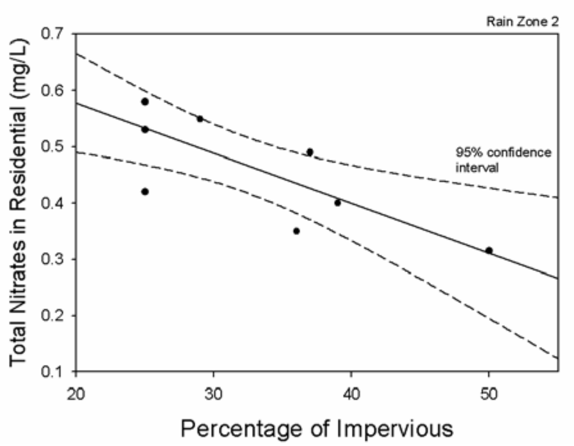

Figure 8 Total nitrates regression at different percentages of impervious

The same regression analysis was performed for commercial and industrial land uses in EPA Rain Zone 2. The results of the regression analyses are shown in Table 7. None of the median stormwater constituents in commercial and industrial areas seem to be affected by changes in impervious cover. There is not enough evidence to indicate a significant relationship between constituent concentration and percentage of imperviousness. More samples will be required to identify those regressions.

Table 7 Regression of Median Concentrations by Percentage of Impervious in Commercial and Industrial land use, EPA Rain Zone 2

CONSTITUENT	N	CONSTANT COEFFICIENT	P-VALUE	IMPERVIOUS COEFFICIENT	P-VALUE	R^2 Adjusted	RESULT
TDS mg/L	5	-4.8	0.854	0.821	0.103	0.523	Not significant
TSS mg/L	5	-22.01	0.406	0.805	0.097	0.541	Not significant
BOD5 mg/L	5	-1.80	0.879	0.153	0.41	0	Not significant
COD mg/L	5	1.41	0.968	0.748	0.215	0.268	Not significant
Ammonia mg/L	5	-0.05	0.906	0.005	0.439	0	Not significant
NO3-NO2 mg/L	5	0.01	0.985	0.007	0.438	0	Not significant
TKN mg/L	5	-0.84	0.467	0.030	0.140	0.426	Not significant
DP mg/L	5	-0.02	0.858	0.001	0.516	0	Not significant
TP mg/L	5	-0.10	0.649	0.004	0.271	0.168	Not significant
Cu µg/L	5	4.26	0.759	0.089	0.679	0	Not significant
Pb µg/L	6	15.69	0585	-0.021	0.961	0	Not significant
Zn µg/L	6	247.9	0.269	-0.949	0.765	0	Not significant

2.7 Concentration Effects Associated with Varying Amounts of Impervious Cover

Another factor that may affect stormwater quality is the season when the sample was obtained. If the few samples collected for a single site were all collected in the same season, the results may not be representative of the whole year. The NPDES sampling protocols were designed to minimize this effect by requiring the three samples per year to be separated by at least 1 month. The few samples still could be collected within a single season, but at least not within the same week. Seasonal variations for residential stormwater data are shown in Figure 9. These variations are not as obvious as the land use or geographical variations, except for bacteria which appear to be lowest during the winter season and highest during the summer and fall (a similar conclusion was obtained during the NURP, EPA 1983, data evaluations). The database does not contain any snowmelt data, so all of the data corresponds to rain-related runoff only.

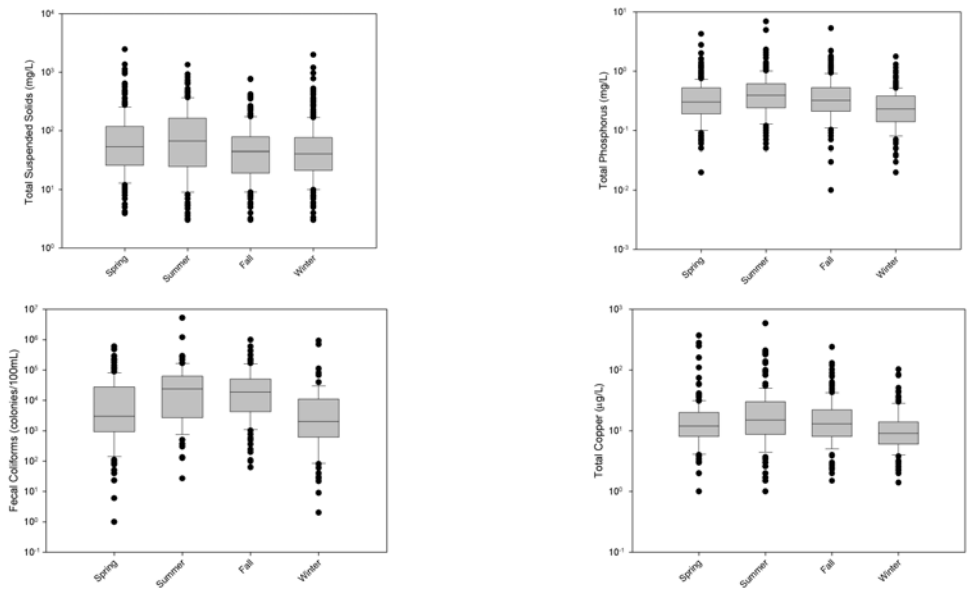

Figure 9. Example residential area stormwater pollutant concentrations sorted by season

2.8 Precipitation Effects on Stormwater Quality

A common assumption is that higher runoff concentrations are associated with smaller rain events. While this has been shown to be true during controlled washoff studies (Pitt 1987, for example), or for sheetflows taken from relatively small paved areas during rains, this has not been frequently detected for samples collected at outfalls for areas having a mixture of surfaces and for typical random periods of high rain intensities. Figure 10 contains several scatter plots showing concentrations plotted against rain depth. There are no obvious trends of concentrations associated with rain depth for the NSQD data.

Figure 11 shows scatter plots of rainfall and runoff depth for each land use. These should follow a 45 degree line for areas having very large amounts of directly-connected impervious areas. These plots show much greater scatter than expected. Some of the plots even indicated larger amounts of runoff than precipitation. This may have occurred due to several reasons: (1) the rainfall was not representative of the drainage area being monitored (especially possible for those sites that relied on off-site rain data); (2) the runoff monitoring was inaccurate (possible when the runoff monitoring relied on stage recording devices and the Manning's equation was applied without local calibration);

(3) the drainage area was inaccurately delineated; or (4) when base flows contributed significant amounts of runoff during the event.

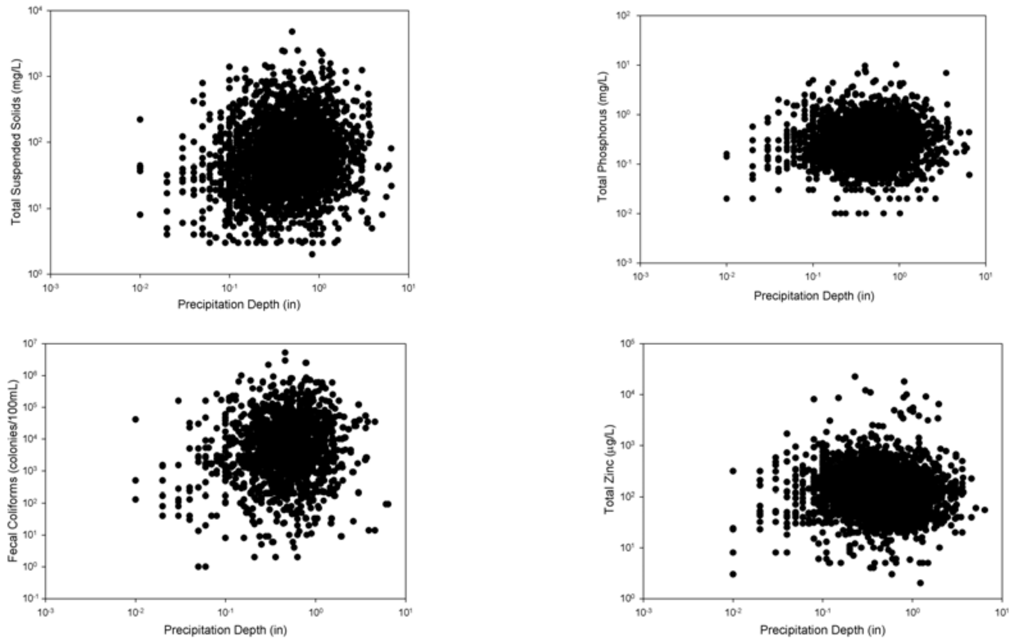

Figure 10. Example of scatter plots by precipitation depth

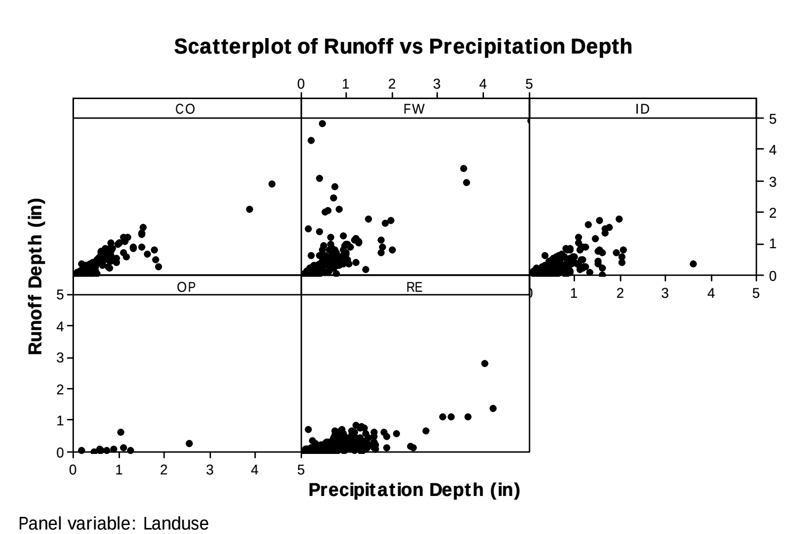

Figure 11 Precipitation depth and runoff depth plotted by land use

When reviewing the runoff plots provided in some of the annual reports, significant base flows were observed. It was also apparent that these base flows were not subtracted from the total flows recorded during the rain event. The magnitude of the error would be greater for smaller rain events when the base flows could be much larger than the direct runoff quantity. Base flows commonly occur when a local spring or high groundwater levels enter the storm drainage system. In addition, runoff may still be occurring from a prior large event that ended soon before the current event started (the 3 day antecedent dry period requirement for monitored events was intended to minimize this last cause of base flows).

2.9 Days Without Rain

The EPA Rain Zones with the longest reported dry interevent periods having data in the NSQD are zones 6 (southern California) and 7 (Oregon). In these EPA Rain Zones, some antecedent dry periods were reported to be longer than 100 days. Monitored events with the shortest interevent periods of no rains were monitored along the east and south east coasts of the country (EPA Rain Zones 2 and 3). The mean interevent dry period in the western states was about 18 days, while eastern states had mean interevent dry periods of about 5 days. Figure 12 shows box and whisker plots of the number of days having no rain before the monitored event by each EPA Rain Zone.

Samples collected using automatic flow-weighted samplers from watersheds having curbs and gutters and without stormwater controls were used during the following analyses. Only EPA Rain Zone 2 has enough observations to evaluate possible effects of the antecedent dry period on the concentration of stormwater pollutants. Table 8 shows the results from the regression analyses. In residential land uses, seven out of 12 constituents indicated that antecedent dry period has a significant effect on the median concentrations. All the regression slope coefficients were positive, indicating that as the number of days having no rain increased the concentrations also increased.

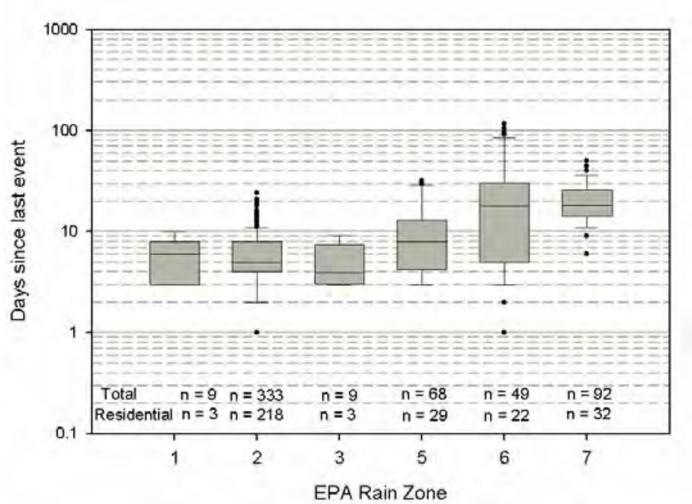

Figure 12 Box and whisker plot of days since preceding event by Rain Zone

Table 8 Regression of Constituent Concentrations (log) by Antecedent Dry Period (log) for Residential Land Use, EPA Rain Zone 2

CONSTITUENT	N	CONSTANT COEFFICIENT	P-VALUE	ANTECEDENT COEFFICIENT	P-VALUE	R^2	RESULT
Oil and Grease mg/L	35	0.737	0	-0.364	0.062	0.074	Not significant
TDS mg/L	208	1.761	0	0.094	0.120	0.007	Not significant
TSS mg/L	214	1.524	0	0.116	0.254	0.001	Not significant
BOD5 mg/L	211	0.887	0	0.211	*0.004*	0.035	Significant
COD mg/L	206	1.682	0	0.151	*0.032*	0.018	Significant
Ammonia mg/L	204	-0.826	0	0.300	*0.003*	0.039	Significant
NO3-NO2 mg/L	208	-0.428	0	0.160	*0.014*	0.024	Significant
TKN mg/L	208	-0.066	0.193	0.232	*0.001*	0.049	Significant
DP mg/L	203	-1.061	0	0.282	*0.002*	0.043	Significant
TP mg/L	214	-0.629	0	0.183	*0.005*	0.031	Significant
Cu µg/L	58	1.082	0	0.025	0.830	0	Not significant
Pb µg/L	53	1.305	0	-0.311	0.277	0.004	Not significant
Zn µg/L	58	1.872	0	-0.058	0.764	0	Not significant

All nutrients in residential land uses showed a positive correlation between days since last event and constituent concentration. In all cases, the coefficients of determination (R2) were smaller than

0.05, indicating that relatively little of the total variation was explained by percent imperviousness. Solids and metals were not affected by the antecedent dry period. Figure 13 shows the regression lines and 95% confidence intervals for four nutrients in residential land uses.

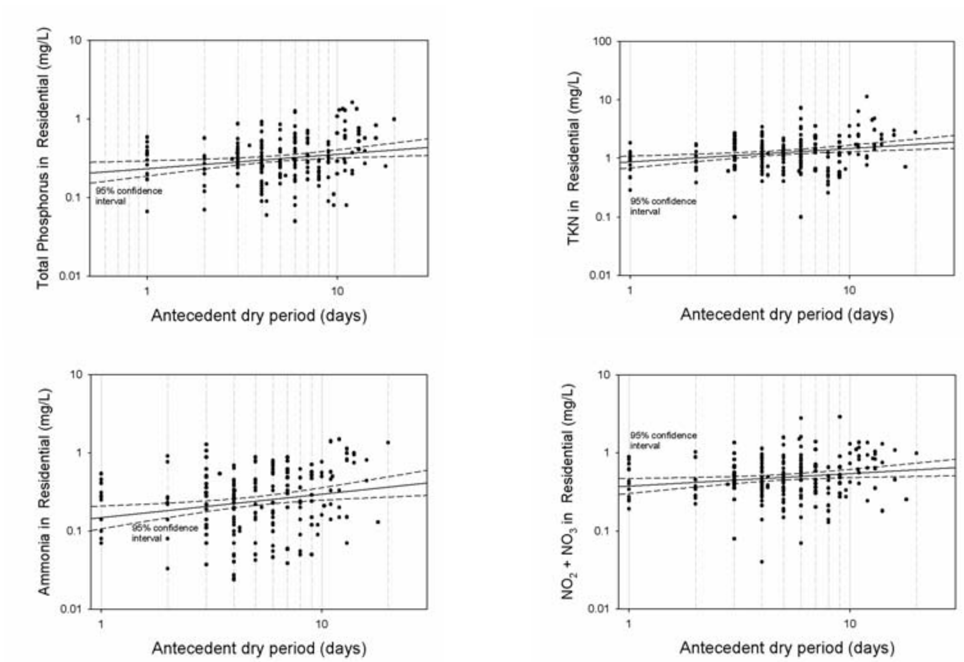

Figure 13. Nutrient concentrations affected by dry periods since last rain in residential land use

Table 9 shows the results from the regression analyses in commercial land uses. Except for nitrates, all the nutrients have positive regressions inside the 95% confidence interval. In commercial land uses, the effects of antecedent dry periods on the median concentrations were less important. Only total phosphorus and total lead had significant regression results. As in the residential case, phosphorus has a positive coefficient with a small coefficient of determination. However, lead decreases with the number of dry days before the storm.

Table 9 Regression of Constituent Concentrations (log) by Antecedent Dry Period (log) for Commercial Land Use, EPA Rain Zone 2

CONSTITUENT	N	CONSTANT COEFFICIENT	P-VALUE	ANTECEDENT COEFFICIENT	P-VALUE	R^2	RESULT
Oil and Grease mg/L	25	0.783	0.001	-0.202	0.402	0	No significant
TDS mg/L	64	1.715	0	0.215	0.169	0.015	No significant
TSS mg/L	82	1.506	0	0.018	0.872	0	No significant
BOD5 mg/L	83	0.971	0	0.149	0.176	0.01	No significant
COD mg/L	64	1.670	0	0.221	0.093	0.029	No significant
Ammonia mg/L	64	-0.591	0	0.258	0.175	0.014	No significant
NO2 mg/L	83	-0.235	0	-0.208	0.176	0.01	No significant
TKN mg/L	83	-0.006	0.949	0.196	0.109	0.019	No significant
DP mg/L	61	-1.329	0	0.241	0.160	0.017	No significant
TP mg/L	83	-0.784	0	0.198	*0.028*	0.047	Significant
Cu µg/L	33	1.081	0	0.959	0.501	0	No significant
Pb µg/L	33	1.498	0	-1.02	*0.001*	0.261	Significant
Zn µg/L	32	2.21	0	-0.082	0.527	0	No significant

Figure 14 shows the regression equations for total phosphorus and total lead for data from commercial land uses. The 95% confidence interval of the regression line for total phosphorus can include zero slope lines. This indicates that there is not a strong correlation between antecedent dry period and total phosphorus concentrations. For total lead, the reduction in concentrations with increasing dry periods is more obvious, but not very explicable.

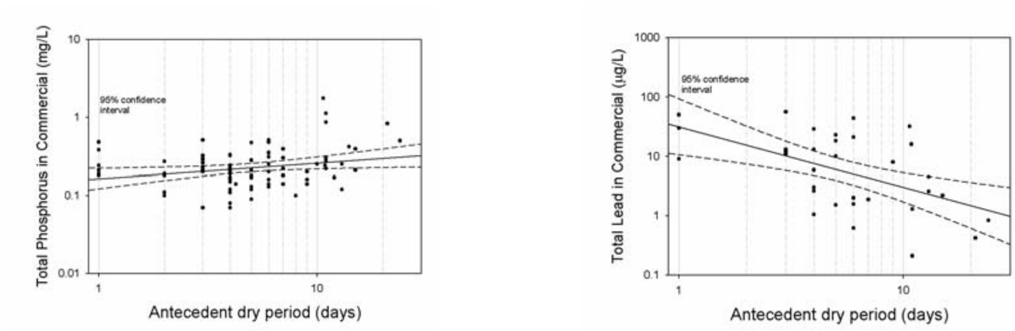

Figure 14. Total phosphorus and total lead as function of antecedent dry period in commercial land use

The effect of the antecedent dry period on stormwater concentrations at industrial land uses was not significant, except for TSS, as shown on Table 10. Figure 5-15 is a plot of the TSS concentrations increasing with increasing dry periods.

Table 10 Regression of Constituent Concentrations (log) by Antecedent Dry Period (log) in Industrial Land Use, EPA Rain Zone 2

CONSTITUENT	N	CONSTANT COEFFICIENT	P-VALUE	ANTECEDENT COEFFICIENT	P-VALUE	R^2	RESULT
Oil and Grease mg/L	3	0.2712	0.773	-0.451	0.700	0	No significant
TDS mg/L	30	1.6509	0	-0.009	0.958	0	No significant
TSS mg/L	31	1.1901	0	0.656	0.025	0.134	Significant
BOD5 mg/L	32	0.78	0	0.201	0.202	0.022	No significant
COD mg/L	29	1.685	0	0.071	0.622	0	No significant
Ammonia mg/L	27	-0.487	0.014	-0.084	0.753	0	No significant
NO2 mg/L	32	-0.1536	0.233	-0.124	0.493	0	No significant
TKN mg/L	32	-0.151	0.215	0.218	0.207	0.021	No significant
DP mg/L	28	-1.176	0	0.190	0.406	0	No significant
TP mg/L	32	-0.966	0	0.373	0.11	0.053	No significant
Cu µg/L	3	1.109	0.124	0.216	0.565	0	No significant
Pb µg/L	3	0.882	0.197	0.119	0.787	0	No significant
Zn µg/L	3	2.072	0.056	0.186	0.555	0	No significant

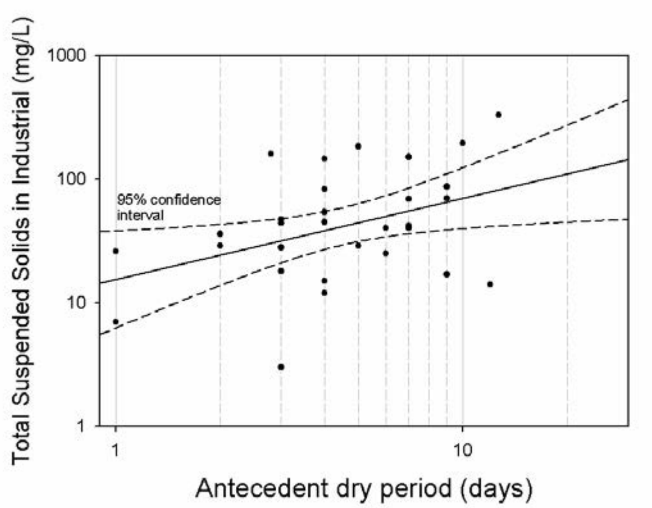

Figure 15. TSS concentrations for days since preceding event in industrial land use

2.10 Trends in Stormwater Quality with Time

In an effort to recognize why differences were observed between the NURP and NSQD databases (see Chapter 2), further examinations of two communities that monitored stormwater during both NURP and the Phase 1 NPDES program were made. As part of their MS4 phase 1 applications, Denver and Milwaukee both returned to some of their earlier sampled monitoring stations used during the local NURP projects (EPA 1983). In the time between the early 1980s (NURP) and the early 1990s (MS4 permit applications), they did not detect any significant differences, except for large decreases in lead concentrations. Figure 16 compares suspended solids, copper, lead, and zinc concentrations at the Wood Center NURP monitoring site in Milwaukee. The average site concentrations remained the same, except for lead, which decreased from about 450 down to about 110 µg/L, as expected due to the decrease in leaded gasoline during this period.

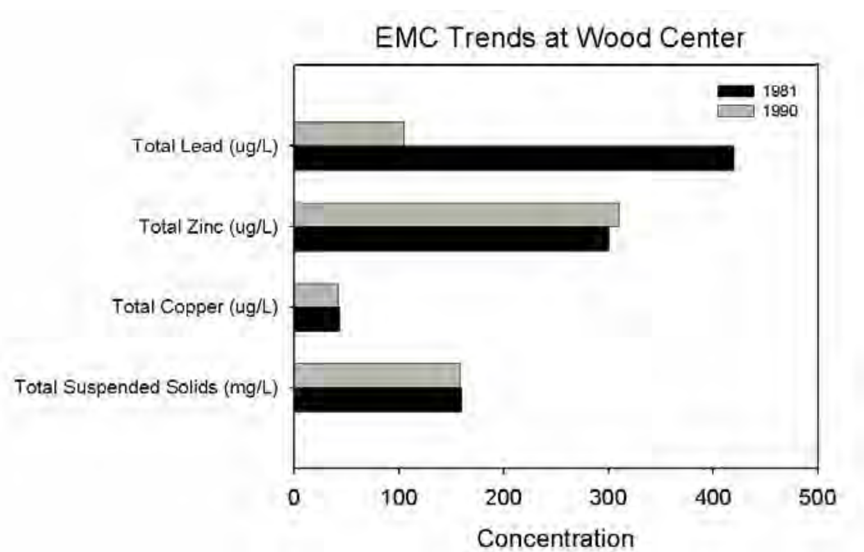

Figure 16. Comparison of pollutant concentrations collected during NURP (1981) to MS4 application data (1990) at the same location (personal communication, Roger Bannerman, WI DNR)

Similar comparisons were made in the Denver Metropolitan area by the Urban Drainage and Flood Control District. Table 11 compares stormwater quality for commercial and residential areas for 1980/81 (NURP) and 1992/93 (MS4 application). Although there was an apparent difference in the averages of the event concentrations between the sampling dates, they concluded that the differences were all within the normal range of stormwater quality variations, except for lead, which decreased by about a factor of four.

Trends of stormwater concentrations with time can also be examined using the NSQD data. A classical example would be for lead, which is expected to decrease over time with the increased use of unleaded gasoline. Older stormwater samples from the 1970s typically have had lead concentrations of about 100 to 500µg/L, or higher (as indicated above for Milwaukee and Denver), while most current data indicate concentrations as low as 1 to 10 µg/L.

Table 11. Comparison of Commercial and Residential Stormwater Runoff Quality from 1980/81 to 1992/93 (Doerfer, 1993)

CONSTITUENT	COMMERCIAL 1980-1981	COMMERCIAL 1992-1993	RESIDENTIAL 1980-1981	RESIDENTIAL 1992-1993
Total suspended solids (mg/L)	251	165	226	325
Total nitrogen (mg/L)	3.0	3.9	3.2	4.7
Nitrate plus nitrite (mg/L)	0.80	1.4	0.61	0.92
Total phosphorus (mg/L)	0.46	0.34	0.61	0.87
Dissolved phosphorus (mg/L)	0.15	0.15	0.22	0.24
Copper, total recoverable (µg/L)	27	81	28	31
Lead, total recoverable (µg/L)	200	59	190	53
Zinc, total recoverable (µg/L)	220	290	180	180

Figure 17 shows a plot of lead concentrations for residential areas only (in EPA Rain Zone 2), for the time period from 1991 to 2002. This plot shows likely decreasing lead concentrations with time. Statistically however, the trend line is not significant due to the large variation in observed concentrations (p=0.41; there is insufficient data to show that the slope term is significantly different from zero). The similar COD concentrations in Figure 17 also have an apparent downward trend with time, but again, the slope term is not significant (p=0.12). Except for lead, it is not likely that time between the data collection efforts is the reason why the NURP and NSQD databases have different values.

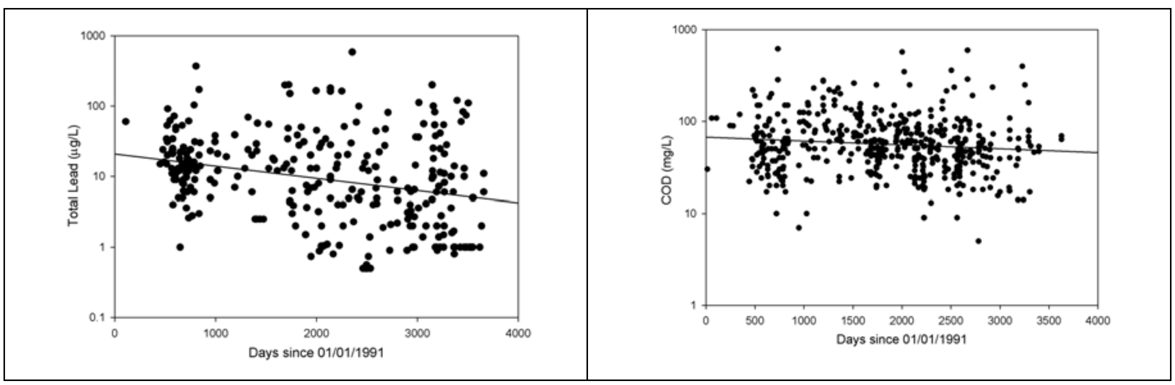

Figure 17. Residential lead and COD concentrations with time (EPA Rain Zone 2 data only)

3 Summary

Several factors were evaluated using data from the NSQD. Only residential, commercial and industrial land uses in EPA Rain Zone 2 and industrial areas in EPA Rain Zone 3 have enough numbers of samples to evaluate factors affecting stormwater concentrations. The effect of each factor cannot be extrapolated to the rest of the country, however they can be used as guidance for communities in other EPA Rain Zones. Additional data from communities that were not included in this first phase of the NSQD database would enable more complete and sensitive analyses. Also, this chapter examined most of these factors in isolation, more as sensitivity analyses and to help identify significant factors. These analyses did not consider factors together and possible interactions.

There is a significant reduction in TSS, nitrite-nitrate, total phosphorus, total copper, and total zinc concentration at sites having wet ponds, the control practice having the largest concentration reductions. No reductions in TKN concentrations were found using wet ponds, however TKN seems to be reduced by dry ponds. Locations with detention storage facilities had smaller reductions of TSS, BOD5, COD, total lead and total zinc concentrations. Unfortunately, there were few sites in the database having grass swales that could be compared with data from sites having curbs and gutters.

The use of automatic or manual sampling methods is a concern. There were statistical differences found between both methods in residential areas for several constituents. Most communities calculate their EMC values using flow-composited sample analyses. If first flush effects are present, manual sampling may likely miss these more concentrated flows due to delays in arriving at the site to initiate sampling. If the first flush is for a very short duration, time-composited samples may overly emphasize these higher flows. Flow compositing produces more accurate EMC values than time composite analyses. An automatic sampler with flow-weighted samples, in conjunction with a bed load sampler, is likely the most accurate sampling alternative.

There is a certain amount of redundancy (self-correlation) between land use and the percentage of impervious areas, as each land use category generally has a defined narrow range of paved and roof areas. Therefore, it is no possible to test the hypothesis that different levels of impervious (surface coverage) are more important than differences in land use (activities within the area). Residential land uses cover only the lower range of imperviousness, while commercial sites have imperviousness amounts larger than 50%. In order to perform a valid comparison test, the range of imperviousness needs to be similar for both test cases.

Antecedent dry periods were found to have a significant effect for residential land uses, at the six percent level of significance, for BOD5, COD, ammonia, nitrates, TKN, dissolved, and total phosphorus. As the number of days increased there was an increase in the concentrations of the stormwater constituents. This relationship was not observed for freeway sites. This may be associated with the very small drainage areas associated with the freeway sites (drainage areas close to 1 acre), while the drainage areas for residential, commercial and industrial areas ranged between 50 and 100 acres (Figure2.2).

No seasonal effects on concentrations were observed, except for bacteria levels that appear to be lower in winter and high in summer. No effects on concentration were observed according to precipitation depth. Rainfall energy determines erosion and washoff of particulates, but sufficient runoff volume is needed to carry the particulate pollutants to the outfalls. Different travel times from different locations in the drainage areas results in these materials arriving at different times, plus periods of high rainfall intensity occur randomly throughout the storm. The resulting outfall stormwater concentration patterns for a large area having various surfaces is therefore complex and rain depth is just one of the factors involved.

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MEMORANDUM

To: **Tom Dalziel**

From: Dan Cloak

Subject: **Design of Integrated Management Practices**
Vertical Position of Underdrains in Bioretention Facilities
Review and Interim Guidance

Date: 22 February 2011

Summary

The elevation of bioretention facility underdrains and exit points should be near the top of the gravel drainage layer except where:

- Infiltration is not allowable and is prevented with an impermeable liner or other impermeable construction, or
- Based on direct knowledge of site conditions, it is expected that the gravel drainage layer will not drain completely within approximately one week of a rain event due to very impermeable soils, bedrock, high groundwater, or similar conditions.

In these latter cases, the elevation of the underdrain pipe and exit point should be at the bottom of the drainage layer. (In flow-through planters, infiltration to native soils is prevented, and underdrain pipes and exit points should always be located at the bottom of the drainage layer.)

Background and Discussion

Design for Flow Control (Hydrograph Modification Management)

Bioretention facilities designed for runoff flow control as well as treatment are equipped with an orifice at the exit point of the underdrain pipe.

Flow-through planters designed for flow control are similarly equipped. Note flow-through planters may be used for flow control only on sites where native soils are Hydrologic Soil Group "C" or "D" and facilities are located on upper-story plazas, adjacent to building foundations, where mobilization of pollutants in soil or groundwater is a concern, and where potential geotechnical hazards are associated with infiltration.

Maximum discharge flow rates and orifice diameters are calculated according to equations provided in the *Stormwater C.3 Guidebook* or by using the IMP Sizing Calculator. The orifice diameter is designed to limit flow to the specified maximum discharge flow when the head of the orifice is one foot.

In the development of these equations, 30+ years of hourly rainfall data were used to continuously simulate inflow to a facility. Soil saturation and the filling and drainage of the underdrain layer were calculated for each hour of the simulation and the head above the orifice was used to calculate the discharge rate during that hour. This hourly discharge data was compiled and compared to hourly discharge data simulated from rainfall on an undeveloped site, and the design iterated until it could be shown that the facility controlled peak flows and durations for the given range of flows.

As part of the modeling, the effect of underdrain exit point elevation was also considered. With a higher exit point, more storage is initially available, and discharges are reduced. However, with closely spaced runoff events, the gravel layer does not drain completely. As a result, uncontrolled discharge through the overflow at the top of the surface storage layer becomes more frequent. A lower exit point ensures storage is available for subsequent events and uncontrolled discharges through the surface overflow are less frequent. Therefore the combined effects of raising or lowering the height of the exit point tend to offset each other, making the flow-control performance of the facility relatively insensitive to this design parameter.

Design to Maximize Infiltration Volume

Municipal Regional Permit Provision C.3.c. requires stormwater treatment facilities for Regulated Projects be designed to provide treatment of the specified volume or flow by infiltration, evapotranspiration, or harvesting and reuse. “Biotreatment” may be used if infiltration, evapotranspiration, and harvesting and reuse are infeasible. BASMAA is developing Infeasibility criteria and will propose those criteria to the Board by May 1, 2011.

Bioretention facilities are designed to facilitate infiltration and evapotranspiration to the extent feasible given conditions at the facility location.

Setting the underdrain and exit point near the top of the gravel layer will tend to maximize the amount of runoff that is captured and made to infiltrate into native soils rather than being discharged through the underdrain. Note that a design which captures a specified runoff volume beneath the underdrain exit height must infiltrate that volume within the corresponding period (typically 48 hours) to successfully meet the objective of infiltrating 80% of average annual runoff.

In balance, in both treatment and treatment-and-flow-control bioretention facilities, it makes sense to locate underdrains near the top of the gravel layer as long as native soils provide sufficient drainage so that the facility does not hold stagnant water for long periods of time. Many Contra Costa “Group D” soils will drain sufficiently fast, particularly if they are not compacted and if there are slopes or retaining walls nearby. However, designers should use their own judgment based on site-specific investigation. Observing soil moisture and surface conditions in the days following a wet period may be sufficient information for making this decision and—as drainage on disturbed urban sites is often anisotropic—such observations may be more directly applicable than *in situ* or laboratory testing of soil characteristics.

California Regional Water Quality Control Board
San Francisco Bay Region
Municipal Regional Stormwater NPDES Permit

ORDER NO. R2-2011-0083
NPDES PERMIT NO. CAS612008

AMENDMENT REVISING ORDER NO. R2-2009-0074 for the following jurisdictions and entities:

The cities of Alameda, Albany, Berkeley, Dublin, Emeryville, Fremont, Hayward, Livermore, Newark, Oakland, Piedmont, Pleasanton, San Leandro, and Union City, Alameda County, the Alameda County Flood Control and Water Conservation District, and Zone 7 of the Alameda County Flood Control and Water Conservation District, which have joined together to form the Alameda Countywide Clean Water Program (Alameda Permittees)

The cities of Clayton, Concord, El Cerrito, Hercules, Lafayette, Martinez, Orinda, Pinole, Pittsburg, Pleasant Hill, Richmond, San Pablo, San Ramon, and Walnut Creek, the towns of Danville and Moraga, Contra Costa County, the Contra Costa County Flood Control and Water Conservation District, which have joined together to form the Contra Costa Clean Water Program (Contra Costa Permittees)

The cities of Campbell, Cupertino, Los Altos, Milpitas, Monte Sereno, Mountain View, Palo Alto, San Jose, Santa Clara, Saratoga, and Sunnyvale, the towns of Los Altos Hills and Los Gatos, the Santa Clara Valley Water District, and Santa Clara County, which have joined together to form the Santa Clara Valley Urban Runoff Pollution Prevention Program (Santa Clara Permittees)

The cities of Belmont, Brisbane, Burlingame, Daly City, East Palo Alto, Foster City, Half Moon Bay, Menlo Park, Millbrae, Pacifica, Redwood City, San Bruno, San Carlos, San Mateo, and South San Francisco, the towns of Atherton, Colma, Hillsborough, Portola Valley, and Woodside, the San Mateo County Flood Control District, and San Mateo County, which have joined together to form the San Mateo Countywide Water Pollution Prevention Program (San Mateo Permittees)

The cities of Fairfield and Suisun City, which have joined together to form the Fairfield-Suisun Urban Runoff Management Program (Fairfield-Suisun Permittees)

The City of Vallejo and the Vallejo Sanitation and Flood Control District (Vallejo Permittees)

The California Regional Water Quality Control Board, San Francisco Bay Region, (hereinafter referred to as the Water Board) finds that:

Findings:

1. On October 14, 2009, the Water Board adopted Order No. R2-2009-0074, NPDES No. CAS612008, prescribing Waste Discharge Requirements under the San Francisco Bay Municipal Regional Stormwater Permit for the discharge of stormwater runoff from the municipal separate storm sewer systems (MS4s) of the named Permittees.
2. Provision C.3.b. of Order No. R2-2009-0074 establishes the scope of development projects that must implement post-construction stormwater treatment and defines them as Regulated Projects.
3. Provision C.3.c. of Order No. R2-2009-0074 requires Permittees to implement Low Impact Development (LID) requirements by December 1, 2011. Under Provision C.3.c., Permittees must require all Regulated Projects to implement source control and site design measures and to treat 100% of the amount of runoff identified in Provision C.3.d. for the Regulated Project's drainage area with LID treatment measures onsite or at a joint stormwater treatment facility.
4. Provision C.3.e.ii.(1) of Order No. R2-2009-0074 acknowledges that certain types of smart growth, high density, and transit-oriented development can either reduce existing impervious surfaces, or create less "accessory" impervious areas and auto-related pollutant impacts. This Provision further states that incentive LID Treatment Reduction Credits approved by the Water Board may be applied to these types of Regulated Projects that are considered "Special Projects."
5. Provision C.3.e.ii.(2) of Order No. R2-2009-0074 requires the Permittees to submit a proposal by December 1, 2010, to the Water Board identifying the types of projects proposed as Special Projects and therefore eligible for LID Treatment Reduction Credit. The proposal was required to include specific criteria for each type of Special Project proposed, including size, location, minimum densities, minimum floor area ratios, other appropriate limitations, and the proposed LID Treatment Reduction Credit.
6. On December 1, 2010, the Bay Area Stormwater Management Agencies Association (BASMAA) submitted a Special Projects proposal on behalf of the Permittees, which defined the types of Special Project Categories and their corresponding LID Treatment Reduction Credits.
7. BASMAA's stormwater proposal was posted on the Water Board's website and circulated for public comment on December 10, 2010. Comments on the proposal were received from USEPA, NRDC, San Francisco Baykeeper, the Building Industry Association, other building industry groups, and developers.
8. Water Board staff has met on a regular basis with representatives of BASMAA and within these negotiations, revisions of the December 10, 2010, proposal have been made and considered. Representatives of USEPA, the Metropolitan Transportation Commission (MTC) and the Association of Bay Area Governments (ABAG) have participated in some of these meetings. Water Board staff has also met separately with representatives of NRDC and San Francisco Baykeeper.

9. This Order amends Order No. R2-2009-0074 to add criteria for determining which types of Regulated Projects may be considered Special Projects. This Order establishes different categories of Special Projects based on size, land use type, and density.

10. For each category of Special Projects, this Order establishes corresponding LID Treatment Reduction Credits that may be used to reduce the amount of stormwater runoff that must be treated with LID stormwater treatment systems.

11. This Order requires that when LID Treatment Reduction Credits are applied, the percentage of stormwater runoff not treated by LID treatment systems to be treated with specific non-LID treatment systems.

12. Provisions C.3.c.i.(2)(vi) and C.3.c.iii.(3) of Order No. R2-2009-0074 require Permittees to submit to the Water Board by May 1, 2011, a proposed set of model biotreatment soil media specifications and soil infiltration testing methods to verify a long-term infiltration rate of 5 to 10 inches/hour.

13. The Permittees submitted a proposal for the soil media specifications and soil infiltration testing methods on December 1, 2010, which was distributed for public comment on December 15, 2010. Comments were received on January 28, 2011, from Roger James of Resources Management and from the Natural Resources Defense Council.

14. Provisions C.3.c.i.(2)(vii) C.3.c.iii.(4) of Order No. R2-2009-0074 require Permittees to submit to the Water Board by December 1, 2011, proposed minimum specifications for green roofs to be considered biotreatment systems.

15. The Permittees submitted a proposal for the minimum green roof specifications on April 29, 2011, which was distributed for public comment on May 4, 2011. No comments were received.

16. This Order approves the model biotreatment soil media specifications, soil infiltration testing methods, and minimum green roof specifications submitted by the Permittees.

17. Provision C.3.g.ii.(5) of Order No. R2-2009-0074 requires the Santa Clara Permittees to comply with all the requirements in Attachment F of the same Order. Requirement 4. of Attachment F (pages F-3 and F-4 of Order No. R2-2009-0074) defines geographical areas where applicable Regulated Projects are required to meet the HM Standard and associated requirements. These areas of HM applicability described in Requirement 4. are shown in the Santa Clara Permittees' HM Map available at http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/muni/mrp/Final%20TO%20HM%20Maps.pdf).

18. Requirement 4.c. of Attachment F states that Pink areas on the HM Map are under review by the Permittees for accuracy of the imperviousness data. The HM Standard and associated requirements apply to projects in areas designated as pink on the map until such time as a Permittee presents new data that indicates that the actual level of imperviousness of a particular area is greater than or equal to 65% impervious. Any new data is to be submitted to the Water Board in one coordinated submittal within one year of permit adoption.

19. The Santa Clara Permittees submitted new impervious data and a revised HM Map that reflects the new data to the Water Board on October 14, 2010. On March 11, 2011, the Santa Clara Permittees submitted a revised HM Map to correct a small error in the October 2010 HM Map, and to provide additional information per Water Board staff request. The revised HM Map shows that in the majority of the Pink area of the original, approved, Santa Clara Permittees' HM

RB-AR33933

Map, the HM Standard and associated requirements do apply. In the revised HM Map, these areas are now shown in green to represent the applicability of the HM Standard and associated requirements. The remaining small portion of the Pink area in the original HM Map is now shown in red to represent areas where the HM Standard and associated requirements do not apply.

20. This Order approves the revised Santa Clara Permittees' HM Map and replaces the HM Map originally adopted by Order No. R2-2009-0074.
21. The Fact Sheet attached to this Order as Appendix III contains background information and rationale for this Order’s requirements. It is hereby incorporated into this Order and therefore constitutes part of the findings for this Order
22. This Order is exempt from the provisions of the California Environmental Quality Act pursuant to California Water Code Section 13389
23. The Water Board notified the Permittees named in this Order and interested agencies and persons of its intent to consider adoption of this Order, and provided an opportunity to submit written comments.
24. In a public meeting, the Water Board heard and considered all comments pertaining to this Order.

IT IS HEREBY ORDERED, pursuant to the provisions of California Water Code Division 7 and regulations adopted thereunder, and the provisions of the federal Clean Water Act and regulations and guidelines adopted thereunder, that the Permittees shall comply with the following:

1. Provision C.3. and Attachment F of Order No. R2-2009-0074, are hereby modified and amended as shown in Appendix I. Additions to Provision C.3. and Attachment F are displayed as underlined type and deletions of text are displayed as ~~strikeout~~ format.
2. Attachments L and M as shown in Appendix II are hereby added to Order No. R2-2009-0074.
3. This Order shall become effective on December 1, 2011.

I, Bruce H. Wolfe, Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of an Order adopted by the California Regional Water Quality Control Board, San Francisco Bay Region, on November 28, 2011.

Digitally signed by Bruce Wolfe
Date: 2011.11.30 13:53:13 -08'00'

Bruce H. Wolfe
Executive Officer

Appendix I: Revisions to Provision C.3. and Attachment F of Order No. R2-2009-0074
Appendix II: Attachments L and M to be added to Order No. R2-2009-0074
Appendix III: Fact Sheet

RB-AR33934

APPENDIX I

Revisions to Provision C.3. and Attachment F
of
Water Board Order No. R2-2009-0074

November 28, 2011

C.3. New Development and Redevelopment

C.3.c. Low Impact Development (LID)

The goal of LID is to reduce runoff and mimic a site's predevelopment hydrology by minimizing disturbed areas and impervious cover and then infiltrating, storing, detaining, evapotranspiring, and/or biotreating stormwater runoff close to its source. LID employs principles such as preserving and recreating natural landscape features and minimizing imperviousness to create functional and appealing site drainage that treats stormwater as a resource, rather than a waste product. Practices used to adhere to these LID principles include measures such as rain barrels and cisterns, green roofs, permeable pavement, preserving undeveloped open space, and biotreatment through rain gardens, bioretention units, bioswales, and planter/tree boxes.

Task Description

i. The Permittees shall, at a minimum, implement the following LID requirements:

(1) **Source Control Requirements**
Require all Regulated Projects to implement source control measures onsite that at a minimum, shall include the following:

(a) Minimization of stormwater pollutants of concern in urban runoff through measures that may include plumbing of the following discharges to the sanitary sewer, subject to the local sanitary sewer agency's authority and standards:
- Discharges from indoor floor mat/equipment/hood filter wash racks or covered outdoor wash racks for restaurants;
- Dumpster drips from covered trash, food waste and compactor enclosures;
- Discharges from covered outdoor wash areas for vehicles, equipment, and accessories;
- Swimming pool water, if discharge to onsite vegetated areas is not a feasible option; and
- Fire sprinkler test water, if discharge to onsite vegetated areas is not a feasible option;

(b) Properly designed covers, drains, and storage precautions for outdoor material storage areas, loading docks, repair/maintenance bays, and fueling areas;

(c) Properly designed trash storage areas;

(d) Landscaping that minimizes irrigation and runoff, promotes surface infiltration, minimizes the use of pesticides and fertilizers, and incorporates other appropriate sustainable landscaping practices and programs such as Bay-Friendly Landscaping;

(e) Efficient irrigation systems; and

(f) Storm drain system stenciling or signage.

(2) **Site Design and Stormwater Treatment Requirements**

(a) Require each Regulated Project to implement at least the following design strategies onsite:

(i) Limit disturbance of natural water bodies and drainage systems; minimize compaction of highly permeable soils; protect slopes and channels; and minimize impacts from stormwater and urban runoff on the biological integrity of natural drainage systems and water bodies;

(ii) Conserve natural areas, including existing trees, other vegetation, and soils;

(iii) Minimize impervious surfaces;

(iv) Minimize disturbances to natural drainages; and

(v) Minimize stormwater runoff by implementing one or more of the following site design measures:

- Direct roof runoff into cisterns or rain barrels for reuse.
- Direct roof runoff onto vegetated areas.
- Direct runoff from sidewalks, walkways, and/or patios onto vegetated areas.
- Direct runoff from driveways and/or uncovered parking lots onto vegetated areas.
- Construct sidewalks, walkways, and/or patios with permeable surfaces.[3]
- Construct driveways, bike lanes, and/or uncovered parking lots with permeable surfaces.[3]

(b) Require each Regulated Project to treat 100% of the amount of runoff identified in Provision C.3.d for the Regulated Project's drainage area with LID treatment measures onsite or with LID treatment measures at a joint stormwater treatment facility.

(i) LID treatment measures are harvesting and re-use, infiltration, evapotranspiration, or biotreatment.

(ii) A properly engineered and maintained biotreatment system may be considered only if it is infeasible to implement harvesting and re-use, infiltration, or evapotranspiration at a project site.

(iii) Infeasibility to implement harvesting and re-use, infiltration, or evapotranspiration at a project site may result from conditions including the following:

- Locations where seasonal high groundwater would be within 10 feet of the base of the LID treatment measure.
- Locations within 100 feet of a groundwater well used for drinking water.

- Development sites where pollutant mobilization in the soil or groundwater is a documented concern.
- Locations with potential geotechnical hazards.
- Smart growth and infill or redevelopment sites where the density and/or nature of the project would create significant difficulty for compliance with the onsite volume retention requirement.
- Locations with tight clay soils that significantly limit the infiltration of stormwater.

(iv) By May 1, 2011, the Permittees, collaboratively or individually, shall submit a report on the criteria and procedures the Permittees shall employ to determine when harvesting and re-use, infiltration, or evapotranspiration is feasible and infeasible at a Regulated Project site. This report shall, at a minimum, contain the information required in Provision C.3.c.iii.(1).

(v) By December 1, 2013, the Permittees, collaboratively or individually, shall submit a report on their experience with determining infeasibility of harvesting and re-use, infiltration, or evapotranspiration at Regulated Project sites. This report shall, at a minimum, contain the information required in Provision C.3.iii.(2).

(vi) Biotreatment (or bioretention) systems shall be designed to have a surface area no smaller than what is required to accommodate a 5 inches/hour stormwater runoff surface loading rate, and infiltrate runoff at a minimum of 5 inches per hour during the life of the facility. The ~~planting and~~ soil media for biotreatment (or bioretention) systems shall be designed to sustain healthy, vigorous plant growth and maximize stormwater runoff retention and pollutant removal. Permittees shall ensure that Regulated Projects use biotreatment soil media that meet the minimum specifications set forth in Attachment L.

~~By December 1, 2010, the Permittees, working collaboratively or individually, shall submit for Water Board approval, a proposed set of model biotreatment soil media specifications and soil infiltration testing methods to verify a long-term infiltration rate of 5 to 10 inches/hour. This submittal to the Water Board shall, at a minimum, contain the information required in Provision C.3.c.iii.(3). Once the Water Board approves biotreatment soil media specifications and soil infiltration testing methods, the Permittees shall ensure that biotreatment systems installed to meet the requirements of Provision C.3.c and d comply with the Water Board-approved minimum specifications and soil infiltration testing methods.~~

(vii) Green roofs may be considered biotreatment systems that treat roof runoff only if they meet certain minimum specifications. ~~By May 1, 2011, the Permittees shall submit for Water Board~~

~~approval, proposed minimum specifications for green roofs. This submittal to the Water Board shall, at a minimum, contain the information required in Provision C.3.c.iii.(4). Once the Water Board approves green roof minimum specifications, the~~ Permittees shall ensure that green roofs installed at Regulated Projects ~~to~~ meet the following ~~requirements of Provision C.3.c and d comply with the Water Board-approved~~minimum specifications~~.~~:

- The green roof system planting media shall be sufficiently deep to provide capacity within the pore space of the media for the required runoff volume specified by Provision C.3.d.i.(1).
- The green roof system planting media shall be sufficiently deep to support the long term health of the vegetation selected for the green roof, as specified by a landscape architect or other knowledgeable professional.

(c) Require any Regulated Project that does not comply with Provision C.3.c.i.(2)(b) above to meet the requirements established in Provision C.3.e for alternative compliance.

ii. Implementation Level – All elements of the tasks described in Provision C.3.c.i shall be fully implemented.

Due Date for Full Implementation – December 1, 2011

(1) For any private development project for which a planning application has been deemed complete by a Permittee on or before the Permit effective date, Provision C.3.c.i shall not apply so long as the project applicant is diligently pursuing the project. Diligent pursuance may be demonstrated by the project applicant's submittal of supplemental information to the original application, plans, or other documents required for any necessary approvals of the project by the Permittee. If during the time period between the Permit effective date and the required implementation date of December 1, 2011, the project applicant has not taken any action to obtain the necessary approvals from the Permittee, the project will then be subject to the requirements of Provision C.3.c.i.

(2) For any private development project with an application deemed complete after the Permit effective date, the requirements of Provision C.3.c.i shall not apply if the project applicant has received final discretionary approval for the project before the required implementation date of December 1, 2011.

(3) For public projects for which funding has been committed and construction is scheduled to begin by December 1, 2012, the requirements of Provision C.3.c.i shall not apply.

iii. Reporting

(1) Feasibility/Infeasibility Criteria Report - By May 1, 2011, the Permittees, collaboratively or individually, shall submit a report to the Water Board containing the following information:

- Literature review and discussion of documented cases/sites, particularly in the Bay Area and California, where infiltration, harvesting and reuse, or evapotranspiration have been demonstrated to be feasible and/or infeasible.
- Discussion of proposed feasibility and infeasibility criteria and procedures the Permittees shall employ to make a determination of when biotreatment will be allowed at a Regulated Project site.

(2) Status Report on Application of Feasibility/Infeasibility Criteria – By December 1, 2013, the Permittees shall submit a report to the Water Board containing the following information:

- Discussion of the most common feasibility and infeasibility criteria employed since implementation of Provision C.3.c requirements, including site-specific examples;
- Discussion of barriers, including institutional and technical site specific constraints, to implementation of harvesting and reuse, infiltration, or evapotranspiration, and proposed strategies for removing these identified barriers;
- If applicable, discussion of proposed changes to feasibility and infeasibility criteria and rationale for the changes; and
- Guidance for the Permittees to make a consistent and appropriate determination of the feasibility of harvesting and reuse, infiltration, or evapotranspiration for each Regulated Project.

~~(3) Model Biotreatment Soil Media Specifications - By December 1, 2010, the Permittees, collaboratively or individually, shall submit a report to the Water Board containing the following information:~~

- ~~Proposed soil media specifications for biotreatment systems;~~
- ~~Proposed soil testing methods to verify a long-term infiltration rate of 5-10 inches/hour;~~
- ~~Relevant literature and field data showing the feasibility of the minimum design specifications;~~
- ~~Relevant literature, field, and analytical data showing adequate pollutant removal and compliance with the Provision C.3.d hydraulic sizing criteria; and~~
- ~~Guidance for the Permittees to apply the minimum specifications in a consistent and appropriate manner.~~

~~(4) Green Roof Minimum Specifications - By May 1, 2011, the Permittees, collaboratively or individually, shall submit a report to the Water Board containing the following information:~~

- ~~Proposed minimum design specifications for green roofs;~~

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- ~~Relevant literature and field data showing the feasibility of the minimum design specifications;~~
- ~~Relevant literature, field, and analytical data showing adequate pollutant removal and compliance with the Provision C.3.d hydraulic sizing criteria;~~
- ~~Discussion of data and lessons learned from already installed green roofs;~~
- ~~Discussion of barriers, including institutional and technical site specific constraints, to installation of green roofs and proposed strategies for removing these identified barriers; and~~
- ~~Guidance for the Permittees to apply the minimum specifications in a consistent and appropriate manner.~~

(3) Report the method(s) of implementation of Provisions C.3.c.i above in the 2012 Annual Report. For specific tasks listed above that are reported using the reporting tables required for Provision C.3.b.v, a reference to those tables will suffice.

C.3.d. Numeric Sizing Criteria for Stormwater Treatment Systems

i. Task Description – The Permittees shall require that stormwater treatment systems constructed for Regulated Projects meet at least one of the following hydraulic sizing design criteria:

(1) **Volume Hydraulic Design Basis –** Treatment systems whose primary mode of action depends on volume capacity shall be designed to treat stormwater runoff equal to:

(a) The maximized stormwater capture volume for the area, on the basis of historical rainfall records, determined using the formula and volume capture coefficients set forth in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998), pages 175–178 (e.g., approximately the 85th percentile 24-hour storm runoff event); or

(b) The volume of annual runoff required to achieve 80 percent or more capture, determined in accordance with the methodology set forth in Section 5 of the California Stormwater Quality Association's Stormwater Best Management Practice Handbook, New Development and Redevelopment (2003), using local rainfall data.

(2) **Flow Hydraulic Design Basis –** Treatment systems whose primary mode of action depends on flow capacity shall be sized to treat:

(a) 10 percent of the 50-year peak flowrate;

(b) The flow of runoff produced by a rain event equal to at least two times the 85th percentile hourly rainfall intensity for the applicable area, based on historical records of hourly rainfall depths; or

(c) The flow of runoff resulting from a rain event equal to at least 0.2 inches per hour intensity.

(3) **Combination Flow and Volume Design Basis –** Treatment systems that use a combination of flow and volume capacity shall be sized to treat at least 80 percent of the total runoff over the life of the project, using local rainfall data.

ii. Implementation Level – The Permittees shall immediately require the controls in this task.

Due Date for Full Implementation – Immediate, except December 1, 2010, for Vallejo Permittees.

iii. Reporting – Permittees shall use the reporting tables required in Provision C.3.b.v.

iv. Limitations on Use of Infiltration Devices in Stormwater Treatment Systems

(1) For Regulated Projects, each Permittee shall review planned land use and proposed treatment design to verify that installed stormwater treatment systems with no under-drain, and that function primarily as infiltration devices, should not cause or contribute to the degradation of groundwater quality at project sites. An infiltration device is any structure that is deeper than wide and designed to infiltrate stormwater into the subsurface and, as designed, bypass the natural groundwater protection afforded by surface soil. Infiltration devices include dry wells, injection wells, and infiltration trenches (includes french drains).

(2) For any Regulated Project that includes plans to install stormwater treatment systems which function primarily as infiltration devices, the Permittee shall require that:

(a) Appropriate pollution prevention and source control measures are implemented to protect groundwater at the project site, including the inclusion of a minimum of two feet of suitable soil to achieve a maximum 5 inches/hour infiltration rate for the infiltration system;

(b) Adequate maintenance is provided to maximize pollutant removal capabilities;

(c) The vertical distance from the base of any infiltration device to the seasonal high groundwater mark is at least 10 feet. (Note that some locations within the Permittees' jurisdictions are characterized by highly porous soils and/or high groundwater tables. In these areas, a greater vertical distance from the base of the infiltration device to the seasonal high groundwater mark may be appropriate, and treatment system approvals should be subject to a higher level of analysis that considers the potential for pollutants (such as from onsite chemical use), the level of pretreatment to be achieved, and other similar factors in the overall analysis of groundwater safety);

(d) Unless stormwater is first treated by a method other than infiltration, infiltration devices are not approved as treatment measures for runoff from areas of industrial or light industrial activity; areas subject to high vehicular traffic (i.e., 25,000 or greater average daily traffic on a main roadway or 15,000 or more average daily traffic on any intersecting roadway); automotive repair shops; car washes; fleet storage areas (e.g., bus, truck); nurseries; and other land uses that pose a high threat to water quality;

(e) Infiltration devices are not placed in the vicinity of known contamination sites unless it has been demonstrated that increased infiltration will not increase leaching of contaminants from soil, alter groundwater flow conditions affecting contaminant migration in groundwater, or adversely affect remedial activities; and

(f) Infiltration devices are located a minimum of 100 feet horizontally away from any known water supply wells, septic systems, and underground storage tanks with hazardous materials. (Note that some locations within the Permittees' jurisdictions are characterized by highly porous soils and/or high groundwater tables. In these areas, a greater horizontal distance from the infiltration device to known water supply wells, septic systems, or underground storage tanks with hazardous materials may be appropriate, and treatment system approvals should be subject to a higher level of analysis that considers the potential for pollutants (such as from onsite chemical use), the level of pretreatment to be achieved, and other similar factors in the overall analysis of groundwater safety).

C.3.e. Alternative or In-Lieu Compliance with Provision C.3.c.

i. The Permittees may allow a Regulated Project to provide alternative compliance with Provision C.3.c in accordance with one of the two options listed below:

(1) **Option 1: LID Treatment at an Offsite Location**
Treat a portion of the amount of runoff identified in Provision C.3.d for the Regulated Project's drainage area with LID treatment measures onsite or with LID treatment measures at a joint stormwater treatment facility **and** treat the remaining portion of the Provision C.3.d runoff with LID treatment measures at an offsite project in the same watershed. The offsite LID treatment measures must provide hydraulically-sized treatment (in accordance with Provision C.3.d) of an equivalent quantity of both stormwater runoff and pollutant loading and achieve a net environmental benefit.

(2) **Option 2: Payment of In-Lieu Fees**
Treat a portion of the amount of runoff identified in Provision C.3.d for the Regulated Project's drainage area with LID treatment measures onsite or with LID treatment measures at a joint stormwater treatment facility **and** pay equivalent in-lieu fees[5] to treat the remaining portion of the Provision

[5] **In-lieu fees** – Monetary amount necessary to provide both hydraulically-sized treatment (in accordance with Provision C.3.d) with LID treatment measures of an equivalent quantity of stormwater runoff and pollutant loading, and a proportional share of the operation and maintenance costs of the Regional Project.

C.3.d runoff with LID treatment measures at a Regional Project.[6] The Regional Project must achieve a net environmental benefit.

(3) For the alternative compliance options described in Provision C.3.e.i.(1) and (2) above, offsite projects must be constructed by the end of construction of the Regulated Project. If more time is needed to construct the offsite project, for each additional year, up to three years, after the construction of the Regulated Project, the offsite project must provide an additional 10% of the calculated equivalent quantity of both stormwater runoff and pollutant loading. Regional Projects must be completed within three years after the end of construction of the Regulated Project. However, the timeline for completion of the Regional Project may be extended, up to five years after the completion of the Regulated Project, with prior Executive Officer approval. Executive Officer approval will be granted contingent upon a demonstration of good faith efforts to implement the Regional Project, such as having funds encumbered and applying for the appropriate regulatory permits.

ii. Special Projects

(1) When considered at the watershed scale, certain land development projects characterized as ~~types of~~ smart growth, high density, ~~and~~ or transit-oriented development can either reduce existing impervious surfaces, or create less "accessory" impervious areas and automobile-related pollutant impacts. Incentive LID T~~t~~reatment R~~r~~eduction C~~c~~redits approved by the Water Board may be applied to these ~~types of~~ Special Projects, which are Regulated Projects that meet the specific criteria listed below in Provisions C.3.e.ii.(2),(3)&(4). For any Special Project, the allowable incentive LID Treatment Reduction Credit is the maximum percentage of the amount of runoff identified in Provision C.3.d. for the Special Project's drainage area, that may be treated with one or a combination of the following two types of non-LID treatment systems:

- Tree-box-type high flowrate biofilters
- Vault-based high flowrate media filters

The allowed LID Treatment Reduction Credit recognizes that density and space limitations for the Special Projects identified herein may make 100% LID treatment infeasible. Under Provision C.3.e.vi, each Permittee is required to report on the infeasibility of LID treatment for each of the Special Projects for which LID Treatment Reduction Credit was applied.

(2) Category A Special Project Criteria

(a) To be considered a Category A Special Project, a Regulated Project must meet all of the following criteria:

[6] **Regional Project –** A regional or municipal stormwater treatment facility that discharges into the same watershed that the Regulated Project does.

(i) Be built as part of a Permittee's stated objective to preserve or enhance a pedestrian-oriented type of urban design.

(ii) Be located in a Permittee's designated central business district, downtown core area or downtown core zoning district, neighborhood business district or comparable pedestrian-oriented commercial district, or historic preservation site and/or district.

(iii) Create and/or replace one half acre or less of impervious surface area.

(iv) Include no surface parking, except for incidental surface parking. Incidental surface parking is allowed only for emergency vehicle access, Americans with Disabilities Act (ADA) accessibility, and passenger and freight loading zones.

(v) Have at least 85% coverage for the entire project site by permanent structures. The remaining 15% portion of the site is to be used for safety access, parking structure entrances, trash and recycling service, utility access, pedestrian connections, public uses, landscaping, and stormwater treatment.

(b) Any Category A Special Project may qualify for 100% LID Treatment Reduction Credit, which would allow the Category A Special Project to treat up to 100% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.

(3) Category B Special Project Criteria

(a) To be considered a Category B Special Project, a Regulated Project must meet all of the following criteria:

(i) Be built as part of a Permittee's stated objective to preserve or enhance a pedestrian-oriented type of urban design.

(ii) Be located in a Permittee's designated central business district, downtown core area or downtown core zoning district, neighborhood business district or comparable pedestrian-oriented commercial district, or historic preservation site and/or district.

(iii) Create and/or replace greater than one-half acre but no more than 2 acres of impervious surface area.

(iv) Include no surface parking, except for incidental surface parking. Incidental surface parking is allowed only for emergency vehicle access, ADA accessibility, and passenger and freight loading zones.

(v) Have at least 85% coverage for the entire project site by permanent structures. The remaining 15% portion of the site is to be used for safety access, parking structure entrances, trash and recycling service, utility access, pedestrian connections, public uses, landscaping, and stormwater treatment.

(b) For any Category B Special Project, the maximum LID Treatment Reduction Credit allowed is determined based on the density achieved by the Project in accordance with the criteria listed below. Density is expressed in Floor Area Ratios (FARs) for commercial and mixed-use development projects and in Dwelling Units per Acre (DU/Ac) for residential development projects.

(i) 50% Maximum LID Treatment Reduction Credit

- For any commercial or mixed use Category B Special Project with a FAR of at least 2:1, up to 50% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.
- For any residential Category B Special Project with a density of at least 50 DU/Ac, up to 50% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.

(ii) 75% Maximum LID Treatment Reduction Credit

- For any commercial or mixed use Category B Special Project with a FAR of at least 3:1, up to 75% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.
- For any residential Category B Special Project with a density of at least 75 DU/Ac, up to 75% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.

(iii) 100% Maximum LID Treatment Reduction Credit

- For any commercial or mixed use Category B Special Project with a FAR of at least 4:1, up to 100% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.
- For any residential Category B Special Project with a density of at least 100 DU/Ac, up to 100% of the amount of runoff identified in Provision C.3.d. for the Project's drainage area may be treated with either one or a combination of the two types of non-LID treatment systems listed in Provision C.3.e.ii.(1) above.

(4) Category C Special Project Criteria (Transit-Oriented Development)

(a) Transit-Oriented Development refers to the clustering of homes, jobs, shops and services in close proximity to rail stations, ferry terminals or bus stops offering access to frequent, high-quality transit services. This pattern typically involves compact development and a mixing of different land uses, along with amenities like pedestrian-friendly streets. To be considered a Category C Special Project, a Regulated Project must meet all of the following criteria:

(i) Be characterized as a non auto-related land use project. That is, Category C specifically excludes any Regulated Project that is a stand-alone surface parking lot; car dealership; auto and truck rental facility with onsite surface storage; fast-food restaurant, bank or pharmacy with drive-through lanes; gas station, car wash, auto repair and service facility; or other auto-related project unrelated to the concept of Transit-Oriented Development.

(ii) If a commercial or mixed-use development project, achieve at least an FAR of 2:1.

(iii) If a residential development project, achieve at least a density of 25 DU/Ac.

(b) For any Category C Special Project, the total maximum LID Treatment Reduction Credit allowed is the sum of three different types of credits that the Category C Special Project may qualify for, namely: Location, Density and Minimized Surface Parking Credits.

(c) Location Credits

(i) A Category C Special Project may qualify for the following Location Credits:

- 50% Location Credit: Located within a ¼ mile radius of an existing or planned transit hub.
- 25% Location Credit: Located within a ½ mile radius of an existing or planned transit hub.
- 25% Location Credit: Located within a planned Priority Development Area (PDA), which is an infill development area formally designated by the Association of Bay Area Government's / Metropolitan Transportation Commission's FOCUS regional planning program. FOCUS is a regional incentive-based development and conservation strategy for the San Francisco Bay Area.

(ii) Only one Location Credit may be used by an individual Category C Special Project, even if the project qualifies for multiple Location Credits.

(iii) At least 50% or more of a Category C Special Project's site must be located within the ¼ or ½ mile radius of an existing or planned transit hub to qualify for the corresponding Location Credits listed above. One hundred percent of a Category C Special Project's site must be located within a PDA to qualify for the corresponding Location Credit listed above.

(iv) Transit hub is defined as a rail, light rail, or commuter rail station, ferry terminal, or bus transfer station served by three or more bus routes (i.e., a bus stop with no supporting services does not qualify). A planned transit hub is a station on the MTC's Regional Transit Expansion Program list, per MTC's Resolution 3434 (revised April 2006), which is a regional priority funding plan for future transit stations in the San Francisco Bay Area.

(d) Density Credits: To qualify for any Density Credits, a Category C Special Project must first qualify for one of the Location Credits listed in Provision C.3.e.ii.((4)(c) above.

(i) A Category C Special Project that is a commercial or mixed-use development project may qualify for the following Density Credits:

- 10% Density Credit: Achieve an FAR of at least 2:1.
- 20% Density Credit: Achieve an FAR of at least 4:1.
- 30% Density Credit: Achieve an FAR of at least 6:1.

(ii) A Category C Special Project that is a residential development project may qualify for the following Density Credits:

- 10% Density Credit: Achieve a density of at least 30 DU/Ac.
- 20% Density Credit: Achieve a density of at least 60 DU/Ac.
- 30% Density Credit: Achieve a density of at least 100 DU/Ac.

(iii) Commercial and mixed-use Category C Projects do not qualify for Density Credits based on DU/Ac and residential Category C Projects do not qualify for Density Credits based on FAR.

(iv) Only one Density Credit may be used by an individual Category C Special Project, even if the project qualifies for multiple Density Credits.

(e) Minimized Surface Parking Credits: To qualify for any Minimized Surface Parking Credits, a Category C Special Project must first qualify for one of the Location Credits listed in Provision C.3.e.ii.(4)(c) above.

(i) A Category C Special Project may qualify for the following Minimized Surface Parking Credits:

- 10% Minimized Surface Parking Credit: Have 10% or less of the total post-project impervious surface area dedicated to at-grade surface parking. The at-grade surface parking must be treated with LID treatment measures.
- 20% Minimized Surface Parking Credit: Have no surface parking except for incidental surface parking. Incidental surface parking is allowed only for emergency vehicle access, ADA accessibility, and passenger and freight loading zones.

(ii) Only one Minimized Surface Parking Credit may be used by an individual Category C Special Project, even if the project qualifies for multiple Minimized Surface Parking Credits.

(5) Any Regulated Project that meets all the criteria for multiple Special Projects Categories (i.e., a Regulated Project that may be characterized as a Category B or C Special Project) may only use the LID Treatment Reduction Credit allowed under one of the Special Projects Categories (i.e., a Regulated Project that may be characterized as a Category B or C Special Project may use the LID Treatment Reduction Credit allowed under Category B or Category C, but not the sum of both.)

~~(2) By December 1, 2010, the Permittees shall submit a proposal to the Water Board containing the following information:~~

- ~~Identification of the types of projects proposed for consideration of LID treatment reduction credits and an estimate of the number and cumulative area of potential projects during the remaining term of this Permit for each type of project;~~
- ~~Identification of institutional barriers and/or technical site-specific constraints to providing 100% LID treatment onsite that justify the allowance for non-LID treatment measures onsite;~~
- ~~Specific criteria for each type of Special Project proposed, including size, location, minimum densities, minimum floor area ratios, or other appropriate limitations;~~
- ~~Identification of specific water quality and environmental benefits provided by these types of projects that justify the allowance for non-LID treatment measures onsite;~~
- ~~Proposed LID treatment reduction credit for each type of Special Project and justification for the proposed credits. The justification shall include identification and an estimate of the specific water quality benefit provided by each type of Special Project proposed for LID treatment reduction credit; and~~
- ~~Proposed total treatment reduction credit for Special Projects that may be characterized by more than one category and justification for the proposed total credit.~~

iii. Effective Date – December 1, 2011.

iv. Implementation Level

(1) For any private development project for which a planning application has been deemed complete by a Permittee on or before the Permit effective date, Provisions C.3.e.i-ii shall not apply so long as the project applicant is diligently pursuing the project. Diligent pursuance may be demonstrated by the project applicant's submittal of supplemental information to the original application, plans, or other documents required for any necessary approvals of the project by the Permittee. If during the time period between the Permit effective date and the required implementation date of December 1, 2011, the project applicant has not taken any action to obtain

the necessary approvals from the Permittee, the project will then be subject to the requirements of Provision C.3.e.i-ii.

(2) For public projects for which funding has been committed and construction is scheduled to begin by December 1, 2012, the requirements of Provisions C.3.e.i-ii shall not apply.

(3) Provisions C.3.e.i-ii supersede any Alternative Compliance Policies previously approved by the Executive Officer

(4) For all offsite projects and Regional Projects installed in accordance with Provision C.3.e.i-ii, the Permittees shall meet the Operation & Maintenance (O&M) requirements of Provision C.3.h.

v. Reporting –The Permittees shall submit the ordinance/legal authority and procedural changes made, if any, to implement Provision C.3.e with their 2012 Annual Report. Annual reporting thereafter shall be done in conjunction with reporting requirements under Provision C.3.b.v.

Any Permittee choosing to require 100% LID treatment onsite for all Regulated Projects and not allow alternative compliance under Provision C.3.e, shall include a statement to that effect in the 2012 Annual Report and all subsequent Annual Reports.

vi. Reporting on Special Projects

(1) Beginning December 1, 2011, Permittees shall track any identified potential Special Projects that have submitted planning applications but that have not received final discretionary approval.

(2) By March 15 and September 15 of each year, Permittees shall report to the Water Board on these tracked potential Special Projects using Table 3.1 found at the end of Provision C.3. All the required column entry information listed in Table 3.1 shall be reported for each potential Special Project. Any Permittee with no potential Special Projects shall so state.

For each Special Project listed in Table 3.1, Permittees shall include a narrative discussion of the feasibility or infeasibility of 100% LID treatment, onsite and offsite. Both technical and economic feasibility or infeasibility shall be discussed, as applicable. The discussion shall also contain enough technical and/or economic detail to document the basis of infeasibility used.

(3) Once a Special Project has final discretionary approval, it shall be reported in the Provision C.3.b. Reporting Table in the same reporting year that the project was approved. In addition to the column entries contained in the Provision C.3.b. Reporting Table, the Permittees shall provide the following supplemental information for each approved Special Project:

(a) Submittal Date: Date that a planning application for the Special Project was submitted.

(b) Description: Type of project, number of floors, number of units (commercial, mixed-use, residential), type of parking, and other relevant information.

(c) Site Acreage: Total site area in acres.

(d) Density in DU/Ac: Number of dwelling units per acre.

(e) Density in FAR: Floor Area Ratio

(f) Special Project Category: For each applicable Special Project Category, list the specific criteria applied to determine applicability. For each non-applicable Special Project Category, indicate n/a.

(g) LID Treatment Reduction Credit Available: For each applicable Special Project Category, state the maximum total LID Treatment Reduction Credit applied. For Category C Special Projects also list the individual Location, Density, and Minimized Surface Parking Credits applied.

(h) List of Stormwater Treatment Systems: List all LID stormwater treatment systems approved. For each type of LID treatment system, indicate the percentage of the total amount of runoff identified in Provision C.3.d. for the Special Project's drainage area that will be treated.

(i) List of Non-LID Stormwater Treatment Systems: List all non-LID stormwater treatment systems approved. For each type of non-LID treatment system, indicate: (1) the percentage of the total amount of runoff identified in Provision C.3.d. for the Special Project's drainage area, and (2) whether the treatment system either meets minimum design criteria published by a government agency or received certification issued by a government agency, and reference the applicable criteria or certification.

Table 3.1 Standard Tracking and Reporting Form for Potential Special Projects

Project Name and No.	Permittee	Address	Application Submittal Date	Description	Site Total Acreage	Density DU/Ac	Density FAR	Special Project Category	LID Treatment Reduction Credit Available	List of LID Stormwater Treatment Systems	List of Non-LID Stormwater Treatment Systems
								Category A: Category B: Category C: Location: Density: Parking:	Category A: Category B: Category C: Location: Density: Parking:	Indicate each type of LID treatment system and the percentage of total runoff treated	Indicate each type of non-LID treatment system and the percentage of total runoff treated. Indicate whether minimum design criteria met or certification received (see footnotes).

Project Name and No: Name of the Special Project and Project No. (if applicable)

Permittee: Name of the Permittee in whose jurisdiction the Special Project will be built.

Address: Address of the Special Project; if no street address, state the cross streets.

Submittal Date: Date that a planning application for the Special Project was submitted; if a planning application has not been submitted, include a projected application submittal date.

Description: Type of project (commercial, mixed-use, residential), number of floors, number of units, type of parking, and other relevant information.

Site Acreage: Total site area in acres.

Density in DU/Ac: Number of dwelling units per acre.

Density in FAR: Floor Area Ratio

Special Project Category: For each applicable Special Project Category, list the specific criteria applied to determine applicability. For each non-applicable Special Project Category, indicate n/a.

LID Treatment Reduction Credit Available: For each applicable Special Project Category, state the maximum total LID Treatment Reduction Credit available. For Category C Special Projects also list the individual Location, Density, and Minimized Surface Parking Credits available.

List of LID Stormwater Treatment Systems: List all LID stormwater treatment systems proposed. For each type, indicate the percentage of the total amount of runoff identified in Provision C.3.d. for the Special Project's drainage area.

List of Non-LID Stormwater Treatment Systems: List all non-LID stormwater treatment systems proposed. For each type, indicate the percentage of the total amount of runoff identified in Provision C.3.d. for the Special Project's drainage area. For each type of non-LID treatment system, indicate: (1) the percentage of the total amount of runoff identified in Provision C.3.d. for the Special Project's drainage area, and (2) whether the treatment system either meets minimum design criteria published by a government agency or received certification issued by a government agency, and reference the applicable criteria or certification.

RB-AR33951

ATTACHMENT F

Provision C.3.g.
Santa Clara Permittees
Hydromodification Management Requirements

Santa Clara Permittees Hydromodification Management Requirements

1. On-site and Regional Hydromodification Management (HM) Control Design Criteria

a. *Range of flows to control:* Flow duration controls shall be designed such that post-project stormwater discharge rates and durations match pre-project discharge rates and durations from 10 percent of the pre-project 2-year peak flow[4] up to the pre-project 10-year peak flow, except where the lower endpoint of this range is modified as described in Section 5 of this Attachment.

b. *Goodness of fit criteria*: The post-project flow duration curve shall not deviate above the pre-project flow duration curve by more than 10 percent over more than 10 percent of the length of the curve corresponding to the range of flows to control.

c. *Allowable low flow rate*: Flow control structures may be designed to discharge stormwater at a very low rate that does not threaten to erode the receiving waterbody. This flow rate (also called *Qcp*[5]) shall be no greater than 10 percent of the pre-project 2-year peak flow unless a modified value is substantiated by analysis of actual channel resistance in accordance with an approved User Guide as described in Section 5 of this Attachment.

d. *Standard HM modeling*: On-site and regional HM controls designed using the Bay Area Hydrology Model (BAHM[6]) and site-specific input data shall be considered to meet the HM Standard. Such use must be consistent with directions and options set forth in the most current BAHM User Manual.[7] Permittees shall demonstrate to the satisfaction of the Executive Officer that any modifications of the BAHM made are consistent with this attachment and Provision C.3.g.

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4 Where referred to in this Order, the 2-year peak flow is determined using a flood flow frequency analysis procedure based on USGS Bulletin 17B to obtain the peak flow statistically expected to occur at a 2-year recurrence interval. In this analysis, the appropriate record of hourly rainfall data (e.g., 35–50 years of data) is run through a continuous simulation hydrologic model, the annual peak flows are identified, rank ordered, and the 2-year peak flow is estimated. Such models include USEPA's Hydrologic Simulation Program—Fortran (HSPF), U.S. Army Corps of Engineers' Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), and USEPA's Storm Water Management Model (SWMM).

5 Qcp is the allowable low flow discharge from a flow control structure on a project site. It is a means of apportioning the critical flow in a stream to individual projects that discharge to that stream, such that cumulative discharges do not exceed the critical flow in the stream.

6 See www.bayareahydrologymodel.org , Resources.

7 *The Bay Area Hydrology Model User Manual* is available at http://www.bayareahydrologymodel.org/downloads.html.

e. *Alternate HM modeling and design*: The project proponent may use a continuous simulation hydrologic computer model[8] to simulate pre-project and post-project runoff and to design HM controls. To use this method, the project proponent shall compare the pre-project and post-project model output for a rainfall record of at least 30 years, and shall show that all applicable performance criteria in 1.a. – c. above are met.

2. Impracticability Provision

Where conditions (e.g., extreme space limitations) prevent a project from meeting the HM Standard for a reasonable cost, *and* where the project's runoff cannot be directed to a Regional HM control[9] within a reasonable time frame, *and* where an in-stream measure is not practicable, the project shall use (1) site design for hydrologic source control, *and* (2) stormwater treatment measures that collectively minimize, slow, and detain[10] runoff to the maximum extent practicable. In addition, if the cost of providing site design for hydrologic source control and treatment measures to the maximum extent practicable does not exceed 2% of the project cost (as defined in "2.a." below), the project shall contribute financially to an alternative HM project as set forth below:

a. *Reasonable cost*: To show that the HM Standard cannot be met at a reasonable cost, the project proponent must demonstrate that the total cost to comply with both the HM Standard and the Provision C.3.d treatment requirement exceeds 2 percent of the project construction cost, excluding land costs. Costs of HM and treatment control measures shall not include land costs, soil disposal fees, hauling, contaminated soil testing, mitigation, disposal, or other normal site enhancement costs such as landscaping or grading that are required for other development purposes.

b. *Regional HM control:* A regional HM control shall be considered available if there is a planned location for the regional HM control and if an appropriate funding mechanism for a regional control is in place by the time of project construction.

c. *In-stream measures practicability:* In-stream measures shall be considered practicable when an in-stream measure for the project's watershed is planned and an appropriate funding mechanism for an in-stream measure is in place by the time of project construction.

d. *Financial contribution to an alternative HM project:* The difference between 2 percent of the project construction costs and the cost of the treatment measures at the site (both costs as described in Section 2.a of this Attachment) shall be contributed to an alternative HM project, such as a stormwater treatment retrofit, HM retrofit, regional HM control, or in-stream measure. Preference shall be given to projects discharging, in this order, to the same tributary, mainstem, watershed, then in the same municipality or county.

3. Record Keeping

[8] Such models include USEPA's Hydrologic Simulation Program—Fortran (HSPF), U.S. Army Corps of Engineers Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), and USEPA's Storm Water Management Model (SWMM).

[9] *Regional HM controls* are flow duration control structures that collect stormwater runoff discharge from multiple projects (each of which should incorporate hydrologic source control measures as well) and are designed such that the HM Standard is met for all the projects at the point where the regional control measure discharges.

[10] Stormwater treatment measures that detain runoff are generally those that filter runoff through soil or other media, and include bioretention units, bioswales, basins, planter boxes, sand filters, and green roofs.

Permittees shall collect and retain the following information for all projects subject to HM requirements:

a. Site plans identifying impervious areas, surface flow directions for the entire site, and location(s) of HM measures;

b. For projects using standard sizing charts, a summary of sizing calculations used;

c. For projects using the BAHM, a listing of model inputs;

d. For projects using custom modeling, a summary of the modeling calculations with corresponding graph showing curve matching (existing, post-project, and post-project with HM controls curves);

e. For projects using the Impracticability Provision, a listing of all applicable costs and a brief description of the alternative HM project (name, location, date of start up, entity responsible for maintenance); and

f. A listing, summary, and date of modifications made to the BAHM, including technical rationale. Permittees shall submit this list and explanation annually with the Annual Report. This may be prepared at the Countywide Program level and submitted on behalf of participating Permittees.

4. HM Control Areas

Applicable projects shall be required to meet the HM Standard when such projects are located in areas of HM applicability as described below and shown in the revised Santa Clara Permittees' HM Map (see Attachment M). ~~the Santa Clara Permittees' HM Map (available at http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/muni/mrp/Final%20TO%20HM%20Maps.pdf).~~

a. **Purple areas**: These areas represent catchments that drain to hardened channels that extend continuously to the Bay or to tidally influenced sections of creeks. The HM Standard and associated requirements do not apply to projects in the areas designated in purple on the map.

Plans to restore a creek reach may reintroduce the applicability of HM requirements, unless the creek restoration project is designed to accommodate the potential hydromodification impacts of future development; if this is not the case, in these instances, Permittees may add, but shall not delete, areas of applicability accordingly.

b. **Red areas**: These areas represent catchments and subwatersheds that are greater than or equal to 65% impervious, based on existing imperviousness data sources. The HM Standard and associated requirements do not apply to projects in the areas designated in red on the map.

~~**c.** **Pink areas**: These are areas that are under review by the Permittees for accuracy of the imperviousness data. The HM Standard and associated requirements apply to projects in areas designated as pink on the map until such time as a Permittee presents new data that indicate that the actual level of imperviousness of a particular area is greater than or equal to 65% impervious. Any new data will be submitted to the Water Board in one coordinated submittal within one year of permit adoption.~~

c. **Green area**: These areas represent catchments and subwatersheds that are less than 65% impervious ~~and are not under review by the Permittees~~. The HM Standard and associated requirements apply to projects in areas designated as green on the map.

5. Potential Exceptions to Map Designations

The Program may choose to prepare a User Guide[11] to be used for evaluating individual receiving waterbodies using detailed methods to assess channel stability and watercourse critical flow. This User Guide would reiterate and collate established stream stability assessment methods that have been presented in the Program's HMP.[12] After the Program has collated its methods into User Guide format, received approval of the User Guide from the Executive Officer,[13] and informed the public through such process as an electronic mailing list, the Permittees may use the User Guide to guide preparation of technical reports for the following: implementing the HM Standard using in-stream or regional controls; determining whether certain projects are discharging to a watercourse that is less susceptible (from point of discharge to the Bay) to hydromodification (e.g., would have a lower potential for erosion than set forth in these requirements); and/or determining if a watercourse has a higher critical flow and project(s) discharging to it are eligible for an alternative Qcp for the purpose of designing on-site or regional measures to control flows draining to these channels (i.e., the actual threshold of erosion-causing critical flow is higher than 10 percent of the 2-year pre-project flow). In no case shall the design value of Qcp exceed 50 percent of the 2-year pre-project flow.

[11] The User Guide may be offered under a different title.
[12] The Program's HMP has undergone Water Board staff review and been subject to public notice and comment.
[13] The User Guide will not introduce a new concept, but rather reformat existing methods; therefore, Executive Officer approval is appropriate.

RB-AR33956

APPENDIX II

Attachments L and M
to be added to
Water Board Order No. R2-2009-0074

November 28, 2011

ATTACHMENT L

Provision C.3.c.i.(1)(b)(vi)

Specification of soils for Biotreatment or Bioretention Facilities

Soils for biotreatment or bioretention areas shall meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

Local soil products suppliers have expressed interest in developing ‘brand-name’ mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a ‘brand-name’ mix from a soil supplier.

Tests must be conducted within 120 days prior to the delivery date of the bioretention soil to the project site.

Batch-specific test results and certification shall be required for projects installing more than 100 cubic yards of bioretention soil.

SOIL SPECIFICATIONS

Bioretention soils shall meet the following criteria. “Applicant” refers to the entity proposing the soil mixture for approval by a Permittee.

1. General Requirements – Bioretention soil shall:
   a. Achieve a long-term, in-place infiltration rate of at least 5 inches per hour.
   b. Support vigorous plant growth.
   c. Consist of the following mixture of fine sand and compost, measured on a volume basis:

      60%-70% Sand

      30%-40% Compost
2. Submittal Requirements – The applicant shall submit to the Permittee for approval:
   a. A sample of mixed bioretention soil.
   b. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.
   c. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.
   d. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in 4.

e. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

f. Grain size analysis results of compost component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

g. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

h. Provide the name of the testing laboratory(s) and the following information:

(1) Contact person(s)

(2) Address(s)

(3) Phone contact(s)

(4) E-mail address(s)

(5) Qualifications of laboratory(s), and personnel including date of current certification by STA, ASTM, or approved equal

3. Sand for Bioretention Soil

a. Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be non-plastic.

b. Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40, #30, #16. #8, #4, and 3/8 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	**Percent Passing (by weight)**	
	Min	***Max***
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40	5	55
No. 100	0	15
No. 200	0	5

Note: all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

4. Compostred Material

Compost shall be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes or other organic materials not including manure or biosolids meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

a. Compost Quality Analysis – Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Evaluation of Composting and Compost (TMECC). The lab report shall verify:

(1) Feedstock Materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.

(2) Organic Matter Content: 35% - 75% by dry wt.

(3) Carbon and Nitrogen Ratio: C:N < 25:1 and C:N >15:1

(4) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable. In addition any one of the following is required to indicate stability:

(i) Oxygen Test < 1.3 O2 /unit TS /hr

(ii) Specific oxy. Test < 1.5 O2 / unit BVS /

(iii) Respiration test < 8 C / unit VS / day

(iv) Dewar test < 20 Temp. rise (°C) e.

(v) Solvita® > 5 Index value

(5) Toxicity: any one of the following measures is sufficient to indicate non-toxicity.

(i) NH4- : NO3-N < 3

(ii) Ammonium < 500 ppm, dry basis

(iii) Seed Germination > 80 % of control

(iv) Plant Trials > 80% of control

(v) Solvita® > 5 Index value

(6) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.

(i) Total Nitrogen content 0.9% or above preferred.

(ii) Boron: Total shall be <80 ppm; Soluble shall be <2.5 ppm

(7) Salinity: Must be reported; < 6.0 mmhos/cm

(8) pH shall be between 6.5 and 8. May vary with plant species.

b. Compost for Bioretention Soil Texture – Compost for bioretention soils shall be analyzed by an accredited lab using #200, 1/4 inch, 1/2 inch, and 1 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight) *Min*	*Max*
1 inch	99	100
1/2 inch	90	100
1/4 inch	40	90
No. 200	2	10

c. Bulk density shall be between 500 and 1100 dry lbs/cubic yard

d. Moisture content shall be between 30% - 55% of dry solids.

e. Inerts – compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.

f. Weed seed/pathogen destruction – provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.

g. Select Pathogens – Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.

h. Trace Contaminants Metals (Lead, Mercury, Etc.) – Product must meet US EPA, 40 CFR 503 regulations.

i. Compost Testing – The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

VERIFICATION OF ALTERNATIVE BIORETENTION SOIL MIXES

Bioretention soils not meeting the above criteria shall be evaluated on a case by case basis. Alternative bioretention soil shall meet the following specification: "Soils for bioretention facilities shall be sufficiently permeable to infiltrate runoff at a minimum rate of 5 inches per hour during the life of the facility, and provide sufficient retention of moisture and nutrients to support healthy vegetation."

The following steps shall be followed by municipalities to verify that alternative soil mixes meet the specification:

1. General Requirements – Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth. The applicant refers to the entity proposing the soil mixture for approval.

   a. Submittals – The applicant must submit to the municipality for approval:

      (1) A sample of mixed bioretention soil.

      (2) Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

      (3) Certification from an accredited geotechnical testing laboratory that the Bioretention Soil has an infiltration rate between 5 and 12 inches per hour as tested according to Section 1.b.(2)(ii).

      (4) Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

      (5) Grain size analysis results of mixed bioretention soil performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

      (6) A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

      (7) The name of the testing laboratory(s) and the following information:

         (i) contact person(s)

         (ii) address(s)

         (iii) phone contact(s)

         (iv) e-mail address(s)

         (v) qualifications of laboratory(s), and personnel including date of current certification by STA, ASTM, or approved equal

   b. Bioretention Soil

      (1) Bioretention Soil Texture

      Bioretention Soils shall be analyzed by an accredited lab using #200, and 1/2" inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight) *Min*	*Max*
1/2 inch	97	100
No. 200	2	5

      (2) Bioretention Soil Permeability testing

      Bioretention Soils shall be analyzed by an accredited geotechnical lab for the following tests:

(i) Moisture – density relationships (compaction tests) shall be conducted on bioretention soil. Bioretention soil for the permeability test shall be compacted to 85 to 90 percent of the maximum dry density (ASTM D1557).

(ii) Constant head permeability testing in accordance with ASTM D2434 shall be conducted on a minimum of two samples with a 6-inch mold and vacuum saturation.

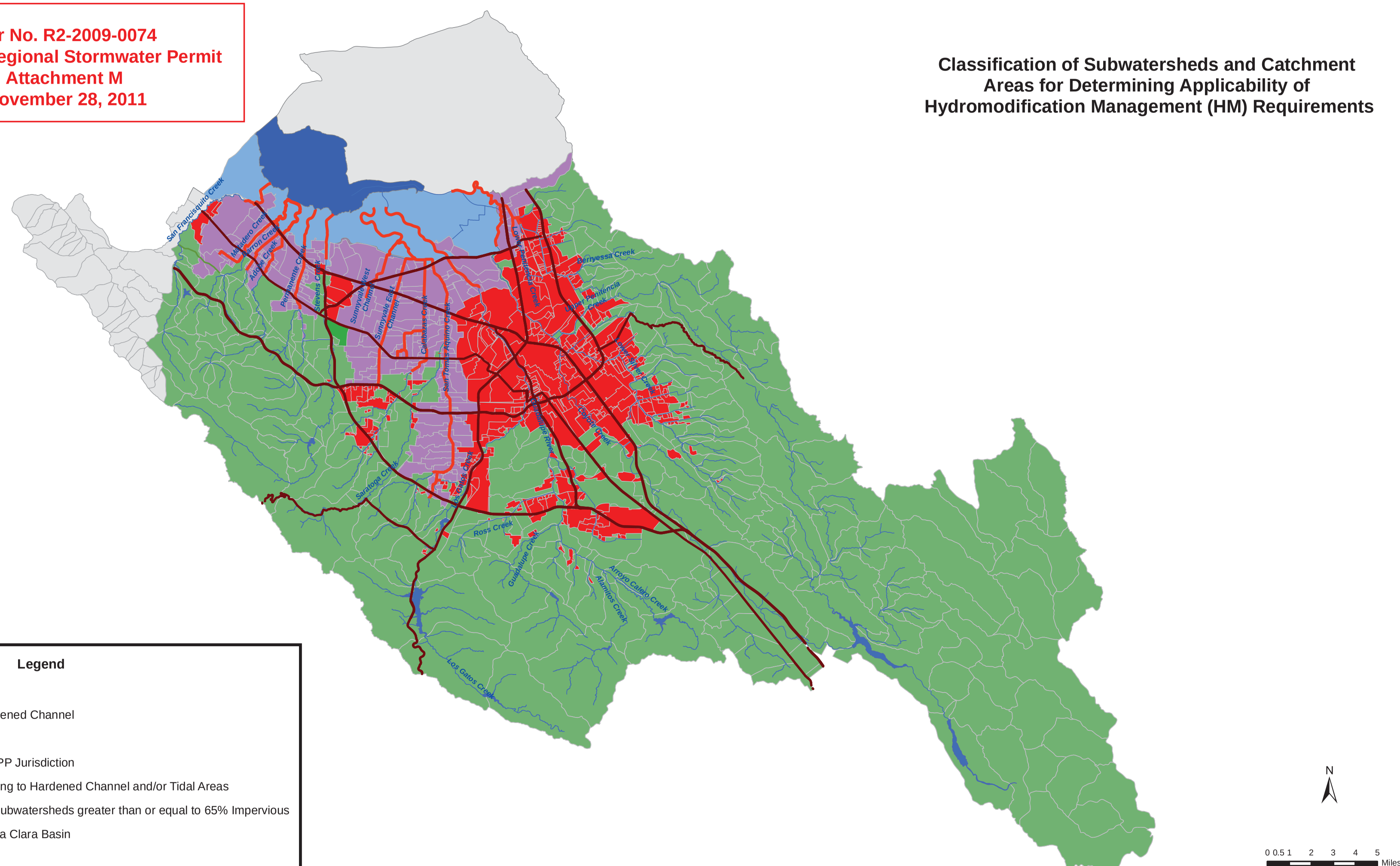
MULCH FOR BIORETENTION FACILITIES

Mulch is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. Projects subject to the State's Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least two inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. It is recommended to apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

RB-AR33963

Order No. R2-2009-0074
Municipal Regional Stormwater Permit
Attachment M
November 28, 2011

Classification of Subwatersheds and Catchment Areas for Determining Applicability of Hydromodification Management (HM) Requirements



Legend

- Major Roads
- Continuously Hardened Channel
- Major Creeks
- Outside SCVURPPP Jurisdiction
- Catchments Draining to Hardened Channel and/or Tidal Areas
- Catchments and Subwatersheds greater than or equal to 65% Impervious
- Reservoirs in Santa Clara Basin
- Baylands
- Subwatersheds less than 65% Impervious

Revision Date: November 2010

This map contains revisions to the March 2009 version to reflect updated impervious surface data and/or catchment boundaries in the Cities of San Jose, Sunnyvale, Mountain View, and Milpitas, as described in the report to the Water Board dated October 14, 2010, consistent with the HM applicability criteria set forth in Attachment F, Section 4 of the MRP.

APPENDIX III

Fact Sheet

This Fact Sheet describes the legal requirements and technical rationale that serve as the basis for this Order's requirements. This Fact Sheet constitutes a portion of the findings for the Order.

Purpose

The purpose of the Order is to amend Water Board Order No. R2-2009-0074, the San Francisco Bay Municipal Regional Stormwater Permit, to add criteria for determining which types of Regulated Projects may be considered Special Projects and to allow these Special Projects to reduce the amount of stormwater runoff that must be treated with Low Impact Development (LID) stormwater treatment systems.

Background and Summary of Existing Requirements

On October 14, 2009, the Water Board adopted Order No. R2-2009-0074, NPDES No. CAS612008, prescribing Waste Discharge Requirements under the San Francisco Bay Municipal Regional Stormwater Permit for the discharge of stormwater runoff from the municipal separate storm sewer systems (MS4s) of the named Permittees.

Provision C.3. of Order No. R2-2009-0074 requires the Permittees to use their planning authorities to include appropriate source control, site design, and stormwater treatment measures in new development and redevelopment projects to address both soluble and insoluble stormwater runoff pollutant discharges and prevent increases in runoff flows from new development and redevelopment projects. Provision C.3. requires that the source control, site design, and stormwater treatment measures be LID measures.

Provision C.3.b. of Order No. R2-2009-0074 defines Regulated Projects as the different categories of new development and redevelopment projects that Permittees must regulate under Provision C.3. These categories are defined on the basis of the land use and the amount of impervious surface created and/or replaced by the project because all impervious surfaces contribute pollutants to stormwater runoff and certain land uses contribute more pollutants. Impervious surfaces can neither absorb water nor remove pollutants as the natural, vegetated soil they replaced can. Also, urban development creates new pollution by bringing higher levels of car emissions that are aerially deposited, car maintenance wastes, pesticides, household hazardous wastes, pet wastes, and trash, which can all be washed into the storm sewer.

Provision C.3.c. of Order No. R2-2009-0074 recognizes LID as a cost-effective, beneficial, holistic, integrated stormwater management strategy[1]. The goal of LID is to reduce runoff and mimic a site's predevelopment hydrology by minimizing disturbed areas and impervious cover and then infiltrating, storing, detaining, evapotranspiring, and/or biotreating stormwater runoff close to its source. LID employs principles such as preserving and recreating natural landscape features and minimizing imperviousness to create functional and appealing site drainage that treat stormwater as a resource, rather than a waste product. Practices used to adhere to these LID principles include measures such as preserving undeveloped open space, rain barrels and cisterns, green roofs, permeable pavement, and biotreatment through rain gardens, bioretention units, bioswales, and planter/tree boxes.

[1] USEPA, *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices* (Publication Number EPA 841-F-07-006, December 2007) http://www.epa.gov/owow/nps/lid/costs07)

This Provision sets forth a three-pronged approach to LID with source control, site design, and stormwater treatment requirements. The concepts and techniques for incorporating LID into development projects, particularly for site design, have been extensively discussed in BASMAA's Start at the Source manual (1999) and its companion document, Using Site Design Techniques to Meet Development Standards for Stormwater Quality (May 2003), as well as in various other LID reference documents.

Provision C.3.c.i.(2)(b) requires each Regulated Project to treat 100% of the Provision C.3.d. runoff with LID treatment measures onsite or with LID treatment measures at a joint stormwater treatment facility. LID treatment measures are harvesting and re-use, infiltration, evapotranspiration, or biotreatment. A properly engineered and maintained biotreatment system may be considered only if it is infeasible to implement harvesting and re-use, infiltration, or evapotranspiration at a project site.

Provision C.3.c.i.(2)(b)(vi) requires the Permittees to propose specifications for soil installed in all biotreatment or bioretention facilities built under the provisions of this permit. These minimum specifications are contained in Attachment L. These specifications were proposed by the Permittees pursuant to Provision C.3.c.iii.(3) after research performed under their direction.[2, 3, 4]

Provision C.3.c.i.(2)(b)(vii) requires minimum specifications for green roofs which are installed as treatment measures under this permit. The Permittees proposed green roof minimum specifications pursuant to Provision C.3.c.iii.(4) and submitted a brief report in support of their proposal.[5]

Special Projects

Provision C.3.e.ii.(1) of Order No. R2-2009-0074 was included based on the Permittees' and building industry stakeholders' comments and testimony during order adoption that certain types of smart growth, high density, and transit-oriented development projects cannot practicably implement LID treatment including biotreatment. LID treatment measures, including infiltration, harvest for use, evapotranspiration and green roofs can be infeasible to implement in a dense urban context in some cases, from a physical or cost basis. The urban centers in this region are often underlain by tight clay soils that make infiltration difficult, requiring storage at possibly prohibitive cost. Stormwater harvest for internal, non-potable use still meets regulatory obstacles from implementation of the plumbing code and lack of winter water demand. Green roofs continue to be very expensive, and evapotranspiration is lowest in the cold winter when rains fall. Many dense, central business district developments lack room for planted areas for biotreatment.

Moreover, these projects have various environmental benefits, including either reducing existing impervious surfaces associated with commercial or residential development due to increased

[2] Technical Memorandum – Regional Bioretention Soil Guidance & Model Specification, Bay Area Stormwater Management Agencies Association – WRA Environmental Consultants, November 12, 2010

[3] Technical Memorandum – Regional Bioretention Installation Guidance, Bay Area Stormwater Management Agencies Association – WRA Environmental Consultants, November 12, 2010

[4] Annotated Bibliography – Regional Biotreatment Soil Guidance, Bay Area Stormwater Management Agencies Association – WRA Environmental Consultants, November 12, 2010

[5] Green Roof Minimum Specifications, Bay Area Stormwater Management Agencies Association, April 29, 2011.

density, or creating less "accessory" impervious areas and less auto-related pollutant impacts. Auto use in general and its associated pollution is reduced because residential areas are closer to commercial areas for jobs and services, and closer to transit hubs. In addition, concentrating development in urban centers should reduce pressure to develop green fields on the urban perimeter.

Incentive LID treatment reduction credits approved by the Water Board may be applied to these types of Regulated Projects that are considered "Special Projects."

Provision C.3.e.ii.(2) of Order No. R2-2009-0074 required the Permittees to submit by December 1, 2010, a proposal to the Water Board identifying the types of projects proposed as Special Projects and therefore eligible for LID Treatment Reduction Credit. The proposal was required to include specific criteria for each type of Special Project proposed, including size, location, minimum densities, minimum floor area ratios, other appropriate limitations, and the proposed LID Treatment Reduction Credit. Specifically, the Provision required the proposal to contain the following:

- Identification of the types of projects proposed for consideration of LID treatment reduction credits and an estimate of the number and cumulative area of potential projects during the remaining term of this permit for each type of project.
- Identification of institutional barriers and/or technical site specific constraints to providing 100% LID treatment onsite that justify the allowance for non-LID treatment measures onsite.
- Specific criteria for each type of Special Project proposed, including size, location, minimum densities, minimum floor area ratios, or other appropriate limitations.
- Identification of specific water quality and environmental benefits provided by these types of projects that justify the allowance for non-LID treatment measures onsite.
- Proposed LID Treatment Reduction Credit for each type of Special Project and justification for the proposed Credits. The justification shall include identification and an estimate of the specific water quality benefit provided by each type of Special Project proposed for LID treatment reduction credit.
- Proposed total treatment reduction credit for Special Projects that may be characterized by more than one category and justification for the proposed total Credit.

On December 1, 2010, the Bay Area Stormwater Management Agencies Association (BASMAA) submitted a Special Projects proposal on behalf of the Permittees, which defined the types of Special Project Categories and their corresponding LID Treatment Reduction Credits.

BASMAA's stormwater proposal was posted on the Water Board's website and circulated for public comment on December 10, 2010. Comments on the proposal were received from U.S. EPA, the Natural Resources Defense Council (NRDC), San Francisco Baykeeper, the Building Industry Association, other building industry groups, and developers.

Water Board staff has met on a regular basis with representatives of BASMAA and, within these meetings, revisions of the December 10, 2010, proposal have been made and publicly circulated. Representatives of U.S. EPA, the Metropolitan Transportation Commission (MTC) and the

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Association of Bay Area Governments (ABAG), among other stakeholders, have participated in some of these meetings. Water Board staff has also met separately with representatives of NRDC and San Francisco Baykeeper.

In the Permittees' original submittal and at subsequent meetings, the Permittees' have provided Water Board staff with estimates of the number and type of projects that may potentially qualify as Special Projects and the percentage of LID Treatment Reduction Credit that may be applied for the various projects.

The proposed revision to Provision C.3.e.ii. of Order No. R2-2009-0074 establishes specific criteria for determining which types of Regulated Projects may be considered Special Projects, which are more stringent than originally proposed by the Permittees. The proposed revision establishes three categories of Special Projects, with different amounts of maximum allowable non-LID treatment, based on size, land use type, and density. Projects that are the most dense and would have the greatest infeasibility problems with LID implementation are allowed to use the most non-LID treatment. Category A projects (Provision C.3.e.ii), which represents the smallest Special Projects, must be under a half acre, built in a pedestrian-oriented business district and have 85% lot coverage. Category B projects (Provision C.3.e.iii) must also have 85% lot coverage, a minimum density, and be between a half acre and 2 acres. Category C, transit-oriented development projects (Provision C.3.e.iv), have no size limitation, but must have a minimum density, and are allowed an additional non-LID treatment percentage based on proximity to transit, density, and parking criteria to establish a tiered approach for determining the total LID Treatment Reduction available. The amount of Provision C.3.d. design stormwater runoff not treated with LID measures, must be treated with one or a combination of the following two specific non-LID treatment systems:

- Tree-box-type high flowrate biofilters
- Vault-based high flowrate media filters

If LID treatment measures are not feasible, these are the best controls for qualifying Special Projects to reduce pollutants in stormwater discharges to the maximum extent practicable.

Provision C.3.e.ii.(2) of Board Order No. R2-2009-0074 is now superseded by a new Provision C.3.e.ii.(2) and Provisions C.3.e.ii.(3) and C.3.e.ii.(4), which specify criteria in three categories for determining which types of Regulated Projects may be considered Special Projects and which are more stringent than originally proposed by the Permittees.

Qualifying Special Projects are dense urban development projects that will reduce development pressure on the greenfield suburban fringe by concentrating residences and commercial development in urban centers. These projects have many more commercial square feet and dwelling units per square foot of impervious surface. Dense urban "smart growth" tends to be more pedestrian-friendly, allowing reduced auto use and reduction of associated pollution.

Transit-oriented developments are designed to reduce automobile use and will reduce associated urban runoff pollution. Typically, high density residential developments are designed to be within ½ mile of a major transit hub, with commercial development also included in the developments so that shops and jobs are all clustered in a central location, with easy transit access. These elements add up to fewer automobile trips and more use of transit.

Page 6 of *New Places, New Choices: Transit-Oriented Development in the San Francisco Bay Area*, November 2006, by the MTC, states:

> In 2002, the Bay Area's "Smart Growth Strategy" —a landmark, long-range regional visioning effort —found that promoting transit-oriented development and focusing housing, jobs and retail along transit corridors would preserve as much as 66,000 acres of open space by 2020, compared with current development trends. Such a strategy also would reduce average weekday driving by as much as 3.6 million vehicle miles in 2020, conserving 150,000 gallons of gasoline a day and reducing daily carbon dioxide emissions (the principal greenhouse gas) by 2.9 million pounds per day. Already, Bay Area households located close to transit stations make fewer driving trips than do others in the region. Households within a half-mile of train stations and ferry stops log only 20 vehicle miles of travel per day, just 56 percent of the regional average. The fewer trips people make, the fewer the pollution-producing "cold starts" of their cars. These factors combine to result in lower fuel use and lower tailpipe emissions by those households living close to transit — and they also add up to powerfully persuasive evidence of the environmental benefits of TOD in the Bay Area.

Page 8 of the same MTC report also states:

> ...Proximity Matters - Bay Area residents who live within a half-mile of rail or ferry stops are four times as likely to use transit, three times as likely to bike, and twice as likely to walk as are those who live at greater distances.

The proposed reporting requirements (Provision C.3.e.vi) provides Water Board staff with early notice of the Special Projects that are being considered by the Permittees prior to the Permittees granting final planning approval. This allows Water Board staff to validate the Permittees' analysis of the number and size of potential Special Projects that may be approved during the remainder of the MRP's permit term. The reporting requirements also require the Permittees to describe in detail the basis for infeasibility of implementing LID treatment when non-LID treatment is used. Also, the Permittees must describe the types of filter vaults or tree filters used, and the certification these systems have achieved. Water Board staff intends to use the data collected in the proposed reporting requirements to revise the Special Projects criteria as appropriate for the next MRP permit term.

Biotreatment Soil Media and Green Roof Minimum Specifications

Provisions C.3.c.i.(2)(vi) and C.3.c.iii.(3) of Order No. R2-2009-0074 required the Permittees to submit to the Water Board by May 1, 2011, a proposed set of model biotreatment soil media specifications and soil infiltration testing methods to verify a long-term infiltration rate of 5 to 10 inches/hour.

The Permittees submitted a proposal for the soil media specifications and soil infiltration testing methods on December 1, 2010, which was distributed for public comment on December 15, 2010. Comments were received on January 28, 2011, from Roger James of Resources Management and from NRDC.

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Provisions C.3.c.i.(2)(vii) and C.3.c.iii.(4) of Order No. R2-2009-0074 require the Permittees to submit to the Water Board by December 1, 2011, proposed minimum specifications for green roofs to be considered biotreatment systems.

The Permittees submitted a proposal for the minimum green roof specifications on April 29, 2011, which was distributed for public comment on May 4, 2011. No comments were received.

This Order approves the model biotreatment soil media specifications, soil infiltration testing methods, and minimum green roof specifications submitted by the Permittees.

Hydromodification Management (HM) – Santa Clara Permittees

Provision C.3.g. of Order No. R2-2009-0074 requires that certain new development projects manage increases in stormwater runoff flow and volume so that post-project runoff shall not exceed estimated pre-project runoff rates and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force.

Based on Hydrograph Modification Management Plans that were developed for the Permittees on a countywide basis, the Water Board adopted HM requirements specific to the Permittees in each county, prior to the 2009 adoption of the MRP. Provision C.3.g. of Order No. R2-2009-0074 restates the major common elements of the specific HM requirements for all Permittees. Within Provision C.3.g., Attachment F contains the specific HM requirements for the Santa Clara Permittees.

Provision C.3.g.ii.(5) of Order No. R2-2009-0074 requires the Santa Clara Permittees to comply with all the requirements in Attachment F of the same Order. Requirement 4. of Attachment F (pages F-3 and F-4 of Order No. R2-2009-0074) defines geographical areas where applicable Regulated Projects are required to meet the HM Standard and associated requirements. These areas of HM applicability described in Requirement 4. are shown in the Santa Clara Permittees' HM Map available at http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/stormwater/muni/mrp/Final%20TO%20HM%20Maps.pdf.

Requirement 4.c. of Attachment F states that pink areas on the HM Map are under review by the Permittees for accuracy of the imperviousness data. The HM Standard and associated requirements apply to projects in areas designated as pink on the map until such time as a Permittee presents new data that indicates that the actual level of imperviousness of a particular area is greater than or equal to 65% impervious. Any new data is to be submitted to the Water Board in one coordinated submittal within one year of permit adoption.

The Santa Clara Permittees submitted new impervious data and a revised HM Map that reflects the new data to the Water Board on October 14, 2010. On March 11, 2011, the Santa Clara Permittees submitted a revised HM Map to correct a small error in the October 2010 HM Map, and to provide additional information per Water Board staff request. The revised HM Map shows that in the majority of the pink area of the originally-approved Santa Clara Permittees' HM Map, the HM Standard and associated requirements do apply. In the revised HM Map, these areas are now shown in green to represent the applicability of the HM Standard and associated requirements. The remaining small portion of the pink area in the original HM Map is now shown in red to represent areas where the HM Standard and associated requirements do not apply.

This Order approves the revised Santa Clara Permittees' HM Map and replaces the HM Map originally adopted by Order No. R2-2009-0074.

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NRDC Technical Report
August 2009

A Clear Blue Future

How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century

Project Director
David S. Beckman
Natural Resources Defense Council

Principal Authors
Noah Garrison
Natural Resources Defense Council

Robert C. Wilkinson, Ph.D.
Donald Bren School of Environmental Science and Management, University of California at Santa Barbara

Richard Horner, Ph.D.
University of Washington

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BREN SCHOOL OF
ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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The Natural Resources Defense Council is an international nonprofit environmental organization with more than 1.2 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in NewYork City, Washington, D.C., Los Angeles, San Francisco, Montana, and Beijing. Visit us at www.nrdc.org.

About the Donald Bren School of Environmental Science and Management

The mission of the Donald Bren School of Environmental Science and Management, University of California, Santa Barbara, is to play a leading role in researching environmental issues, identifying and solving environmental problems, and training research scientists and environmental management professionals.

Acknowledgments

This report received substantial input and review from a number of individuals. Their participation contributed greatly to the quality of the report and its conclusions and recommendations. We acknowledge that they may not necessarily endorse all of the reports recommendations. In particular, we wish to thank our peer reviewers: Martha Davis, Inland Empire Utilities Agency; Lillian Kawasaki, Water Replenishment District of Southern California; and Ted Johnson, Water Replenishment District of Southern California. We also wish to thank Paula Daniels, City of Los Angeles; Haan-Fawn Chau, City of Los Angeles; Fran Spivy-Weber, California State Water Resources Control Board; Caren Trgovcich, California State Water Resources Control Board; Bob Languell, California Air Resources Board; Aubrey Dugger, GreenInfo Network; Stacy Tellinghuisen, Wester Resource Advocates; Michael Antos, Los Angeles and San Gabriel Rivers Watershed Council; Edward Belden, Los Angeles and San Gabriel Rivers Watershed Council; Mark Wildermuth, Wildermuth Environmental, Inc.; Doug Pushard, American Rainwater Catchment Systems Association; Jack Schultz, American Rainwater Catchment Systems Association; Dr. Tamim Younos, Virginia Water Resources Research Center, Virginia Tech; Robb Whitaker, Water Replenishment District of Southern California; David Nahai, Los Angeles Department of Water and Power; James McDaniel, Los Angeles Department of Water and Power; James Yannotta, Los Angeles Department of Water and Power; Nancy Sutley, Council on Environmental Quality; Dr. Arturo Keller, UC Santa Barbara; Fiona Sanchez, Irvine Ranch Water District; Brad Cross, LFR, Inc. In addition, NRDC would like to thank The Summit Foundation and Environment Now for their generous support of our work.

NRDC Director of Communications: Phil Gutis

NRDC Marketing and Operations Director: Alexandra Kennaugh

NRDC Publications Manager: Lisa Goffredi

NRDC Publications Editor: Anthony Clark

Production: Maxine Kim, maxinekim1@gmail.com

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Executive Summary

As global warming threatens our water resources, communities are faced with a need to respond quickly and economically to water supply shortfalls. Both the snowpack and surface runoff that form a critical supply of potable water for western states are being affected by higher temperatures. Low impact development, or LID, is a land planning and engineering design approach to stormwater management that enables cities, states, and individuals to increase access to safe and reliable sources of water while reducing the amount of energy consumed and global warming pollution generated by supplying the water. New NRDC and UCSB analysis shows that implementing LID practices at new and redeveloped residential and commercial properties in parts of California can increase water supplies by billions of gallons each year, providing an effective and much-needed way to mitigate global warming's impact on California.

LID Techniques Can Deliver Water and Energy Savings for Californians

The NRDC and UCSB analysis found that implementing LID practices that emphasize rainwater harvesting, which includes infiltration of water into the ground as well as capture in rain barrels or cisterns for later use onsite, at new and redeveloped residential and commercial properties in the urbanized areas of southern California and limited portions of the San Francisco Bay area has the potential to increase local water supplies by up to 405,000 acre-feet (af) of water per year by 2030. This volume represents roughly two-thirds of the volume of water used by the entire City of Los Angeles each year. The water savings translate into electricity savings of up to 1,225,500 megawatt hours (MWh), avoiding the release of as much as 535,500 metric tons of CO_2 per year, as the increase in energy-efficient local water supply from LID results in a decrease in the need to obtain water from imported sources of water such as the California State Water Project (SWP) or the use of processes such as ocean desalination, both of which require tremendous amounts of energy. These benefits would increase in each year thereafter.

One acre-foot of water is the volume of water (325,851 gallons) that will cover an acre of land—or a football field to the 91 yard line—to a depth of one foot. An acre-foot is enough water to supply two families in California for a full year.

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And the true value of LID is likely much higher. Our analysis currently assumes a conservative figure for future development rates and does not account for the loss of water that currently occurs as it is conveyed from distant sources. Expanding the use of LID to industrial, government, public use, and transportation development and redevelopment in southern California has the potential to yield an additional 75,000 acre-feet of savings per year by 2030, with corresponding reductions in energy use and CO_2 emissions.

Moreover, even greater overall water and electricity savings—and associated reductions in global warming pollution—would result from full application of LID practices statewide and in other areas of the United States where augmenting local water supplies may reduce the amount of energy required to supply water from more energy-intensive sources.

The 1,225,500 megawatt hours of electricity savings that can be achieved each year through use of LID practices represents enough energy to power more than 102,000 single family homes for one full year.[1] Emissions reductions of 535,500 metric tons of CO_2 each year are the equivalent of taking more than 97,000 cars off the road.[2] The analysis we present in this paper shows that LID can play a significant role in terms of addressing issues of water supply and climate change throughout California and the southwest United States.

Vegetated swale in a parking lot CREDIT: HAAN-FAWN CHAU

Green roof in Vista Hermosa Park, Santa Monica Mountains Conservancy, Los Angeles / CREDIT: Ken Weston and Reza Iranpour/ City of Los Angeles

LID Technologies Provide Multiple Benefits

LID was developed to ameliorate—and where possible, eliminate—the pollution and erosion problems generated by runoff from urban and suburban development at the source, where rain falls on paved surfaces, by maximizing the natural onsite infiltration and treatment abilities of soils and vegetation or by capturing water for later use. It provides important environmental benefits by reducing pollution of downstream rivers, lakes, and coastal waters.

Successful LID practices include:

- maximizing infiltration, which recharges local and regional groundwater systems;
- providing retention areas and slowing runoff, which reduce flooding and erosion;
- minimizing the impervious footprint of a project through reducing paved surfaces;
- directing runoff from impervious areas onto landscaping; and
- capturing runoff in rain barrels or cisterns for beneficial use.

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By preventing site runoff altogether in many situations, LID is substantially more effective at protecting water quality than many types of conventional water management practices that rely on structural treatment devices to remove a percentage of pollution after it has already entered stormwater runoff. In addition to serving as a superior method of stormwater pollution control, LID can increase water supply reliability in a region prone to natural disasters, serve to reduce flooding and erosion associated with urban runoff, reduce the "heat island" effect from solar radiation in urban settings, and provide green space and open land, enhancing property values. The use of LID can also reduce the costs of municipal stormwater infrastructure and decrease the frequency and severity of combined sewer overflow events.

LID Is Cost Effective

The U.S. Environmental Protection Agency (EPA) states that "LID practices can reduce project costs and improve environmental performance" of development and that, with few exceptions, LID has been "shown to be both fiscally and environmentally beneficial to communities."[3] As a result, LID practices can provide a targeted, cost-effective means of addressing issues of water pollution, water supply, and climate change all at once.

Current and Emerging Regulatory Policies Support the Implementation of LID

Federal and state regulatory policies already require that developed sites in larger and midsized cities control post-construction stormwater runoff. Requiring implementation of LID technologies can therefore reduce energy use and global warming pollution and serve as a cost-effective means of complying with existing mandates of federal and state laws.

Groundwater's Role in California's Water Supply

By allowing more water to infiltrate the ground and recharge aquifers, LID can reduce demand for energy-intensive imported water or desalinated ocean water. Recharging these aquifers is particularly useful given that most areas of the state already have infrastructure in place to extract and distribute groundwater. California extracts more groundwater—approximately 17 million acre-feet per year—than any other state in the country. As much as 50 percent of the state's population receives some portion of their potable water supply from groundwater, including the vast majority of urbanized southern California areas that also receive a portion of their water from energy-intensive sources in northern California. In fact, nearly 50 percent of the total population of the United States depends on groundwater for some part of their water supply, meaning that LID practices can be used to help recharge local and regional groundwater aquifers across large portions of the country.

The reliance on groundwater is particularly strong in southern California where an average of 1.56 million acre-feet per year—or about 40 percent of the region's total water needs—are met through local groundwater pumping. Rainwater is the primary source that recharges the aquifers, and the Metropolitan Water District of Southern California recently estimated that ground water basins in the southern California region have 3.2 million acre-feet of storage space available for possible recharge. This existing capacity underlines the potential for LID practices that emphasize infiltration to greatly enhance local groundwater supplies. The use of LID represents a practical solution to California's water supply needs.

Capturing Rooftop Runoff

For areas where surface soil conditions, aquifer capacity, or traditional water supply patterns may favor capturing runoff rather than groundwater recharge, practices that promote capture and beneficial use provide a similar opportunity to reduce energy use and greenhouse gas (GHG) emissions. LID practices for capturing rainfall can reduce runoff volumes by as much as 75 percent, saving much of the water to be used onsite.

The Climate Challenge

Global warming is already affecting water resources in California, and temperatures are projected to rise by as much as 8 to 10.5 degrees Fahrenheit in the state toward the end of the century. The Sierra snowpack, which forms California's largest freshwater surface reservoir and serves as a critical source of drinking and agricultural irrigation water, is expected to shrink

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by between 25 and 40 percent by 2050, and as much as 70 to 90 percent by the end of the century, drastically increasing the strain on a water management system that will be needed to supply an additional 24 million people by midcentury. Reservoirs along the Colorado River, which supply large portions of the southern California population, have slowly emptied to less than half their capacity as drought conditions grip the region. California must look for fresh and innovative ways to address climate change and reduce the emission of greenhouse gases that threaten its water supply.

The safe and sufficient supply of water in California is both a casualty of global warming and a contributor to it. Water must often be conveyed long distances and at great energy cost that results in substantial GHG emissions. In fact, water now constitutes one of the largest uses of energy in California, consuming an astonishing 19 percent of all electricity and 33 percent of non-power-plant natural gas used in the state. A significant portion of the electricity, substantially more than the national average, is used for the conveyance of water. The California State Water Project (SWP), which pumps water a distance of 444 miles from the Sacramento-San Joaquin Delta to southern California, and lifts the water from just above sea level at the Delta nearly 3,000 feet over the Tehachapi Mountains in the process, is the single-largest individual user of electricity in the state. And as California confronts issues related to limited water supplies and a growing economy, 20 ocean desalination plants have been proposed statewide, each of which would supply water at an energy cost comparable to conveying water through the SWP. By contrast, the energy required to supply groundwater can be 5 to 20 times less than that required to supply water through the SWP or ocean desalination, and the energy required for capture and onsite use of stormwater can be 8 to more than 25 times less—if there are any energy requirements at all. LID presents a way to augment local water supply and avoid the energy consumption and GHG emissions associated with transporting water over long distances.

The white "bathtub rings" show the pre-drought water level of Lake Powell in Arizona. In March 2008, the lake's water levels had fallen more than 100 feet below its corresponding levels a decade ago.

PHOTO CREDIT: Mike Reyfman, *Lake Powell.*

The LID Solution

LID provides new ways to adapt to and mitigate the serious challenges to our water supply posed by global warming. Our study indicates that rainwater harvesting through use of LID can be of considerable help to California—and at bargain prices. LID can play a significant role in addressing water supply and global warming challenges throughout California and the southwestern United States.

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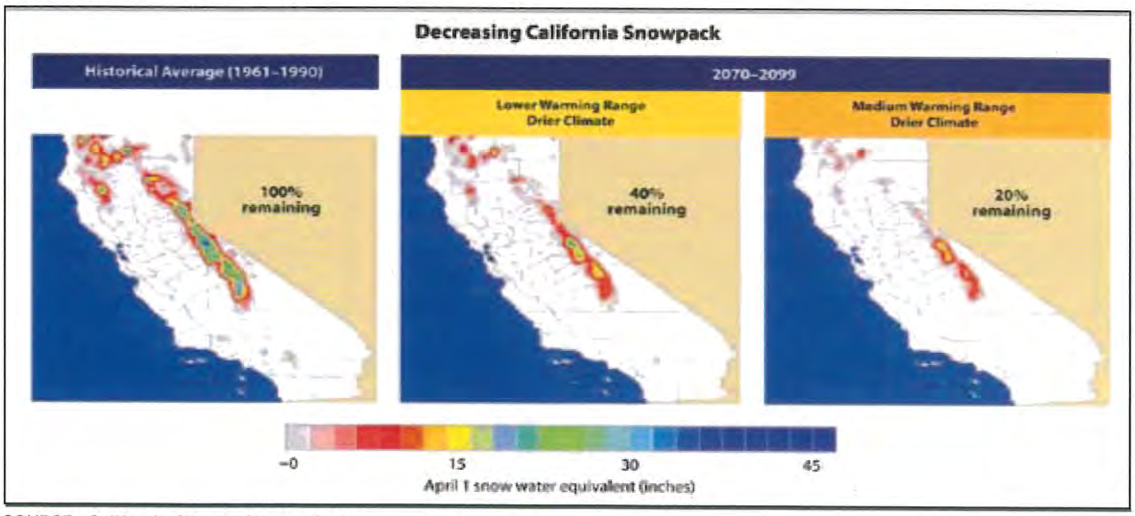
GLOBAL WARMING

Global warming is already affecting water resources throughout the western United States. The California Department of Water Resources (DWR) states that, although "the exact conditions of future climate change remain uncertain, there is no doubt about the changes that have already happened."[1] According to DWR, "[t]he average early spring snowpack in the Sierra Nevada decreased by about 10 percent during the last century, a loss of 1.5 million acre-feet of snowpack storage."[2] Forming the largest freshwater reservoir in California, the Sierra snowpack is a critical source of water for the entire state. "Snowmelt currently provides an annual average of 15 million acre-feet of water, slowly released between April and July each year. Much of the state's water infrastructure was designed to capture the slow spring runoff and deliver it during the drier summer and fall months."[3] However, changes as a result of global warming threaten the continued viability of this vital water source. Largely because of temperature increase, the Sierra snowpack is projected to shrink by between 25 to 40 percent by 2050, and as much as 70 to 90 percent by the end of the century (see Figure 1).[4,5]

The rise in temperatures in the Sierra Nevada Mountains has two major implications for California's water supply. First, "more precipitation is falling as rain and less as snow."[6] An air temperature increase of 1.8°F (1°C) is predicted to reduce the average annual volume of water produced from snowmelt by approximately 15 percent, while a 7.2°F (4°C) increase would result in about a 60 percent reduction in snowmelt.[7] Second, snowmelt is occurring progressively earlier in the season.[8] In the early spring, man-made reservoirs in California are operated for flood control purposes. Water must be released from the reservoirs, rather than stored, to protect against the possibility of storms or heavy precipitation events late in the wet season. As snowmelt and the resulting runoff shifts to earlier times in the year, it reduces the amount of water

Figure 1: Projected dry-climate reduction in the Sierra Nevada snowpack, from 2070–2099; from the California Climate Change Center, 2006. Projections are based on warming ranges of 3–5.5°F (1.7-3.3°C) (Lower Warming Range) and 5.5–8°F (3-4.4°C) (Medium Warming Range). The High Warming Range estimate, which projects a temperature increase of 8 to 10.5°F (4.4 to 5.8°C), is not shown.



SOURCE: California Climate Change Center.

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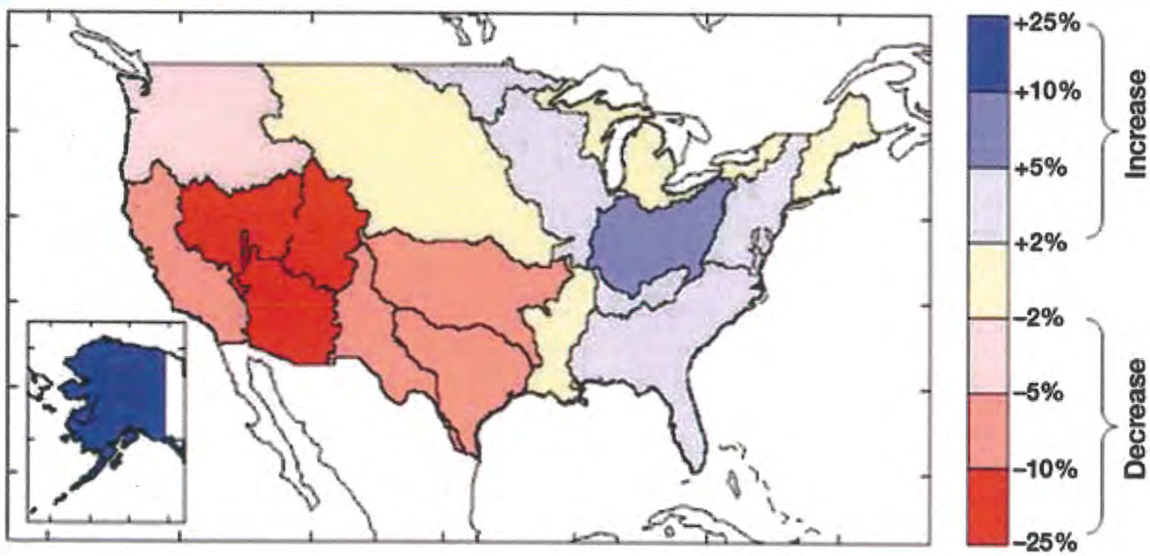
AND WATER

available for storage in California's water supply system. An increase in the average temperature of 7.2°F (4°C) would shift the mean snowmelt runoff from mid-March to mid-February, when reservoirs must still release water. Thus, even if the same volume of snowmelt were to occur in the future, less of the water could be stored and later made available for use during the dry California summer.[9]

Global warming is predicted to have a significant impact on surface streamflow and runoff as a result of the increased temperatures and altered precipitation patterns. The overall surface runoff in California could decrease by up to 10 percent by midcentury, with far greater decreases in runoff in the intermountain Southwest (see Figure 2).[10] With a rise in temperatures of between 5.5 and 8°F (3 to 4.4°C) by the century's end, the medium warming range predicted by the California Climate Change Center, late spring streamflow could drop by as much as 30 percent.[11]

These changes come in addition to projected increases in sea level rise that threaten coastal aquifers with saltwater intrusion, an increase in the number and intensity of extreme storm events that cause erosion and flooding, warmer temperatures that increase evapotranspiration rates and therefore the amount of water needed for irrigation of crops and landscaping, and increased water pollution resulting from rising temperatures and decreased streamflow.[12] There is an urgent need to both manage water and reduce GHG emissions, and LID offers a potential avenue for addressing these concerns. In addition to providing GHG emissions reductions (known as "mitigation" in climate discussions), LID also provides potentially valuable adaptation attributes such as improved water supply reliability and water quality.

Figure 2. Projected changes in runoff for the period of 2041–2060 relative to 1901–1970. Modified from U.S. Climate Change Science Program, 2008.



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CHAPTER 1

LOW IMPACT DEVELOPMENT AND THE URBAN ENVIRONMENT

Low Impact Development is a "comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds."[13] Low Impact Development evolved initially as a stormwater management approach aimed at eliminating—or at least ameliorating—the problems generated by runoff from urban and suburban development at the source. By maintaining or restoring natural hydrologic functions, LID can reduce the volume of runoff and associated pollution discharged from a site. LID incorporates a number of practices to accomplish this goal, including: maximizing infiltration, which recharges local and regional groundwater systems; providing retention areas and slowing runoff, which reduce flooding and erosion; minimizing the impervious footprint of a project; directing runoff from impervious areas into landscaping; and capturing water in rain barrels or cisterns for later use.[14] Through the use of harvesting water, by either infiltration or capture, LID can increase the local supply of water and therefore decrease the need to obtain water from imported or other energy-intensive sources. The Los Angeles Economic Development Corporation has recently cited practices that infiltrate or capture stormwater as having the potential to provide "[h]undreds of thousands of acre-feet" of water.[15]

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Benefits of LID

LID provides important benefits with respect to water quality, pollution abatement, flooding, and erosion control, and it can be implemented under a wide variety of climactic and geographic settings. LID practices, such as green roofs, can additionally be designed to reduce the "urban heat island effect," thereby reducing the need for air conditioning and other energy-intensive residential and commercial uses of electricity.[16] By increasing green space in development projects, LID can improve overall urban aesthetics and provide natural-looking, pleasing cityscapes. The additional open space created by LID site designs can be especially important for low-income communities otherwise disadvantaged with regard to usable urban outdoor areas.

LID techniques can be put into practice, and the above benefits realized, at a broad range of land use types and scales. The EPA has stated that, "LID can be applied to new development, redevelopment, or as retrofits to existing development. LID has been adapted to a range of land uses from high density ultra-urban settings to low density development."[17] Site specific conditions, which may include low permeability soils or the existence of shallow or contaminated groundwater, may mean that not every individual LID practice can be used at every site. But because of the breadth of available LID techniques and strategies, EPA has stated succinctly, "LID Works Everywhere."[18]

Urbanization, Stormwater, and Pollution

Urbanization and development increase the percentage of impervious cover in the landscape (i.e., roads, rooftops, and parking lots that prevent the infiltration of water into soil). Greater impervious cover, in turn, increases the volume and velocity of runoff that results from precipitation.[19] Overall, "most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development."[20] For example, a one-acre parking lot produces 16 times more runoff than a one-acre meadow.[21] This can lead to increasingly severe flooding and erosion and can greatly amplify levels of pollution in surface waterbodies.[22] When the increased volume of runoff flows over paved surfaces, it picks up proportionally higher levels of automotive fluids and debris, pesticides, pet wastes, trash, and other contaminants and carries them to receiving waters.[23]

As the population has grown across the western United States, an ever-increasing percentage of the landscape has been paved and covered with impervious surfaces, drastically altering the natural hydrologic regime of entire watersheds. Land use maps indicating changing activities and land surface cover in the Chino Basin in San Bernardino County, California exemplify this phenomenon, highlighting the type of rapid and intense urban development that has occurred over the last 50 years (see Figure 3). The depicted large-scale shift from agrarian or open land to urban development is characteristic of many areas of the state, which has seen its population grow from 10.5 million in 1950, to more than 36.7 million in 2008, with a further 24 million expected to settle in the state by midcentury.[24,25,26] With the increased impervious surface comes drastically increased runoff and increased stormwater-related pollution.

As a result, the EPA views urban runoff as one of the greatest threats to water quality in the country and considers it "one of the most significant reasons that water quality standards are not being met nationwide."[27] The EPA found that "54 percent of California's impaired waterways are polluted by runoff."[28] California experienced 4,133 beach closing and advisory days in 2008, and "polluted urban stormwater runoff," i.e., runoff from roads, roofs, lawns, construction sites, and other impervious surfaces, "continues to be the largest source of pollution in Santa Monica Bay and across California."[29]

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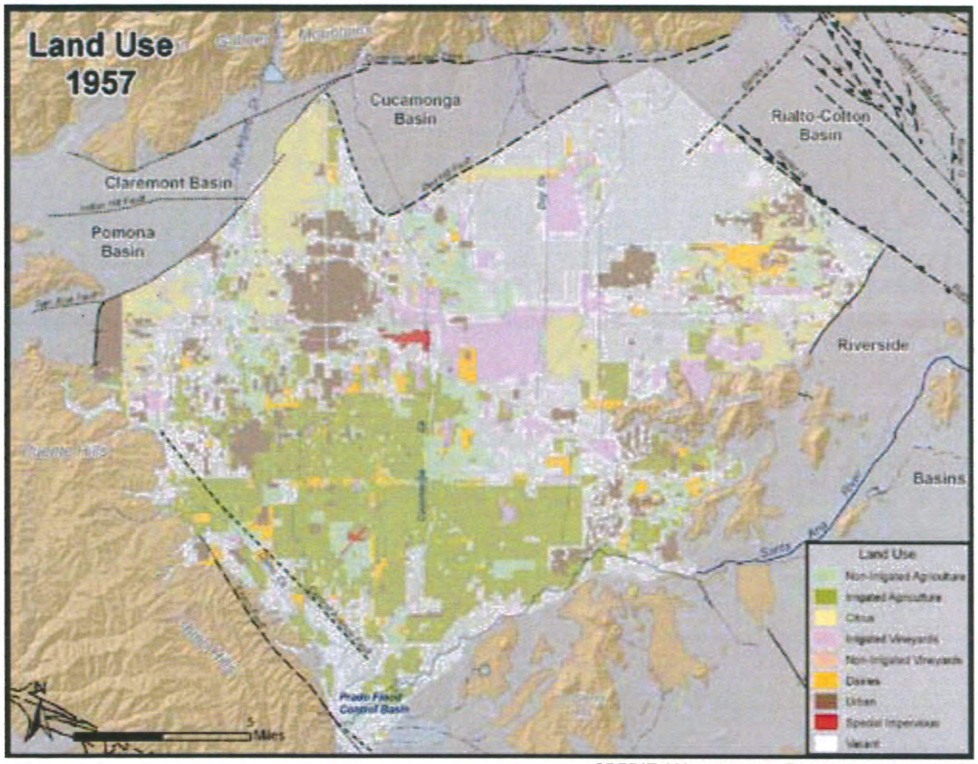

Figure 3a.
Land cover and land use in the Chino Basin, 1957

CREDIT: WILDERMUTH ENVIRONMENTAL, 2009

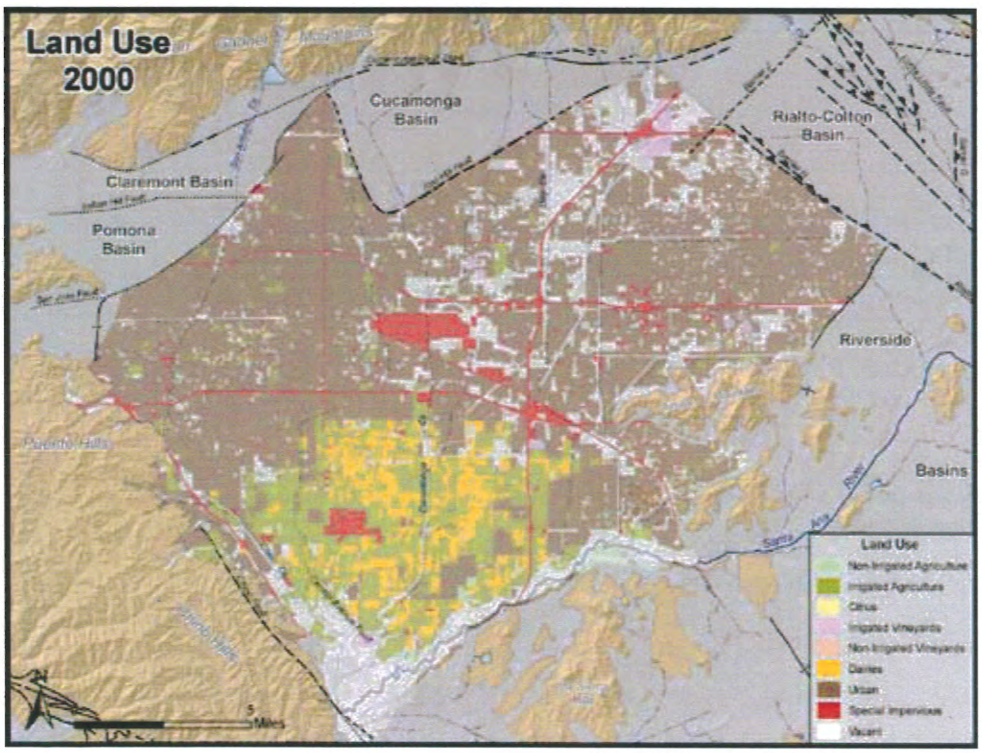

Figure 3b.
Land cover and land use in the Chino Basin, 2000

CREDIT: WILDERMUTH ENVIRONMENTAL, 2009

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Stormwater Regulation and Conventional Management Approaches

In order to prevent the pollution and other harms that result from urban runoff, the Federal Clean Water Act requires municipalities, counties, and other dischargers to impose "controls to reduce the discharge of pollutants to the maximum extent practicable."[30] Dischargers must use "management practices, control techniques and system, design, and engineering methods, and such other provisions which are appropriate."[31] To meet these conditions, dischargers apply for permits under the National Pollutant Discharge Elimination System (NPDES) program. Permittees in California have been increasingly required to treat a certain percentage of runoff that sites generate in order to prevent further pollution to the state's waters.[32] For example, in 2001, the California State Water Resources Control Board adopted Order WQ 2000-11, which "created objective and measurable criteria for the amount of runoff that must be treated or infiltrated" and established a requirement that treatment or infiltration occur for "85 percent of the runoff from specified categories of development."[33]

One method of complying with such permit conditions has been to use conventional stormwater management practices to address water quality concerns (as opposed to addressing or limiting the volume of runoff generated at a site directly). With conventional practices, "structural" or engineered solutions are employed to transport runoff away from developed sites as quickly as possible—through curbs, gutters, buried drainage pipes, and centralized combined sewer systems—to treatment facilities or directly to receiving waters.[34] Because treatment occurs in this system, if at all, only after pollutants have already entered stormwater, conventional practices are often less effective than LID at removing pollution in urban runoff and mitigating its impacts on surface waterbodies.[35]

In combined sewer systems, stormwater runoff is collected and conveyed in the same pipe as domestic sewage and industrial wastewater. Under normal conditions, the wastewater is transported to a sewage treatment plant for treatment. However, during periods of heavy rainfall or snowmelt, "the wastewater volume in a combined sewer system can exceed the capacity of the sewer system or treatment plant."[36] For this reason, combined sewer systems are designed to overflow occasionally and discharge excess wastewater directly to nearby streams, rivers, or other waterbodies, resulting in "stormwater, . . . untreated human and industrial waste, toxic materials, and debris" pouring directly into receiving waters.[37] Consequently, the EPA considers combined sewer overflows to be "a major water pollution concern for the approximately 772 cities in the U.S. that have combined sewer systems."[38] In municipalities that maintain separate sewer systems, which collect and convey stormwater independently of domestic sewage, "polluted stormwater runoff is commonly transported through [the storm sewer], from which it is often discharged untreated into local waterbodies."[39] Use of these conventional controls has been the dominant paradigm for addressing the challenges posed by stormwater across the United States for decades, with unfortunate consequences to the health of our nation's surface waterbodies.


Drainage swale as part of Seattle's SEA (Street Edge Alternatives) Project / CREDIT: EPA/ Abby Hall

Stormwater Management through LID

The California Ocean Protection Council recently found that "LID is a practicable and superior approach" to stormwater management and that LID practices can be used "to minimize and mitigate increases in runoff and runoff pollutants and the resulting impacts on downstream uses,

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coastal resources and communities" at a variety of development and redevelopment projects.[40] LID uses improved design approaches such as strategically placed beds of native plants, rain barrels, green roofs, permeable or porous surfaces for parking lots and roads, and other features to reduce runoff by helping rainfall soak into the ground or to otherwise retain rainfall onsite, rather than allowing runoff to pollute the nearest waterbody. This aspect of LID mimics nature's own infiltration and filtering systems;[41] runoff accumulates less pollution because it flows over less impervious surface. Bioswales, basins, trenches, and other infiltration devices use absorption, settling, and the soil's natural capacity to filter pollutants to achieve 70 to 98 percent contaminant removal.[42] The result is less water pollution from stormwater runoff, reduced flooding, replenished water supplies, and more natural-looking, aesthetically pleasing cityscapes. One recent study concluded that through implementing "Green Solution" projects that "employ soil, plants, and natural processes to capture, filter and clean polluted urban and stormwater runoff" solely on existing public lands within Los Angeles County, nearly 40 percent of the county's polluted runoff clean-up needs could be met.[43] Furthermore, LID strategies that preserve existing vegetation and include vegetated and grassy swales and tree-box filters can help sequester GHG emissions and reduce the "heat island" effect in urban areas.

Under the Clean Water Act, dischargers are required to control post-construction stormwater runoff. In some jurisdictions, use of LID has already become the required paradigm for addressing this runoff.[44] Moving to require the implementation of LID practices simply represents a commonsense means of requiring compliance with the law.

Cost Effectiveness of LID

In addition to the environmental benefits, implementation of LID practices instead of conventional stormwater controls often results in substantial financial savings and provides a valuable water supply at low cost. The EPA has stated that "[i]n the vast majority of cases...implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality."[45] Further, "LID...provides ecosystem services and associated economic benefits that conventional stormwater controls do not."[46] Our findings suggest that increased water supply, energy savings, and GHG emissions reductions should be added to the list of benefits.

Because traditional stormwater management approaches involve the construction of complex systems of infrastructure, they can entail substantial costs. Since LID attempts to mimic the predevelopment hydrology of a site, emphasizing storage and use, infiltration, and use of a site's existing drainage conditions, "[c]ost savings are typically seen in reduced infrastructure because the total volume of runoff to be managed is minimized."[47] Although costs of LID implementation vary depending on site and/or project conditions and the specific practices or techniques implemented, with only "a few exceptions," the EPA found that "total capital cost savings ranged from 15 to 80 percent when LID methods were used" instead of conventional stormwater management techniques.[48,49] The City of Seattle found similar savings for street design or improvement projects, as projects that employ natural drainage techniques "cost about 10 to 20 percent less than traditional street redevelopment with curb, gutter, catch basins, asphalt, and sidewalks."[50] Further, because LID practices represent a new technology with initial costs for learning, design, and installation, costs are declining with time.[51] The U.S. Department of Defense notes that, "As with any new approach, the cost of implementing LID will decrease as institutional experience increases and the benefits of using LID are realized in practice."[52]

The savings identified in studies documented by federal and other agencies are all the more noteworthy considering that they count only the costs of installation for LID and conventional controls. The savings identified do not reflect the additional economic benefits that LID provides. This is particularly relevant for projects that capture rainwater; the EPA study stated that for one of the "few exceptions" in the report, the cost of a rooftop runoff capture system installed at a site "was assumed to be offset somewhat by savings on stormwater utility bills" that were not calculated into the cost of the project.[53] Further savings would be available in the form of reduced water bills resulting from the increased availability of onsite supply. In addition to offsetting project costs, LID can result in economically beneficial externalities including reduced costs of municipal infrastructure, greater control of combined sewer overflow (CSO) events, and increased value of real estate.[54,55,56]

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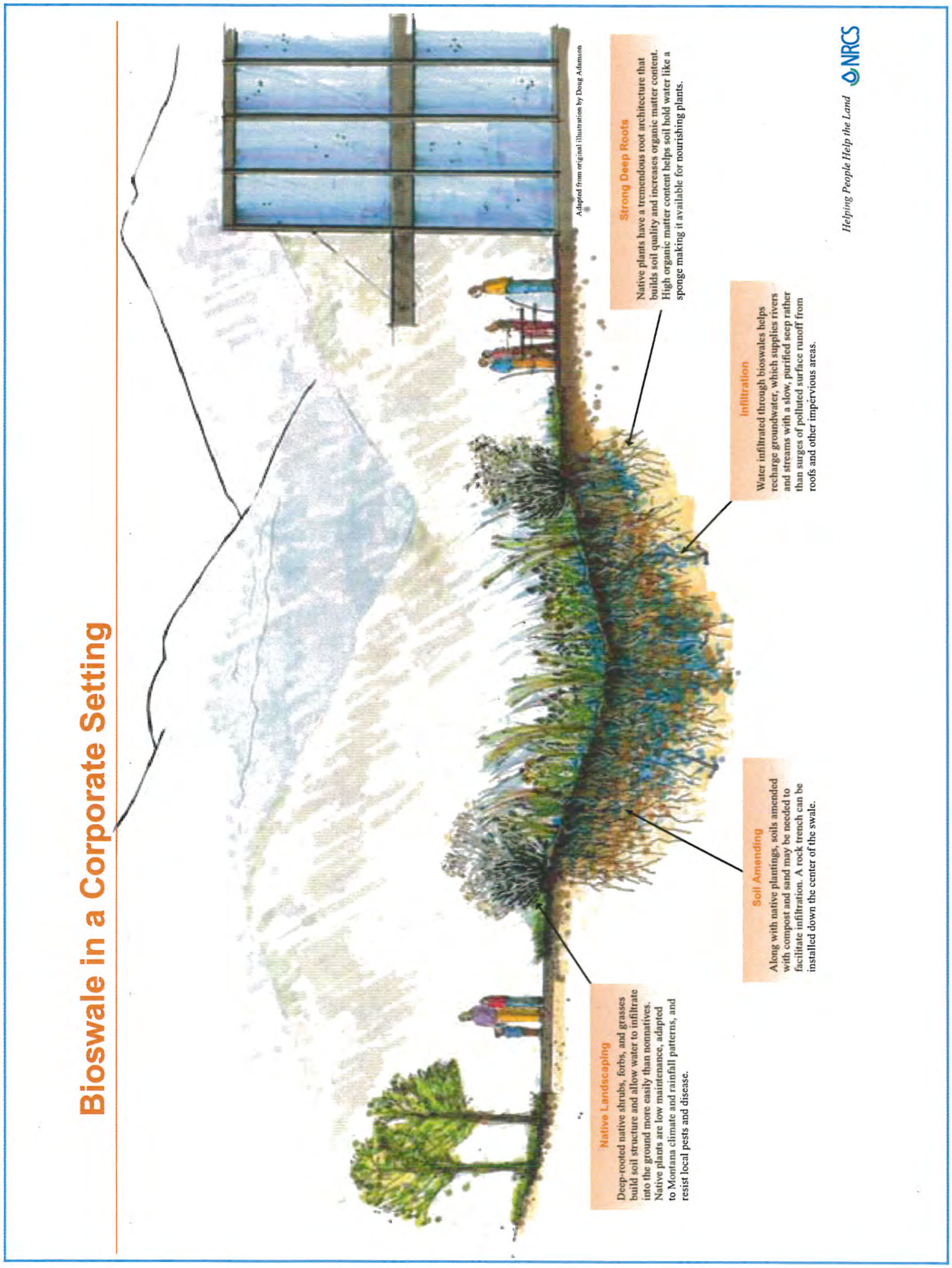
Figure 4. Example of a LID practice promoting infiltration (USDA/Iowa NRCS, 2008).[57]



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Examples of LID practices that promote infiltration or capture.

PHOTO CREDIT: Haan-Fawn Chau

Vegetated swales: Vegetated swales are broad, shallow channels with dense stands of vegetation, such as trees, shrubs, or grasses, covering the side slopes and bottom. Swales are designed to trap or filter particulate pollutants, promote infiltration, and reduce the flow velocity and erosive impacts of storm water runoff.[58]

PHOTO CREDIT: Photo courtesy of USDA NRCS

Rain gardens: Rain gardens are small gardens generally planted with native vegetation and designed to withstand extremes of moisture and high concentrations of nutrients such as nitrogen and phosphorous commonly found in stormwater runoff. Rain gardens collect stormwater runoff both to slow the flow of water and give the water more time to infiltrate.[59]

PHOTO CREDIT: EPA/Abby Hall

Porous pavement and permeable pavers : Porous and permeable pavement surfaces absorb water and allow stormwater runoff to infiltrate into the soil beneath the paved surface. Porous pavements may include porous asphalts and porous concretes, which contain little fine grained material, leaving void spaces that allow for rapid percolation of runoff.[60] Permeable pavers create networks of interlocking blocks that allow water to percolate through gaps between the paving blocks.[61]

PHOTO CREDIT: HEPA/Abby Hall

Rainbarrels and cisterns: Rainbarrels and cisterns are used to collect and store rainwater from rooftops or other paved surfaces that would otherwise be diverted to storm sewer systems and lost. The water can then be used for nonpotable purposes such as landscape irrigation or flushing toilets. Rainbarrels typically collect water from gutters and downspouts, and are small, generally inexpensive solutions for smaller residential buildings. Cisterns can vary in size from small household units to large, several thousand gallon tanks, and can be sited above ground or underground.

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CHAPTER 2

CALIFORNIA'S WATER SUPPLY, WATER HARVESTING, AND LID

LID practices that emphasize harvesting rainwater, or redirecting and collecting runoff for beneficial use, include two general categories of techniques: use of infiltration to recharge groundwater supplies, or capture for onsite use. Groundwater forms when precipitation falling on land infiltrates the soil and percolates to depth, creating aquifers in water-bearing rock layers. In the natural hydrologic regime, up to 40 or 50 percent of this precipitation may be lost to evapotranspiration, a combination of evaporation from the soil and transpiration by plants, and up to 10 percent is converted to surface runoff that does not infiltrate.[1] This still leaves up to 50 percent or more of the precipitation to infiltrate the ground surface, either as shallow infiltration or as deep percolation reaching the water table. However, as impervious surfaces such as roads, rooftops, and parking lots have increased dramatically with development, water is prevented from penetrating the ground surface, the volume of runoff increases, and the volume of infiltration decreases.[2]

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When impervious cover reaches 75 percent and above, as it does in many urban areas, it may result in more than a five-fold increase in surface runoff and a corresponding 70 percent drop in infiltration, with the greatest decrease seen in the quantity of water that percolates to sufficient depths to recharge groundwater.[3] LID practices that maximize infiltration allow for natural recharge to augment local supplies of water despite the effects of urbanization. A fundamental LID technique is amending native soils to increase their ability to absorb and store water for subsequent infiltration, which can broaden opportunities to employ infiltrative LID practices. LID techniques that promote capture of rainfall, used either to augment or in conjunction with infiltration practices, can also offer a significant opportunity to increase local water supplies where the natural hydrologic regime has been altered by development.

Groundwater Resources and Recharge in California

California is the nation's largest producer of groundwater, extracting nearly twice as much as the next state, Texas.[4] The average of 17 million acre-feet withdrawn in the state per year accounts for nearly 20 percent of all groundwater extracted in the United States annually.[5] Approximately 30 percent of California's urban and agricultural water needs are supplied by groundwater in an average year, a figure that rises to 40 percent or more during periods of drought.[6] As such, groundwater is rightfully called "one of California's greatest natural resources" and its continued supply is integral to California's environmental, economic, and social well-being.[7]

In southern California, groundwater has been used for over 150 years, and "the story of the growth of the region becomes the story of the utilization and application of its available waters."[8,9] Since settlers drilled the first groundwater wells, population has boomed, urban areas have sprawled, and the percentage of landscape covered with paved and impervious surfaces has expanded dramatically. This, in turn, has transformed the hydrologic regime that forms and replenishes groundwater upon which the region depends. Rainfall that would infiltrate the ground and recharge groundwater supplies under natural conditions is instead diverted and transported away by stormwater conveyance systems. Despite the diminishing recharge, groundwater continues to supply an average of 1.56 million acre-feet of water per year to the region.[10] Approximately 40 percent of the Metropolitan Water District of Southern California's (MWD) member agencies' water supply consists of groundwater in an average year.[11] Based on data from the most recent urban water management plans for each of the 26 member agencies located within the MWD service area, we created a map to illustrate the magnitude of southern California's dependence on groundwater supply. Each pie chart on the map in Figure 5 represents the overall water supply for an individual agency, with each sector of a chart indicating the percentage of water for that agency supplied from groundwater, the SWP, Colorado River, or other source. As the map illustrates, water agencies in a number of areas, including eastern Los Angeles, San Bernardino, and Orange counties, rely on groundwater as the principal source for municipal water supply. Even for the majority of those MWD agencies where groundwater is not the dominant source of water, it still forms a substantial percentage of the supply.

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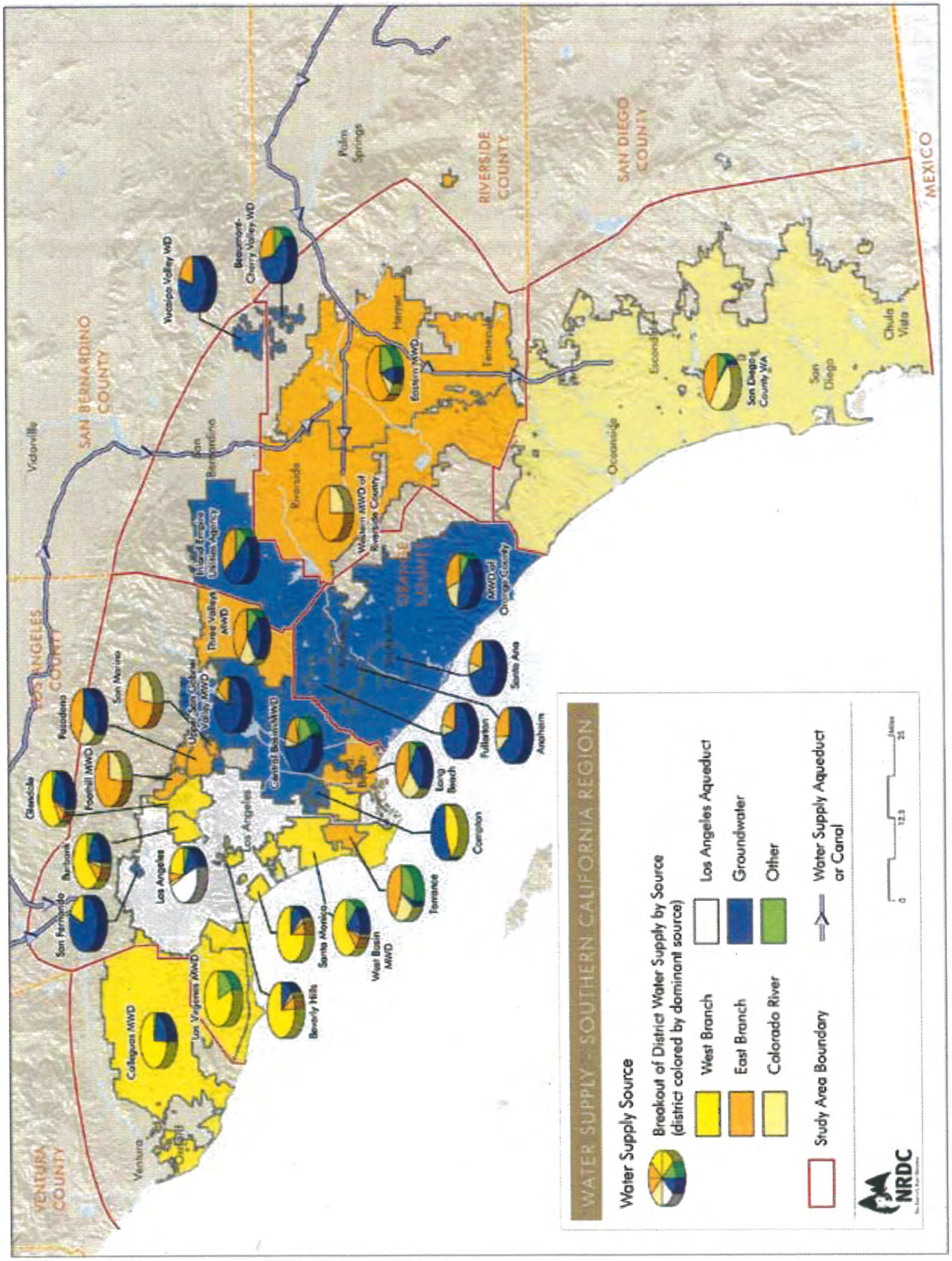
Figure 5: Water supply sources and classification for southern California (based on 2005 statistics)



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Moreover, southern California is rich in groundwater potential, with a total estimated available basin capacity in MWD's service area of 3.2 million acre-feet.[12] Recharge of these basins is currently provided by imported water as well as local precipitation and runoff. Particularly where groundwater basins are currently or have historically been subject to overdraft (i.e., the amount of water withdrawn from the aquifer exceeds the amount of recharge it receives), such as the Chino Groundwater Basin or the Central and West Coast Groundwater basins on the coastal plain of Los Angeles, opportunities exist to restore natural hydrologic function that has been disrupted by development. Current trends are toward increased local rainwater recharge, and the LID strategies examined in this study would both follow and enhance this trend. Conditions for groundwater recharge are generally favorable throughout much of southern California, as soils underlying most of the region are highly permeable, allowing rapid infiltration into groundwater basins.

In the San Francisco Bay Area, groundwater plays a more limited, yet still vitally important role in ensuring the safe, sufficient supply of water to the region's population. For example, the Santa Clara Valley Water District, which provides water to 1.7 million Californians, has stated that "[g]roundwater is our most critical local asset for ensuring adequate water supplies now and in the future."[13,14] About one-half of the water used in Santa Clara County each year comes from local groundwater supply, and the Water District there considers it to be the region's "best protection against droughts."[15]

Groundwater recharge potential further exists in areas not traditionally viewed as having ideal conditions for infiltration. In the Los Angeles-Orange County coastal plain aquifer system contrasting layers of highly permeable gravels and finer-grained deposits that shape the region's hydrologic characteristics have resulted in large deposits of relatively shallow groundwater separated from the deeper, regional groundwater systems by the finer-grained deposits.[16] Generally, water managers have not utilized the shallow aquifers that characterize portions of the basin because of low yields, and in some places, poor water quality.[17] The increasing need for viable water supplies has begun to shift thinking on the potential for obtaining water from these aquifers. According to Ted Johnson, chief hydrogeologist at the Water Replenishment District of Southern California, the water has not generally been used for domestic or irrigation supply in recent years, "but it could be done... the water could be extracted and treated as needed for use... reverse osmosis may be needed if the water is too mineralized, or activated carbon if there is volatile organic contamination, but these technologies exist. There are entities pumping out shallow groundwater right now for dewatering purposes and we are looking at putting that water to beneficial use instead of losing it to the ocean."[18] All told, there is significant potential for LID practices that emphasize infiltration of stormwater to replenish water supply in this area.

Capture

Capturing rainfall for use onsite offers a similar opportunity to increase local supply of water and may be used where soils or surface conditions, such as the presence of shallow groundwater or groundwater contamination, are not highly amenable to infiltration or may be used concomitant with infiltration. For example, where development occurs over relatively impermeable soils or in densely developed urban environments, LID techniques favoring capture can "reduce annual runoff volumes by almost half to more than 3/4...with much of the water saved available for a beneficial use."[19] Water capture techniques are typically, though not exclusively, used to harvest rooftop runoff and can be applied at both large scale in commercial developments and residential subdivisions and at small scale using cisterns or rain barrels. Existing LID development has shown that capturing water is successful at reducing runoff discharged to storm drain systems and at conserving water for later use at all scales and under a variety of conditions. For example, the King Street Center in downtown Seattle uses water captured from roof runoff to supply over 60 percent of the building's toilet flushing and irrigation requirements, saving approximately 4.3 acre-feet of potable water per year.[20] On a smaller scale, the Carkeek Environmental Learning Center in Seattle drains rooftop runoff into a 3,500-gallon cistern to supply toilets.[21] As the average urban roof at a residential or commercial development accounts for 40 to 60 percent of the site's total impervious surface area (and therefore 40 to 60 percent of impervious surface runoff), vast quantities of water are available for harvesting to offset the need for other, more energy-intensive sources of water.

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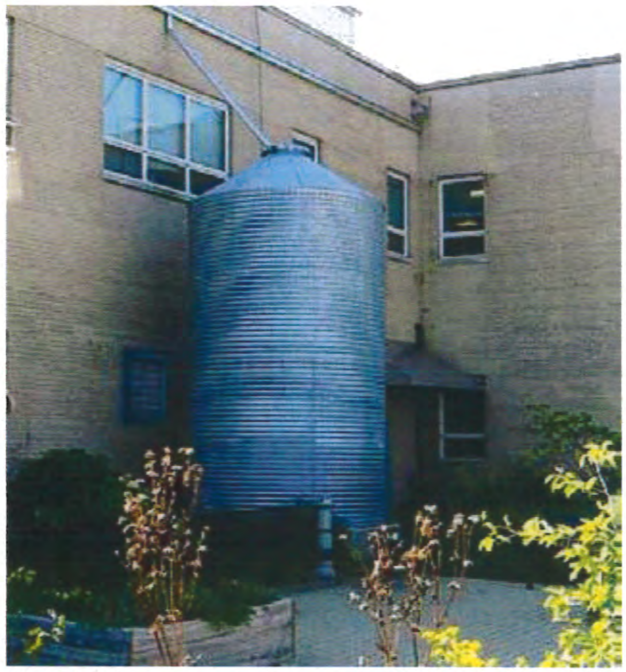
Regardless of the method used, there is tremendous potential throughout California to increase local water supply and reduce reliance on imported water or desalinated ocean water sources that generate considerable GHG emissions.

Rain barrel in Santa Monica, CA CREDIT: EPA/Abby Hall



Cistern in Chicago CREDIT: EPA/Abby Hall

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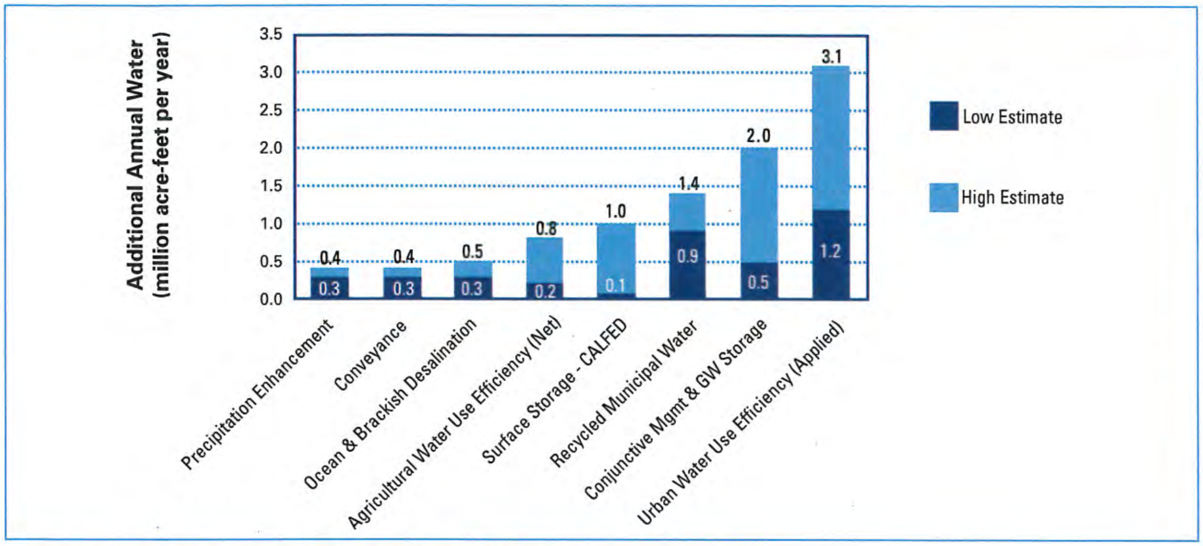
CHAPTER 3

WATER SUPPLY AND ENERGY IN CALIFORNIA

In California, water systems account for a staggering 19 percent of total electricity use and about 33 percent of non-power-plant natural gas use.[1] A significant portion of the electricity is used in the conveyance of water, which in California requires electricity inputs "substantially above the national average."[2] Water is now recognized as one of the largest electricity users in California, and both the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have concluded that the energy embedded in water presents large, untapped opportunities for cost effectively improving energy efficiency and reducing GHG emissions.[3] Although the energy embodied in a unit of water varies with location and source, moving large quantities of water long distances and over mountain ranges, treating and distributing it within communities, water use and collecting and treating the resulting wastewater are each energy-intensive processes. Urban water use efficiency, groundwater management, and recycling or reuse have been identified by the Department of Water Resources (DWR) in its 2005 State Water Plan as the largest new water supply sources for the next quarter century. Capture presents an additionally significant opportunity to increase the energy-efficient supply of water. The following graph indicates the critical role these measures will play in California's water future.

Figure 6. Water management and supply options for the next 25 years. From the California State Water Plan 2005, California Department of Water Resources, 2005.[4]



The Energy Intensity of Water in California

Importing Water

California's water systems are energy intensive due in part to the pumping requirements of major conveyance systems that move large volumes of water long distances and over thousands of feet in elevation. Certain interbasin transfer systems, such as California's SWP and the Colorado River Aqueduct (CRA), require large amounts of electrical energy to convey water.

Figure 7. Energy intensity of major water supply options in southern California. Robert Wilkinson, based on data from IEUA, West Basin MWD, DWR, and desalination estimates.

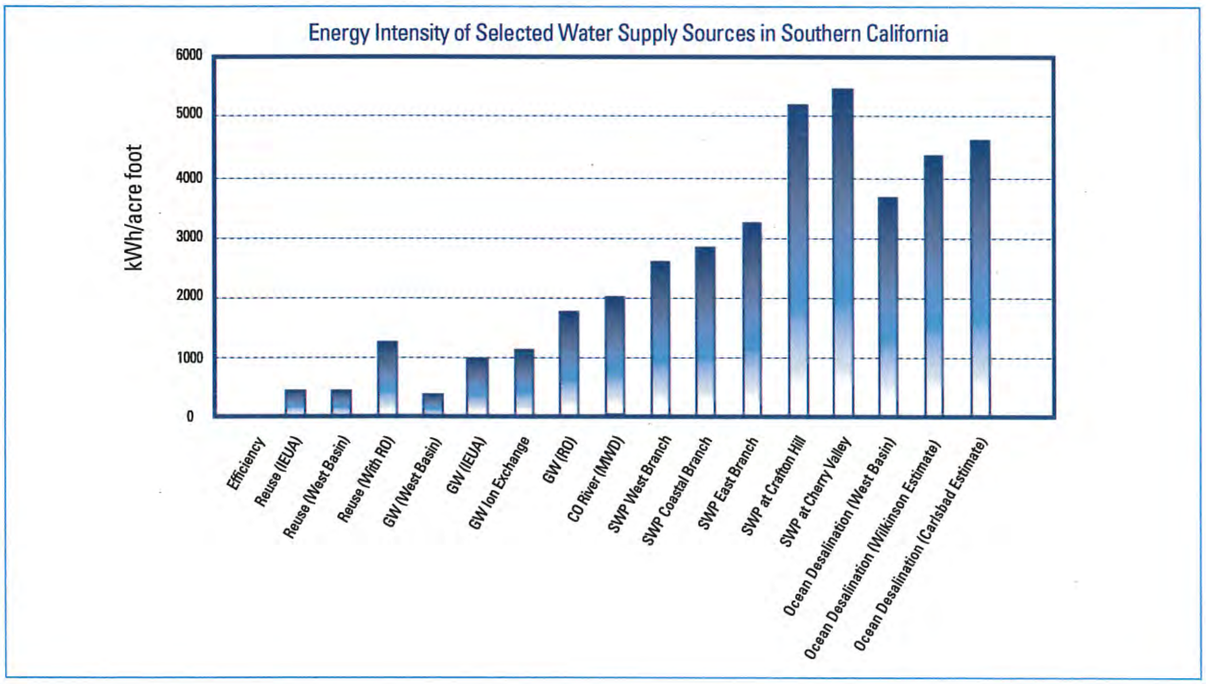


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Figure 7 shows the energy intensity of major water supply options for inland and coastal locations in southern California. Each bar represents the energy intensity, expressed in kilowatt-hours per acre-foot, of a specific water supply source delivered at selected locations in southern California. Since water efficiency requires no energy inputs for pumping or treatment, it is shown as zero. For all other water resources, there are energy inputs that depend on many factors, including the quality of source water; the energy intensity of technologies used to treat the source water to quality standards for end users; the distance water needs to be transported to reach end users; and the efficiency of the conveyance, distribution, and treatment facilities and systems.[5]

Water pumping plants employed in the supply of imported water account for some of the largest electrical loads in the state. For example, the SWP's Edmonston Pumping Plant, situated at the foot of the Tehachapi Mountains, pumps water up 1,926 vertical feet, the highest single lift of any pumping plant in the world. It is the largest single user of electricity in the state.[6] In total, the SWP is the largest overall user of electricity in California.[7] Water use (based on embedded energy) is the second or third largest consumer of electricity in a southern California home after refrigerators and air conditioners,[8] and the electricity required to support water service in the typical home in southern California is estimated to be 14–19 percent of total residential energy demand.[9]

Figure 8. State Water Project Energy Inputs and Recover . Robert Wilkinson, based on data from California Department of Water Resources. (kilowatt-hours per acre-foot pumped—includes energy recovery)

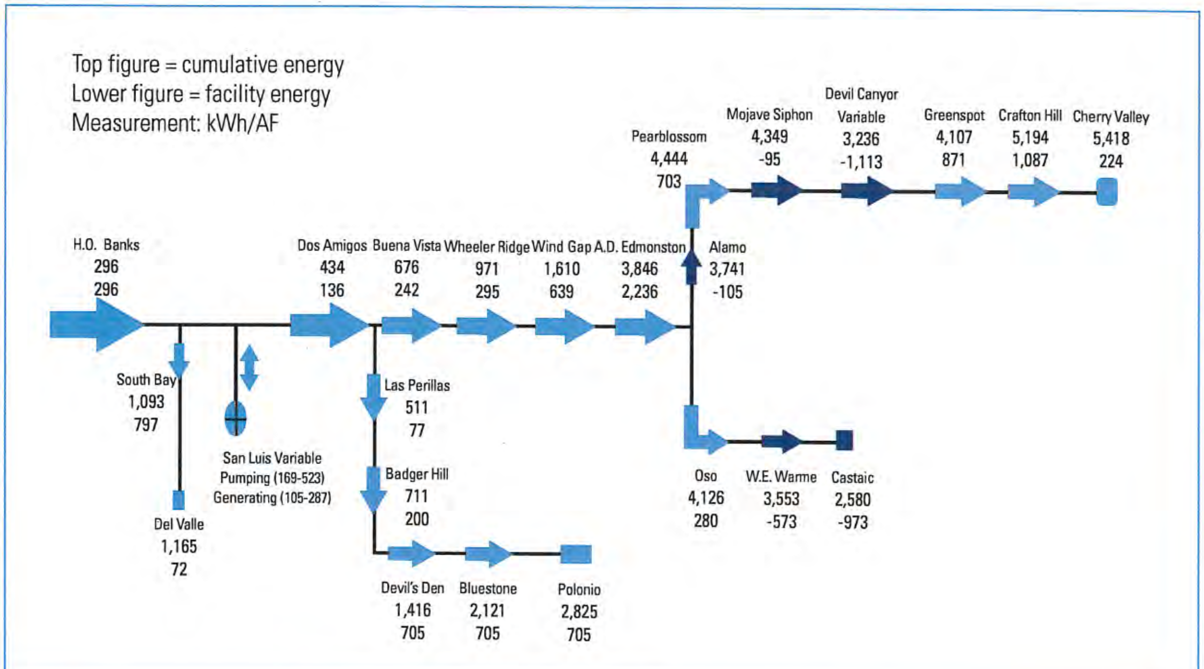

Figure 8 shows the cumulative net energy requirements and the incremental energy inputs or outputs at each of the pumping and energy recovery facilities of the SWP. Energy recovery is indicated with negative numbers, which reduce net energy at that point in the system.

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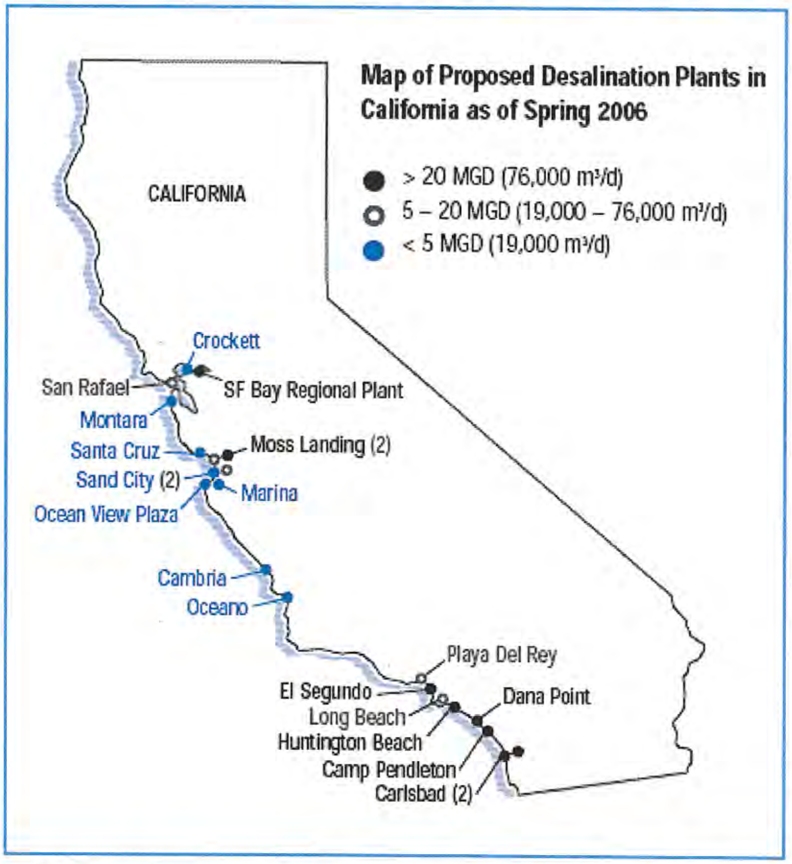
As shown in Figure 8, approximately 2,580 kWh are required to pump one acre-foot of SWP water from the Sacramento-San Joaquin Delta to Castaic on the West Branch of the SWP; 3,236 kWh/af are required to reach the Devil's Canyon Power Plant on the East Branch.[10] Additionally, approximately 2,000 kWh/af are required to pump Colorado River water to southern California.[11] The water from these systems is delivered raw (untreated) to those points. From there, conveyance continues by gravity or pumping to treatment and distribution systems within individual service areas. In general, service areas at higher elevations have higher energy requirements. Thus, at Cherry Valley and other locations near the terminus of the East Branch, the energy intensity required for raw water supply is as high as 5,418 kWh/af.

Ocean Desalination

Twenty individual seawater desalination plants have been proposed for operation in California. Four plants, with a combined maximum proposed capacity of more than 100,000 acre-feet per year, have been proposed in the San Francisco Bay area alone.

Figure 9. Planned seawater desalination plants as of 2006 (Cooley, Heather, Peter H. Gleick, and Gary Wolff, 2006).[12]



Whereas ocean desalination is being pursued as a potential measure for supplying additional water, environmental and cost concerns regarding the desalination process remain controversial. Pacific Ocean salinity is 34–38 grams/Liter (g/L), while brackish water contains 0.5–3.0 g/L. Potable water salt levels should be below 0.5 g/l. Using existing technologies to reduce salt levels from over 30 g/L to 0.5 g/L and lower (to meet drinking water standards) requires considerable amounts of energy for the pressure to drive water through extremely fine filters in the process of reverse osmosis (RO). (All of the desalination facilities proposed in California utilize RO technology.) As a result, ocean desalination requires an estimated 4,400 kWh/af to supply potable water. Improvements in desalination technology have lessened the amount of pumping energy required for this process, but high energy intensity is still an issue. Furthermore, the seawater intake process for many coastal plants raises significant ecological concerns, as impingement and entrainment can result in the deaths of large numbers of aquatic organisms, including fish, invertebrates, and their eggs and larvae.[13] Disposal of highly concentrated brine resulting from the RO process also remains a concern.

Groundwater Recharge and Capture

Next to efficiency, recycled water and groundwater are lower energy-intensive options than other marginal (e.g., new) water resources in most heavily populated areas of California.[14] Even with advanced treatment to remove salts and other

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contaminants, recycled water and groundwater (the Reuse and GW columns in Figure 7) usually require far less energy than imported water (CO River and SWP) and seawater desalination (Desal), as does capture and onsite use. For example, even the Chino desalter, which uses an RO treatment process to provide high-quality potable water by removing dissolved solids such as salt from impaired groundwater in the inland Chino groundwater basin (GW (RO) in Figure 7), is far less energy intensive than any of the imported sources. From an energy standpoint, greater reliance on LID practices that emphasize groundwater recharge and capture provides considerable benefits. These energy benefits also include significant potential GHG emissions reductions.

Groundwater pumping energy requirements vary depending on the lift required. As illustrated in Figure 7, the energy required to produce groundwater in the West Basin municipal water district is approximately 350 kWh/af, while in the Inland Empire groundwater production requires 950 kWh/af. In the City of Los Angeles, groundwater requires 580 kWh/af to produce.[15] Analysis of different sources provides a reasonably consistent finding: local groundwater is less energy intensive than imported water from the SWP, CRA, or ocean desalination.

Increasing the availability of energy-efficient, local water supply could therefore result in a savings for individual end users and an overall reduction in the energy required to supply water.

Figure 10. Energy intensity of marginal water supply sources in Southern California by area

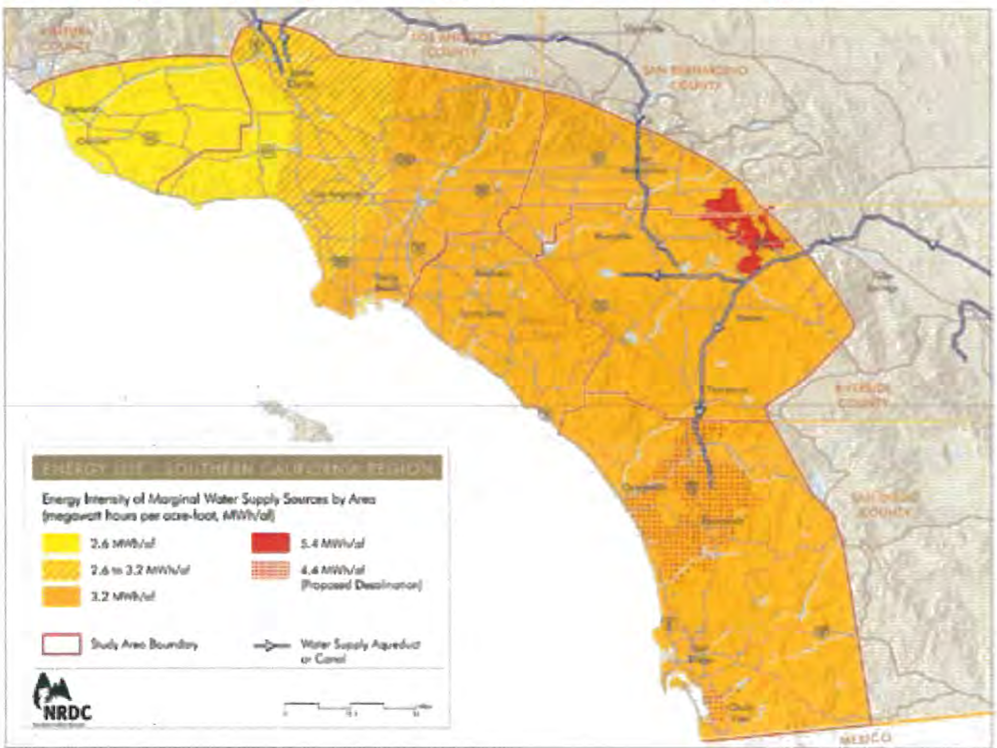

Figure 10 shows the energy intensity of marginal water supply in southern California, based on our review of water supplies and corresponding energy requirements for water sources. In all of these areas, the increased use of groundwater or of water captured from rooftop runoff can be used to offset the more energy-intensive water supply.

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CHAPTER 4

THE POTENTIAL FOR LOW IMPACT DEVELOPMENT IN CALIFORNIA

We analyzed land use, water supply patterns, and the energy consumption of water systems in order to determine the benefits of LID, including: 1) the volume of additional water supply that could be provided through the implementation of LID practices; 2) the resulting savings of energy due to increased availability of local water supply; and 3) the associated reduction of GHG emissions. Our study represents one of the first attempts to quantify the water supply benefits of LID on a regional basis by using large-scale, GIS-based land use data. Further, it quantifies the connection between the energy intensity of water supply and LID water management practices that can serve to reduce energy use. In this section, we discuss the details of our analysis, as well as study parameters and the assumptions made in quantifying the water, energy, and GHG emissions reduction benefits that can be derived from LID.

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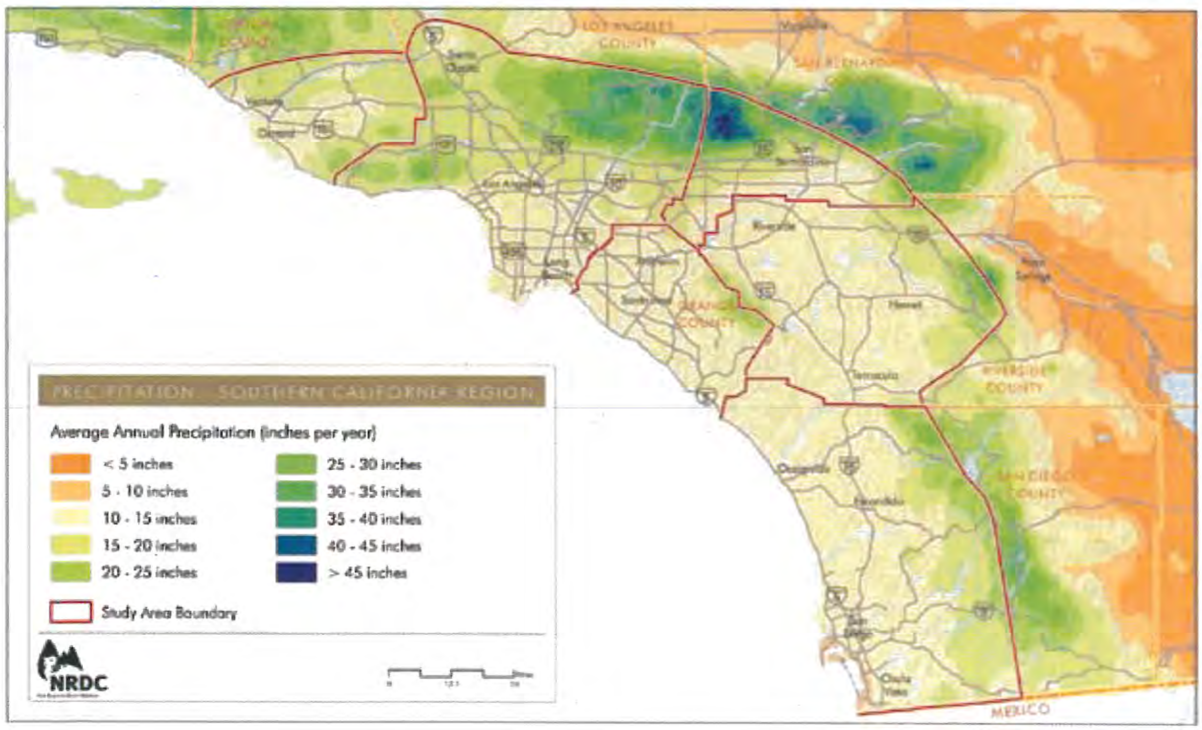
Selection of Study Areas

In order to assess LID's potential for water and energy benefits and emissions reductions, the study focused on coastal areas of urbanized southern California and the San Francisco Bay area. These regions represent the two most heavily urbanized and developed regions of California and incorporate the majority of the state's population—approximately 50 percent of the state's residents live in the counties located within the southern California study area and an additional 20 percent live in the San Francisco Bay region.[1] The study areas include a wide range of energy use per unit of water delivered. Imported water accounts for roughly half of urban water supply in the southern California region, with energy inputs requiring between 2,000 kWh (Colorado Aqueduct) and 5,418 kWh (SWP at the terminus of the East Branch) per acre-foot delivered. (See Figures 5 and 10 detailing marginal supply of energy from imported sources.) The San Francisco Bay region, which relies heavily on imported surface water, is the site of four proposed ocean desalination plants with an estimated capacity of between 35,800 and 108,700 af/year and an embedded energy requirement of an estimated 4,400 kWh/af.[2,3] Rainfall averages roughly 10 to 15 inches annually in most portions of the southern California study area (Figure 11) and from 18 to more than 30 inches annually in the San Francisco Bay region.[4] These areas are projected to see substantial population growth accompanied by development that could implement LID practices to maximize groundwater recharge and/or rainfall capture.

Figure 11. Precipitation map of urbanized southern California (based on NRCS PRISM average annual precipitation, 1961-1990)

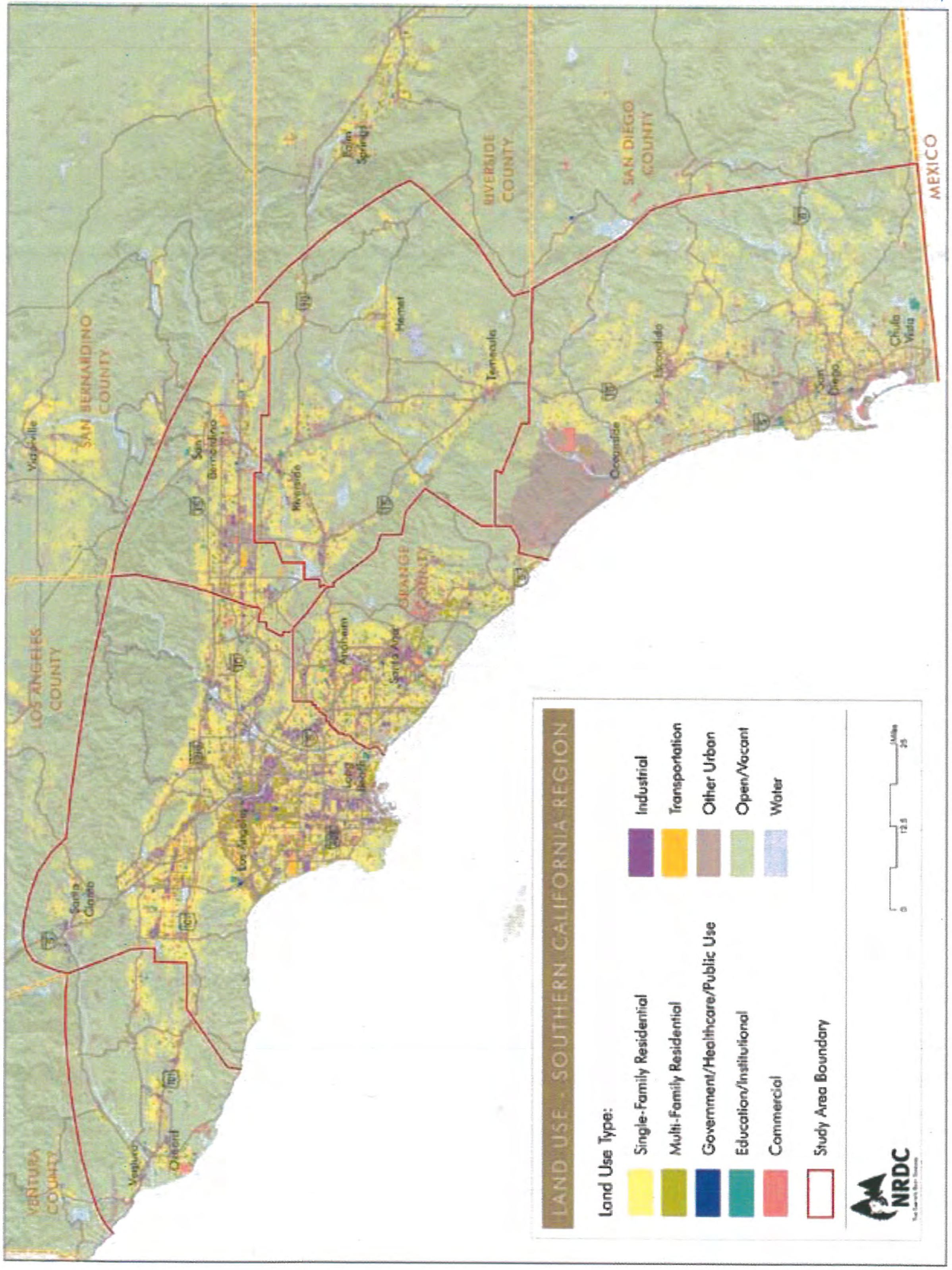


Coastal Urban Southern California

The southern California study area includes San Diego County, Orange County, and portions of Ventura, Los Angeles, San Bernardino, and Riverside counties (Figure 12). The study area is loosely defined by the Topatopa Mountains to the northwest, the San Gabriel Mountains and San Bernardino Mountains (which form a border between the greater Los Angeles area and San Bernardino and the Mojave desert) to the north, and the San Jacinto Mountains to the east.

RB-AR34000

Figure 12. Map of land use within the southern California study area (based on SCAG 2005 and SANDAG 2007 land use data sets)



San Francisco Bay Region

The San Francisco Bay region study area includes all or portions of San Francisco, Marin, Contra Costa, Alameda, Santa Clara, and San Mateo counties (Figure 12).

Seawater desalination plants have been proposed to supplement water supply in areas serviced by agencies including Marin County, the East Bay Municipal Utilities District, Contra Costa Water Agency, San Francisco Public Utilities Commission, and Santa Clara Valley Water District. Because ocean desalination has not yet been proposed for supply in Sonoma, Napa, and Solano Counties, we do not include these areas in our analysis, though substantial opportunities to increase local water supply through groundwater recharge and capture do exist in these areas.

Figure 13. Map of land use within the San Francisco Bay study area (based on ABAG 2006 planned land use data set)

Results

Our analysis found that LID has a substantial potential to save both water and energy in California. In just the urbanized areas of southern California and limited portions of the San Francisco Bay area, LID could provide 229,000–405,000 acre-feet of water per year by 2030, with a corresponding annual electricity savings of 573,000–1,225,500 megawatt-hours and a reduction of 250,500–535,500 metric tons of CO_2.[5] The wide ranges of potential water supply, energy, and GHG reductions reflect a set of variables and input values that include low, medium, and high estimates. These figures will increase with continued development and redevelopment after 2030. As much as an additional 75,000 acre-feet of water could be saved annually by 2030 through implementing LID practices at new industrial, government and public use, and transportation development or redevelopment in southern California alone.

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION WATER SAVINGS—2030 (Acre-feet per year, af/yr)

	Southern California	San Francisco Bay	TOTAL
Low	194,500	34,500	229,000
Medium	265,500	49,000	314,500
High	342,000	63,000	405,000

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION ENERGY SAVINGS—2030 (Megawatt-hours per year, MWh/yr)

	Southern California	San Francisco Bay	TOTAL
Low	443,500	129,500	573,000
Medium	676,500	190,500	867,000
High	974,500	251,000	1,225,500

FINDINGS FOR SOUTHERN CALIFORNIA AND SAN FRANCISCO BAY REGION CO_2 SAVINGS—2030 (Metric tons per year)

	Southern California	San Francisco Bay	TOTAL
Low	194,000	56,500	250,500
Medium	295,500	83,500	379,000
High	426,000	109,500	535,500

Methodology

The volume of water, associated energy savings, GHG emissions reductions were calculated based on analyses of urbanized southern California and portions of the San Francisco Bay area. Though LID practices are ultimately applicable to any land use or development type, we focused our initial analysis on commercial and residential development because of data availability regarding future new development and redevelopment rates, as discussed below.

RB-AR34003

Energy savings are calculated based on current and projected marginal water supply sources in each area. Although individual water suppliers will determine what source to take less of for supply if it is not required (for example, if additional water were to become available through use of LID practices), in general, suppliers will reduce supply of the most expensive source, which in California is usually the most energy intensive. Imported water and ocean desalination would be the sources for which demand would be reduced, and we compare the energy required to augment water supplies through LID to these marginal sources. The difference between energy requirements for LID applications (groundwater pumping, onsite capture and use, treatment, etc.) and current marginal water supplies (SWP, desalinated ocean water) is the basis for the calculations.

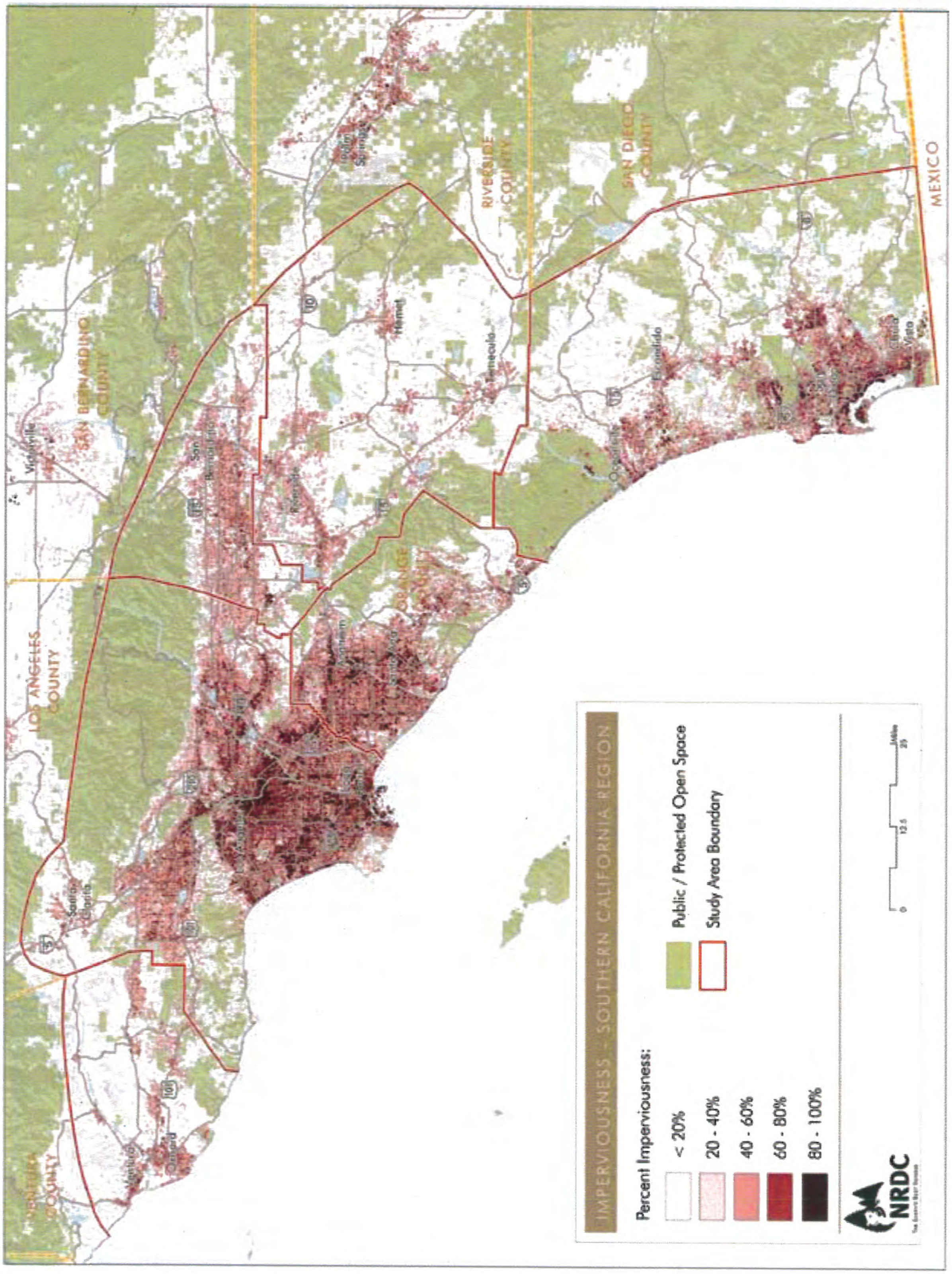
Land Use Analysis and Impervious Surface Cover

After establishing the study area boundaries, we conducted a GIS-based land use study of each area, broken down by county, to determine the total area occupied by each land use type—e.g., single-family residential home, high-rise office building, park and ride lot, etc.[6] We selected land use types characterized by "urban" density, having greater than 20 percent impervious surface cover over contiguous areas, or for residential purposes, having greater than two single-family residential structures per acre. For each land use category we calculated the percentage of surface area covered by roads or streets. We then subtracted this area from the identified land use category in order to designate municipal road construction as a separate land use type for analysis of runoff.

Based on GIS analysis, we calculated the average percent of impervious surface cover and average annual precipitation for each land use type. We used these values to determine the total volume of rain falling over impervious surface for each land use category. For each identified land use type, we further subdivided our analysis to separately evaluate different land use subgroups based on: 1) those with moderate (less than 85 percent) impervious surface cover overlying soils with generally adequate infiltrative capacity; or 2) those for which capture may represent the preferred means of harvesting water, such as those characterized by high impervious surface area (greater than 85 percent impervious surface) or by D-soils that may exhibit decreased infiltrative capacity.

RB-AR34004

Figure 14. Map of impervious surface cover within the southern California study area (based on NLCD 2001 impervious surface data set)



RB-AR34005

Runoff Volume

We evaluated land use data for all commercial and residential development within both study areas, as well as separately for industrial, government and public use, and transportation development in southern California, and determined the average percentage of impervious surface for each designated land use type. (See Figure 14, map of impervious surface in southern California. Note the increased impervious coverage in areas such as downtown Los Angeles, Santa Monica, and San Diego.) Impervious surface runoff from development at all land use types was calculated based on average rainfall compiled from the NRCS 1961–1990 data set and averaged across each of the designated land uses to determine the total volume of annual impervious surface runoff from the current distribution of specified land use types within the study area.[7] Runoff from paved and other nonroof surfaces was calculated based on a runoff coefficient for impervious areas of $C = (0.009) * I + 0.05$, where I is the impervious percentage (with $I = 100$ percent for fully impervious areas).[8] This is essentially equivalent to 95 percent of precipitation falling on paved surfaces mobilizing as runoff.

For calculating rooftop runoff directed to capture and use, our analysis assumed a runoff coefficient for rooftop surfaces of $C = 0.9$, meaning 90 percent of rainfall on roof surfaces will occur as runoff available for capture and use. Runoff coefficients for rooftop surfaces are generally estimated to vary between 0.75 and 0.95, reflecting differences in how materials, slope, and other variables of rooftop construction may affect runoff.[9] Stormwater management agencies in California commonly differ in their selection of runoff coefficients. For example, the City of Salinas bases rooftop runoff on a coefficient of 1.0, whereas the Santa Clara Valley Urban Runoff Pollution Prevention Program bases runoff at the low end of generally accepted values, using a coefficient of 0.75.[10,11] However, many architectural and engineering experts treat rooftop runoff as occurring at the higher end of the accepted range, stating for example, "a built-up roof is considered to have a runoff coefficient of 0.95; in other words, about 95 percent of the water hitting a conventional roof will leave the surface and needs to be accounted for in the design of the building's storm-water system" and many states and municipalities use a coefficient of 0.9 to determine runoff volumes from rooftop surfaces.[12,13] As a result, we find a coefficient of 0.9 to represent a reasonable estimate for rooftop-runoff collection potential.

In addition to precipitation-based runoff, dry-weather runoff stemming from human activities, such as landscape irrigation and car washing, was calculated within the southern California study area and Santa Clara portion of the San Francisco Bay study area. Dry-weather runoff was calculated based on a figure of 0.152 gallons per acre of pervious surface per minute for residential and commercial land use types likely to include landscaped cover. This figure was derived from the "Residential Runoff Reduction Study" performed by the Irvine Ranch Water District and extrapolated to include commercial development for our study.[14]

Recharge

Land use and impervious surface runoff totals were calculated based on the underlying soil type from a combination of U.S. Department of Agriculture Natural Resources Conservation Service Soil Survey Geographic (NRCS SSURGO) soil data and State Soil Geographic (STATSGO) soil data in order to determine infiltrative capacity of soil underlying each land use type. Areas were categorized as having soils in NRCS Hydrologic Soil Group A, B, C, or D, which refer to "soils grouped according to their runoff potential" and the soils' infiltrative capacity.[15] Where infiltration and groundwater recharge was selected as the preferred method for increasing local supply, such as for development with less than 85 percent impervious surface cover occurring over A, B, or C type soils, the study assumes that with adequate conditions capacity exists to infiltrate 100 percent of the impervious surface runoff generated at a given site, less the portion of runoff lost to evapotranspiration.

Selection of Infiltration vs. Capture

For the purposes of this study, where impervious surface runoff occurred over areas characterized as having D soils, capture of rooftop runoff, rather than groundwater recharge, was selected as the method for increasing local water supply and reducing energy use. While local variation is likely to allow for some groundwater recharge to occur in many locations underlain by D soils, we uniformly based our model on capture in these circumstances to simplify the model parameters. Water from rooftop runoff was also used as the primary basis for calculating the potential water savings in areas of high impervious surface cover, defined as areas greater than 10 acres in size and containing contiguous impervious cover of greater than 85 percent (e.g., downtown Los Angeles, which is characterized by high percentage of impervious cover). Though these areas may encompass sufficient pervious cover to infiltrate a large percentage, if not the total volume of associated impervious surface runoff, we assumed a conservative bias in characterizing the potential opportunities for groundwater recharge and selected capture as the preferred method, with only limited use of infiltration, under these conditions. We recognize as well that site-specific conditions that do not favor infiltration may exist, such as the presence of shallow groundwater that could pose a liquefaction hazard or already require dewatering, as well as the existence of groundwater contamination.[16] In order to address this possibility, certain of our model scenarios employ capture as the principal means of augmenting water supply for large portions of the southern California study area (see section on Assumptions and Variables, below).

Finally, for all areas of the San Francisco Bay area other than the Santa Clara Valley, where extensive groundwater production does occur, we selected rooftop runoff as the preferred means of increasing local supply. Although opportunities for infiltration exist throughout the Bay area, outside of Santa Clara County and some other smaller regions, groundwater currently accounts for only about five percent (or 68,000 af/year) of the region's average annual water supply.[17] As a result, capture may provide greater opportunity to immediately increase local water supplies (and consequently, reduce energy consumption) on a wide scale.

Development and Redevelopment: New Construction and Changes to the Existing Built Environment.

Water supplies generated by LID for 2030 were calculated based on projected commercial and residential development rates for each county included within the study area (using commercial development rates as a proxy for industrial, government and public use, and transportation development). Development projections were provided by the Southern California Area Governments, San Diego Association of Governments, Association of Bay Area Governments, California Department of Finance, and national-scale land use data.[18,19,20,21,22] Redevelopment rates were calculated based on an annual national "loss rate" of 1.37 percent for commercial buildings and 0.63 percent for residential structures.[23] These numbers are likely conservative, as the rate of development in the selected study areas exceeds national rates. This is particularly the case because the report forming the basis for loss estimates states that, "In 2030, about half of the buildings in which Americans live, work, and shop will have been built after 2000."[24] However, based on these estimates, our study assumes that 100 percent of future development and redevelopment at each land use type would be constructed using LID practices.

Reduction in Energy Use for Water Supply

Energy savings were calculated based on reducing the volume of supply from the marginal, or highest, energy-intensive source of water for each area. Within the southern California study area, SWP imports and projected ocean desalination are the marginal or most energy-intensive water supply sources (though for the purposes of this study we used only water from the SWP for calculating the marginal source in southern California). Projected use of ocean desalination water in the San Francisco Bay area is the marginal or most energy-intensive source in the San Francisco Bay study area. In each instance, the volume of imported or ocean desalination water to be offset was calculated based on the volume of water estimated to be either infiltrated for groundwater recharge or harvested through use of LID practices. In southern California, the marginal water source was determined based on a review of water agency Urban Water Management Plans. The marginal source was determined to be the West Branch of the State Water Project for Ventura and the western half of Los Angeles County; and the East Branch of the State Water Project for the eastern half of Los Angeles, Orange, San Bernardino, Riverside, and San Diego counties. Energy savings were calculated by determining the total amount of water to be recharged or captured within the study area, then calculating the energy required to treat and supply the same volume of water through the marginal supply source, less the energy required to supply the volume of water through either groundwater pumping or rainwater use.

GHG Conversion Factor

Estimated reductions in GHG emissions were calculated based upon a conversion factor established by the California Air Resources Board for climate change measures to reduce electricity and natural gas use in California. The reductions in GHG emissions are based on reduction of in-state natural gas electricity generation, with an emission factor of 4.37x10-7 MMTCO2E/MWh (963 lbsCO2E/MWh).[25] This is equal to 0.437 metric tons of carbon dioxide equivalent per MWh.

Conservative Bias in Assumptions

We note that the overall estimates for both water savings and resultant energy savings presented here are conservative. The analysis includes only a subset of the urban areas within California, as detailed above, and assumes a cautious figure for future development rates for these areas. Within the subset of commercial and residential development analyzed, the study does not incorporate the vast majority of existing development that could be retrofitted using LID practices. The analysis includes only new and redeveloped properties with a lesser percentage of retrofitted structures, while excluding the remaining built environment. For example, in the portion of Los Angeles County located within the study area, there were more than 540,000 acres of development as of 2005 in the land use categories selected for analysis. The study considers in its highest estimate that, by 2030, only approximately 135,000 of these developed acres will undergo redevelopment or retrofitting to incorporate LID practices, leaving 75 percent of the existing built environment (as of 2005) outside of the study's parameters. As stated earlier, the estimates incorporate only commercial and residential development and do not consider the potential water and energy savings available from implementation of LID practices at industrial, government and public use, and transportation development or redevelopment. These land use types cover more than 100,000 acres within the southern California study area, adding a substantial area of impervious surface and corresponding runoff not included in the current analysis.

Finally, the estimates do not take into account the loss rates for water supplied through the State Water Project, Colorado River Aqueduct, or local distribution systems. These systems lose a portion of the total water conveyed through a combination of evaporation and leakage during the course of transport, and the additional energy required to transport or pump this water has not been factored into the above calculations. As a result, and given the additional opportunities for implementation of LID practices not considered by our analysis, these findings should be considered to be conservative estimates of the total savings that would result from implementation of LID statewide.

Assumptions and Variables in Estimates of Water and Energy Savings Due to LID

Following from the above methodology, we developed low, medium, and high savings estimates for the potential water, energy, and GHG emissions savings that LID can produce with implementation at new development and redevelopment within the study areas. This range reflects the unknowns and potential variability of individual factors that may affect water harvesting through both infiltrative and capture practices, as well as the energy requirements of local supply.

Within this framework, we have considered the following factors in developing the estimates of water and energy savings. For each factor, we present the range of values used to calculate our low, medium, and high savings estimates. For a complete discussion of the parameters of each variable, including data sources, see Appendix A: [26]

- Percentage of runoff directed to infiltration and groundwater recharge but lost to evapotranspiration: For the study estimates, we base the estimated loss of groundwater recharge due to evapotranspiration on studies being conducted by the Los Angeles-San Gabriel Rivers Watershed Council, at a range of between 10 and 30 percent of total runoff generated.[27]

- Percentage of impervious surface comprised of rooftop: In six different case studies of southern California building permits, rooftop surface averaged between approximately 40 percent and 60 percent of total impervious surface area.[28]

- Percentage of retrofitted development employing LID principles: For properties that will undergo a substantial retrofit or redesign that does not include a complete rebuild or reconstruction of existing structures, we assume a construction rate equal to the overall redevelopment within each study area, but that only 25 to 50 percent of these retrofits will employ LID practices.[29]

- Energy required for extraction of infiltrated water by groundwater pumping: We base our energy requirements for water supplied through groundwater pumping on the range of energy intensity of groundwater supply that exists between groundwater sources for the West Basin Municipal Water District (350 kWh/af) and Inland Empire Utilities Agency (950 kWh/af). (See Figure 7.)

- Energy required for capture and use of rooftop water: As with groundwater production, a range of potential energy requirements exists in order to use water from rooftop capture, though it may require essentially no energy for low-volume, nonpressurized systems at single-family residences. We base our energy requirements for rooftop capture on an average of 186 kWh/af for use of drip-based irrigation in our high estimate and 338 kWh/af for sprinkler-based irrigation systems in our low estimate.[30]

- Percentage of roads to be developed as green streets: The study assumes that 50–80 percent of streets constructed in areas of new development and 25–50 percent of streets corresponding to redevelopment will be green streets.

- Local variation in groundwater conditions and infiltrative capacity: As a final variable, we recognize that there may be areas, such as those overlying shallow or contaminated groundwater, that we have initially identified as having the greatest potential savings available through infiltration, for which capture may ultimately prove to be a preferred method for augmenting water supply (these areas represent land use over and above those areas designated as having a high percentage of impervious surface or as underlain by D soils). In order to address this possibility, we assume for our low and medium savings estimates that up to 50 percent of Los Angeles County within the study area will augment water supplies through practices emphasizing use of capture rather than infiltration.

Given the framework within which we have considered these variables, we regard even our high savings estimate to be a reasonable calculation of the real-world savings that LID practices can achieve in California. Under these scenarios, and in light of the assumptions made in calculating each estimate, it can be seen that the ratio of energy saved per unit of water increases significantly from the low-end estimate (2,502 kWh saved per acre-foot) to the high-end estimate (3,025 kWh saved per acre-foot). This difference results from the lower requirements of energy supply for groundwater or capture assumed in the high savings estimate, which we consider to more accurately reflect likely real-world conditions overall. However, and regardless of the difference in total water savings, total energy savings, or energy saved per unit of water, the results compel the same conclusion to be drawn—the use of LID presents a significant and currently untapped opportunity to reduce the use of energy required to supply water in California or other regions reliant on energy-intensive sources of water.

Conclusion

LID offers important opportunities to tackle climate change and its impacts on California, while simultaneously addressing vital issues of water quality and quantity. California, and other states in similar circumstances, must act rapidly to reduce global warming pollution. LID, by reducing the need to rely on energy-intensive sources of water, should be aggressively implemented. Indeed, our research has demonstrated that significant opportunities for increasing water supply while reducing the energy used to supply water exist at a wide variety of development types, in many different geographic locations. Given the multiple benefits LID provides and the robust contributions its use can make to reducing GHG emissions, LID practices that emphasize water harvesting should be required for dischargers throughout California and in other jurisdictions where the energy and GHG intensity of water supply may be reduced by augmenting local groundwater or capturing runoff.

APPENDIX A
ASSUMPTIONS AND VARIABLES FOR LID QUANTIFICATION

- Percentage of runoff directed to infiltration and groundwater recharge but lost to evapotranspiration: A part of the Water Augmentation Study conducted by the Los Angeles and San Gabriel Rivers Watershed Council (LASGRWC) and partners based on the Ground Water Augmentation Model—a soil-moisture accounting model created by the U.S. Bureau of Reclamation—estimates that the evapotranspiration loss of water retained for onsite infiltration and groundwater recharge is minimal across various soil types and development patterns, often on the order of only 10 percent of the retained flow. For the most conservative savings estimate, we assumed that 30 percent of the water infiltrated onsite will be lost through evapotranspiration (reflecting a situation closer to predevelopment conditions, in which 40 to 50 percent of water may be lost). For our middle estimate, we have assumed a 20-percent loss rate, and for the high savings estimate, a 10-percent loss rate.

- Percentage of roads to be developed as green streets: Surface roads and sidewalks account for as much as 20 percent of the total impervious cover in residential and commercial developments within the study area. Using "green streets," or streetscapes designed according to LID principles, can significantly increase the volume of water available to augment local water supply through infiltration and recharge. While broad data were not available on the rate of green street development in California, we have assumed in our low-end savings estimate that 50 percent of roads constructed in areas of new development will be engineered according to LID principles. In the medium estimate, we assume that 65 percent of roads in areas of new development and 25 percent of roads in areas of redevelopment will be engineered or resurfaced according to LID principles. In the high savings estimate, we assume that 80 percent of roads in areas of new development and 50 percent of roads in areas of redevelopment will be engineered using LID principles.

- Percentage of retrofitted development employing LID principles: In addition to calculating a rate of redevelopment within the study areas, we include an estimate for properties that will undergo a substantial retrofit or redesign that does not include a complete rebuild or reconstruction of existing structures. We have assumed the rate of retrofitting of existing development to occur at the same rate as overall redevelopment within each of the study areas. In the low-end savings estimate, however, we assume that only 25 percent of these structures will employ LID practices, while in the medium- and high-end savings estimates we assume that 50 percent of the retrofitted structures are re-engineered to incorporate LID practices.

- Percentage of impervious surface comprised of rooftop: The percentage of impervious cover present as rooftop surface area at any individual site varies significantly. However, an analysis of six different case studies of building permits in southern California found that rooftop surface averaged between approximately 40 percent and 60 percent of total impervious surface area at a given site.[1] As a result, our low-end savings estimate assumes that water harvesting will occur from 40 percent of the impervious surface area onsite, the medium estimate assumes a 50 percent rooftop scenario, and the high savings estimate assumes 60 percent of impervious surface as rooftop area.

- Energy required for extraction of infiltrated water by groundwater pumping: The energy required to pump and produce potable water through groundwater supply is determined by numerous factors, including depth to groundwater, pump and motor efficiency, and other variables. Energy requirements for treatment are impacted by the presence of salts or other contaminants that may require treatment. Thus, uncertainty exists in calculating the specific energy requirements for augmenting water supply through groundwater recharge. Whereas pumping and treating groundwater in areas such as the West Basin require only a few hundred kWh/af, groundwater production may require greater than 1,500 kWh/af in the Chino Basin because of use of reverse osmosis. To be conservative, we have assumed a moderate-to-high overall embedded energy requirement for groundwater production. For the low savings estimate, we use the energy required to produce groundwater for the Inland Empire Utilities Agency (950 kWh/af, see Figure 7); for the middle estimate, the energy required to produce groundwater in Los Angeles (580 kWh/af); and for the high savings estimate, the energy required in the West Basin Municipal Water District (350 kWh/af).[2]

- Energy required for capture and use of rooftop water: As with groundwater production, a range of potential energy requirements exists in order to provide water through rooftop capture. We have reviewed a variety of rainwater capture systems and find that at low volumes for single-family residences there is essentially no energy required. However, for pressurized irrigation systems or internal building uses such as flushing toilets, use of a small sump may be required. We base our energy requirements for the low savings estimate on sprinkler-based systems requiring 338 kWh/af; for the middle estimate we assume a mixture of drip- and sprinkler-system use for irrigation requiring 262 kWh/af; and for the high savings estimate we assume use of drip-based irrigation requiring 186 kWh/af.[3]

- Local variation in soil type and infiltrative capacity: As a final variable, we recognize there may be areas that we have identified as having the greatest potential savings supplied through infiltration and groundwater recharge (not including those areas designated as having a high percentage of impervious surface or as underlain by D soils) for which water harvesting may ultimately prove to be a preferred method for augmenting water supply. These may include areas underlain by shallow or contaminated groundwater. In order to demonstrate that LID is capable of achieving substantial water savings and corresponding reductions in energy use and GHG emissions regardless of what LID practice is employed, we assume, in our low savings estimate, that only 50 percent of Los Angeles County within the study area will augment water supply through infiltration, with 50 percent employing capture to augment water supply. The medium estimate assumes 75 percent infiltration and 25 percent capture, and only the high savings estimate assumes 100 percent use of LID practices that emphasize infiltration in areas overlying A, B, or C soils and containing less than 85-percent impervious surface.

APPENDIX B
GIS DATA SOURCES AND METHODOLOGY

GIS Data Sources

Data Layer	Source	Type	Scale	Date	Description
Imperviousness	National Land Cover Database (NLCD) Imperviousness Layer, U.S. Geological Survey	Raster	30m cell size	2001	Estimates impervious surface coverage as a percent imperviousness (0 - 100%) by 30-m cell.
Land Use - Los Angeles, Orange, Riverside, San Bernardino, Ventura Counties	Existing Land Use, Southern California Association of Governments (SCAG)	Polygon	Minimum 2-acre mapping unit	2001 and 2005	Aerial-based existing land use survey across SCAG region.
Land Use - San Diego County	Existing Land Use, San Diego Association of Governments (SANDAG)	Polygon	Unspecified	2000 and 2007	San Diego County land use information based on aerial photography, County Assessor Master Property Records file, and other ancillary information.
Land Use - Almeda, Contra Coast, Marin, Napa, Santa Clara, San Francisco, San Mateo, Solano, Sonoma Counties	Generalized Planned Land Use, Association of Bay Area Governments (ABAG)	Polygon	Unspecified	2006	Compilation of city and county general plans for the ABAG region.
Soils - Detailed (where available)	SSURGO, U.S. Department of Agriculture, Natural Resources Conservation Service	Polygon	1:24,000	2002 - 2007	Detailed soil map units and associated attribute date (hydrologic group).
Soils - General (where detailed is unavailable)	STATSGO, U.S. Department of Agriculture, Natural Resources Conservation Service	Polygon	1:250,000	1994	Generalized soil map units and associated attribute data (hydrologic soils group).
Roads	U.S. Detailed Streets, StreetMap USA, ESRI	Line	1:50,000	2000	Enhanced TIGER 2000-based streets dataset, with road type classification.

GIS PROCESSING STEPS

Soils Data Processing:

1. Combine all SSURGO datasets that overlay the selected land use sets (2000/01 and 2005/07), and convert the mixed hydrologic groups (A/D, B/D, C/D) to D groups. Remove NO DATA records and records without a hydrologic group. Dissolve by hydrologic group.
2. Isolate STATSGO datasets that overlay the selected land use sets (2000/01 and 2005/07). Set a relate between the STATSGO map units and the STATSGO component table, and select all component records that correspond to the isolated STATSGO units.
3. In the subset STATSGO component table, create a concatenated field of the MUID and the HYDGRP. Sum the COMPPCT (component percents) by this concatenated field to get a total percent in each hydrologic group by map unit.
4. Create a new summary table from the summed STATSGO component percent table by selecting the maximum component percent for each map unit. This will be the "dominant" hydrologic group for that map unit. Verify these maximums, and if the maximum percent was assigned a null hydrologic group (e.g., URBAN LANDS), then take the next highest percentage hydrologic group.
5. Join the cleaned and verified maximum hydrologic group table to the STATSGO layer and dissolve by hydrologic group.
6. Create a copy of the SSURGO dataset and merge all polygons into a smaller set of units (all together or, if that gives errors, in a few sections). Erase this layer from the STATSGO layer.
7. Merge the original SSURGO layer with the erased STATSGO layer to create a single combined soils layer.

Road Buffer Delineation:

1. Add buffer distance attribute to streets layer based on type. For road classes 0, 1, 2, and 3 assign a buffer of 48ft (96ft total width) and for classes 4, 5, 6 assign a buffer of 24ft (48ft total width). Classes 7, 8, and 9 are dropped from the analysis. NOTE FOR BAY AREA ANALYSIS: For classes 0 and 1 assign a buffer of 80ft (160ft total width) and remove completely from the land use layer to approximate a "Highways" land use class. The rest of the classes are the same as described.
2. Select roads that intersect the model (2005/07) land uses, and port to a new file.
3. Using the new roads subset, dissolve by the buffer distance field.
4. Buffer the dissolved roads layer using the buffer distance field. Do NOT opt to dissolve adjacent boundaries – this tends to cause problems when buffering the larger streets files. Repair Geometry.
5. Start editing completed buffer file, manually select all features and merge. If the number of features is very large, do this in batches. Once the feature merge is complete, explode multipart polygons – if you had to do the merge in batches, then port each batch to its own shapefile before attempting the explode multipart.
6. Union the completed road buffer sections into one file. Use this processed road buffer dataset for road surface acreage calculations.

Land Use / Soils Analysis:

1. Intersect the model land use layer with the soils layer – once using the 2000/01 data and once using the 2005/07 data. In each new dataset, add a new text field that concatenates the county name, hydrologic soils group, and the land use group. Update the area and acres fields.
2. Run zonal statistics using the land use/soils intersected layer from 2000/01 and the imperviousness grid. Make sure to set the Spatial Analyst options to use the extent of the imperviousness grid, snap to the imperviousness grid, and use a cell size of 10m. The zone is the concatenated county/soils group/land use group field.
3. Create a summary table of the land use/soils 2005/07 attribute table by the concatenated county/soils group/land use group field. Summarize the total acreage, first county, first soils group, and first land use group.
4. Intersect the land use/soils 2005/07 layer with the roads buffer layer. Repair Geometry. Update the area and acreage fields.

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5 Create a summary table of the intersected land use/soils and road buffer layer by the concatenated county/soils group/land use group field. Summarize the total acreage, first county, first soils group, and first land use group.
6 Run zonal statistics using the land use/soils intersected layer from 2005/07 and the precipitation grid. Make sure to set the Spatial Analyst options to use the extent of the precipitation grid, snap to the precipitation grid, and use a cell size of 10m. The zone is the concatenated county/soils group/land use group field.

Southern California High/Low Impervious Area Delineation:

1 Set the Spatial Analyst options to the extent of the imperviousness grid, snap to the imperviousness grid, and set the cell size to 10m. Run a reclassify to classify all areas less than 85 as NoData and all areas greater than or equal to 85 as 85.
2 Convert the reclassified grid to a polygon coverage. Add and update an acreage field, and delete all polygons less than 10 acres.
3 Union the high imperviousness polygons with the already intersected land use/soils layer, once for each year.
4 Select all polygons from the unioned layer that have a grid value of 85 and a land use value of greater than 0 (or non-null) – these are the new high impervious areas.
5 Select all polygons from the unioned layer that have a grid value of 0 and a land use code value of greater than 0 (or non-null) – these are the new low impervious areas.
6 Run steps 2-6 of the land use / soils analysis using the high and low imperviousness layers.

Bay Area High/Mid/Low Impervious Area Delineation:

7 Set the Spatial Analyst options to the extent of the imperviousness grid, snap to the imperviousness grid, and set the cell size to 10m. Run a reclassify to classify all cells less than or equal to 20 as 20, between 20 and 85 as NoData, and greater than or equal to 85 as 85.
8 Convert the reclassified grid to a polygon coverage. Add and update an acreage field, and delete all polygons with (a) a value of 20 and size less than 5 acres, or (b) a value of 85 and a size less than 10 acres.
9 Union the high/low imperviousness polygons with the already intersected land use/soils layer.
10 Select all polygons from the unioned layer that have a grid value of 85 and a land use value of greater than 0 (or non-null). Export to new layer – these are the new high impervious areas.
11 Select all polygons from the unioned layer that have a grid value of 20 and a residential land use class. Export to new layer – these are the new low impervious areas.
12 Select all polygons from the unioned layer that have a non-null land use value and have not already been classified as either low or high impervious. Export to new layer – these are the new mid impervious areas.
13 Run steps 2-6 of the land use / soils analysis using the low, mid, and high imperviousness layers.

APPENDIX C - Sample Calculations for Riverside County

Runoff Calculations for A,B, and C Soils

	Low Rise Apartments	Strip Development	Total	Calculation
Percent impervious surface	49.37	52.71		Taken from land use data
Percent impervious surface (w/o roads)	41	42		
Acres Development (dev.), 2007	2,856.47	3,885.34		Taken from land use data
Est. impervious acres 2007	1,410.10	2,047.99		Acres dev. 2007 × percent impervious surface
Road acres 2007	406.25	742.41		
Impervious acres w/o roads 2007	1,003.86	1,305.58		Est. impervious acres 2007 – Road acres 2007
Avg. annual precipitation (feet)	0.974	1.024		
Annual precipitation (for whole property) (af)	2385.90	3219.35		Avg. annual precipitation × (Acres dev. 2007 – Road acres 2007)
Post-dev. impervious runoff (af)	928.63	1270.46	2199.09	Avg. annual precipitation × Impervious acres w/o roads 2007 × runoff coefficient (0.95)
Dry weather runoff (af)	320.61	407.28	727.89	Runoff volume per acre of pervious surface per minute (0.152 gallons) × Total Pervious Acres (Calculated by: (Acres dev. 2007 – Est. impervious acres 2007) × minutes per day (1440) × days without precipitation (335 in Riverside County) / gallons per acre-foot (325851 gallons)
Est. annual acres of dev.	87.23	43.06	130.29	(Acres dev. 2007 – Road acres 2007) × Annual dev. rate for Riverside County (Residential (3.56%); Commercial (1.37%))

	Low Rise Apartments.	Strip Development	Total	Calculation
Est. acres new dev. 2030	1919.01	947.28	2866.29	Est. annual acres of dev. × 22 years
Est. acres new dev. impervious surface 2030	786.22	393.50	1179.72	Est. acres new dev. 2030 × Percent impervious surface (w/o roads)
New post-dev. impervious surface runoff 2030 (af)	727.30	382.92	1110.22	Est. acres new redev. impervious surface 2030 × Avg. annual precipitation × runoff coefficient (0.95)
Est. annual acres redevelopment (redev.)	15.44	43.06	58.49	(Acres dev. 2007 – Road acres 2007) × Redevelopment rate for Riverside County (Residential (0.63%); Commercial (1.37%))
Est. acres redev. 2030	339.60	947.28	1286.88	Est. annual acres redev. × 22 years
Est. acres new redev. impervious surface 2030	139.13	393.50	532.63	Est. acres redev. 2030 × Percent impervious surface (w/o roads)
New post-redev. surface runoff 2030 (af)	128.71	382.92	511.62	Est. acres new redev. impervious surface 2030 × Avg. annual precipitation × runoff coefficient (0.95)
New dry weather runoff 2030 (af)	295.54	245.51	541.05	Runoff volume per acre of pervious surface per minute (0.152 gallons) × Total Pervious Acres from New Development and Redevelopment (Calculated by: ((Est. acres new dev. 2030 – Est. acres new redev. impervious surface 2030) + (Est. acres redev. 2030 – Est. acres new impervious redev. surface 2030)) x minutes per day (1440) × days without precipitation (335 in Riverside County) / gallons per acre-foot (325851 gallons)
Runoff from new roads 2030 (af)	294.33	217.74	512.07	Avg. annual precipitation × Road acres 2007 × Development Rate (Residential (3.56%); Commercial (1.37%)) × 22 years
Runoff from resurfaced roads 2030 (af)	113.27	217.74	331.01	Avg. annual precipitation × Road acres 2007 × Development Rate (1.37%) × 22 years

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Water Calculations

	Total	Calculation
Post-dev. impervious runoff (af)	2199.09	
Dry weather runoff (af)	727.89	
A, B, C soil total runoff (w/o Roads) 2008 (af)	2926.98	Post-dev. impervious runoff + Dry weather runoff
New and redevelopment runoff 2030 (af)	1621.84	New post-dev. impervious surface runoff 2030 + New post-redev. surface runoff 2030
New dry weather runoff 2030 (af)	541.05	
Runoff from new roads 2030 (af)	512.07	
Runoff from resurfaced roads 2030 (af)	331.01	
Retrofit runoff 2030 (af) (equal to redevelopment)	255.81	New post-redev. surface runoff 2030
2030 ABC SOIL LOW TOTAL WATER SAVINGS (AF)	1782.78	30% evapotranspiration loss; 50% of new roads developed as green streets; retrofits incorporate LID at 25% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 × 0.5) + (Retrofit runoff 2030 × 0.25)) × 0.7 (evapotranspiration)
2030 ABC SOIL MED TOTAL WATER SAVINGS (AF)	2267.44	20% evapotranspiration loss; 65% of new roads developed as green streets; 25% of resurfaced roads developed as green streets; retrofit incorporate LID at 50% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 x 0.65) + (Runoff from resurfaced roads 2030 x 0.25) + Retrofit runoff 2030 x 0.5) × 0.8 (evapotranspiration)
2030 ABC SOIL HIGH TOTAL WATER SAVINGS (AF)	2694.48	10% evapotranspiration loss; 80% of new roads developed as green streets; 50% of resurfaced roads developed as green streets; retrofit incorporate LID at 50% rate of redevelopment: (New and redevelopment runoff 2030 + New dry weather runoff 2030 + (Runoff from new roads 2030 x 0.65) + (Runoff from resurfaced roads 2030 x 0.25) + Retrofit runoff 2030 x 0.5) × 0.9 (evapotranspiration)

Energy Calculations

	Total (MWh)	Calculation
2030 ABC SOIL LOW TOTAL ENERGY	4075.44	(2030 ABC SOIL LOW TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL LOW TOTAL WATER SAVINGS × Groundwater energy requirement Inland Empire Utilities District (0.95 MWh/af))
2030 ABC SOIL MED TOTAL ENERGY	6022.33	(2030 ABC SOIL MED TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL MED TOTAL WATER SAVINGS × Groundwater energy requirement Los Angeles County (0.58 MWh/af))
2030 ABC SOIL HIGH TOTAL ENERGY	7776.27	(2030 ABC SOIL HIGH TOTAL WATER SAVINGS × East Branch State Water Project Energy (3.236 MWh/af)) - (2030 ABC SOIL HIGH TOTAL WATER SAVINGS × Groundwater energy requirement West Basin (0.35 MWh/af))

Variables for calculations (all figures in MWh/af):
Groundwater energy requirement: West Basin: 0.35
Groundwater energy requirement: LA County : 0.58
Groundwater energy requirement: Inland Empire Utilities Agency: 0.95
Capture pump energy – Drip: 0.186
Capture pump energy – Mix: 0.262
Capture pump energy – Sprinkler: 0.338
West Branch SWP: 2.58
East Branch SWP: 3.236
Carlsbad desalination: 4.6
San Francisco Bay area desalination: 4.4

To calculate estimated CO_2 reductions for each estimate, multiply the energy savings total (MWh) by 0.437 to determine metric tons CO_2 equivalent.

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Executive Summary

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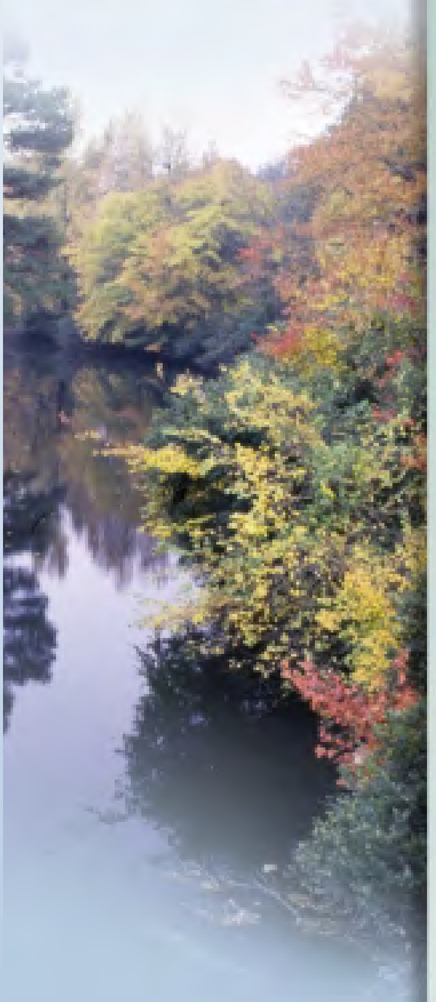

Protecting Stream and River Corridors

Creating Effective Local Riparian Buffer Ordinances

by Seth J. Wenger and Laurie Fowler

Model Ordinance Included

Carl Vinson Institute of Government
The University of Georgia

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Protecting Stream and River Corridors: Creating Effective Local Riparian Buffer Ordinances

Editing: Inge Whittle
Design and production: Reid McCallister
Cover design: Jessica Mendelson
Cover photo: Ed Jackson
Digital composition: Lisa Carson
Proofreading: Norma Pettigrew

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ISBN 0-89854-198-0

Library in Congress Cataloging-in-Publication Data Pending

Opinions expressed in the Public Policy Research Series papers are those of the authors and are not necessarily endorsed by the Vinson Institute of Government or the University of Georgia.

Foreword

Sooner or later, every Georgia county or municipality that has experienced a significant amount of growth must turn its attention to the issue of water quality. Local officials now have a number of tools at their disposal for offsetting the impacts of development and protecting aquatic resources. Among the most cost-effective of these methods is the riparian buffer ordinance. Buffers are mandated by state law and in recent years have been the subject of much debate. The purpose of this paper, part of the Public Policy Research Series of the Carl Vinson Institute of Government, is to inform that debate and to provide local officials with the information they need to craft buffer ordinances that are appropriate for their jurisdictions.

The foundation of *Protecting Stream and River Corridors: Creating Effective Local Riparian Buffer Ordinances* is a set of buffer-width guidelines that are based upon one of the most comprehensive scientific reviews conducted to date. This scientific basis is designed to ensure that buffer ordinances established in accordance with the recommendations will meet water quality goals and be defensible. Guidelines are also provided for minimizing the possibility of infringing on the rights of property owners, which is often a concern in the introduction of new land-use ordinances. A model ordinance specifically designed for Georgia counties and municipalities is included.

The authors of this paper are Seth J. Wenger, a conservation ecologist and policy analyst at the University of Georgia Institute of Ecology; and Laurie Fowler, director of Public Service and Outreach at the Institute of Ecology. Ms. Fowler also holds an appointment at the University of Georgia School of Law and has 17 years of experience in environmental law and the development of local policies for natural resource protection. Dr. Wenger is the author of *A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation*.

To ensure that the guidelines presented here are reasonable, the authors asked several leading riparian buffer researchers, as well as other scientists, to review them. Their comments and changes were incorporated into the final recommendations.

The intent of the Public Policy Research Series is to present objective and systematic research on complex policy problems and issues confronting the state of Georgia and its local governments. As part of this effort, *Protecting Stream and River Corridors* is targeted at elected officials who are considering establishing or improving their riparian

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buffer ordinances, along with planning and zoning officials who will implement and enforce such ordinances. Property owners, developers, and other citizens may also find the contents informative. We hope that these individuals benefit from the publication.

Henry M. Huckaby
Director
Carl Vinson Institute of Government

April 2000

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Acknowledgments

Many people contributed to the successful completion of this publication. First, we would like to acknowledge the scientists who reviewed the riparian buffer literature review: Ronald Bjorkland, Judy Meyer, Michael Paul, and Cathy Pringle, University of Georgia; David Correll, Smithsonian Environmental Research Center; and Richard Lowrance (USDA Agricultural Research Service). Various other scientists and faculty members answered questions: Miguel Cabrera, Bruce Ferguson, Byron J. "Bud" Freeman, Mary Freeman, Jim Kundell, University of Georgia; Robin Goodloe, U.S. Fish and Wildlife Service; and Parke Rublee, University of North Carolina-Greensboro.

Numerous local, federal, and state officials were very helpful: Ken Patton, Cherokee County Planning and Zoning Office; Gail Cowie, Institute for Community and Area Development; Dee West, City of Alpharetta; Michael Gleaton, Jim Frederick, and Lucy Herring, Georgia Department of Community Affairs; Lee Carmon and Joseph Tichy, Northeast Georgia Regional Development Center (RDC); Lisa Hollingsworth, Chattahoochee-Flint RDC; Tom O'Bryant and Larry Sparks, Georgia Mountains RDC; Nap Caldwell and Chris Skelton, Georgia Department of Natural Resources; and Jimmy Bramblett and Steve Lawrence, Natural Resources Conservation Service.

Most of the GIS work was conducted by Thom Litts and Andrew Homsey. Additional assistance was provided by Liz Kramer, Karen Paine, J. P. Schmidt, and Brian Toth of the NARSAL lab. Assistance in drafting the ordinance was provided by Karen Tyler, University of Georgia. Dell MacGregor, DeKalb County Soil and Water Conservation District, provided comments and suggestions. Scott Crabtree and Thelma Richardson, University of Georgia, provided computer support. Finally, we thank the students of the Fowler and Pringle labs, as well as all the other students, faculty, and staff at the University of Georgia Institute of Ecology for their suggestions and support.

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Executive Summary

The purpose of this paper is to support the efforts of local governments in Georgia that have made policy decisions to develop riparian buffer programs. A riparian buffer is a strip of naturally vegetated land along a stream or river which is protected to maintain healthy aquatic ecosystems and to provide a range of other environmental, economic, and social benefits. These benefits are numerous:

- Trapping and removing sediment from runoff
- Stabilizing stream banks and reducing channel erosion
- Trapping and removing nutrients and contaminants
- Storing flood waters, thereby reducing property damage
- Maintaining habitat for fish and other aquatic organisms
- Providing terrestrial habitat
- Maintaining good water quality
- Improving aesthetics, thereby increasing property values
- Offering recreational and educational opportunities

Despite their importance, several barriers stand in the way of effective buffer ordinances. For one, the riparian buffer requirements imposed by state laws do not provide a uniform and effective system of protection. For another, concerns over property rights have led many local officials to shy away from ordinances, however beneficial, due to fears of "takings" lawsuits. This paper is intended to help local governments develop effective, comprehensive riparian buffer ordinances that, properly administered, will not generate takings claims. A model ordinance is included.

In a monograph published by the Institute of Ecology of the University of Georgia (Wenger 1999), the author provides a thorough analysis of scientific buffer research that is applicable to Georgia. That review determined that the most effective buffers are at least 30 meters or 100 feet wide, composed of native forest, and are applied to all streams, including very small ones. Ideally, the width of the buffer will vary based on local conditions such as slope, width of the floodplain, presence of wetlands, and other factors. Two variable-width formulas that incorporate such factors are presented. The first specifies a minimum width of 100 feet, while the second provides for a minimum width of 50 feet. For local governments that find a variable-width formula too cumbersome to administer, recommendations are also provided for a fixed width buffer of 100 feet. Other widths are possible and reasonable, but narrower buffers provide significantly less benefits, and no buffer under 50 feet can be considered very effective.

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The following activities and structures are not appropriate within a riparian buffer:

- Land-disturbing activities, including construction
- Impervious surfaces
- Logging roads
- Mining
- Septic tank drain fields
- Application of pesticides and fertilizer
- Waste disposal sites
- Livestock

The 1999 study included a review of existing riparian buffer ordinances from Georgia and neighboring states. Among the local governments in Georgia that have passed effective buffer ordinances are Alpharetta, Douglas County, and Fulton County. These ordinances, together with selected buffer programs from a more thorough national review by other researchers in 1993, can provide guidance for other local governments in Georgia and are discussed in this paper. The study showed that a local buffer ordinance can take a number of different forms. For those local governments with zoning laws, an ordinance that creates a buffer overlay district is the best approach. The next best alternative is a stand-alone ordinance. Buffer protection could also be incorporated into a floodplain ordinance or an erosion and sedimentation control ordinance.

An effective riparian buffer ordinance will have the following characteristics:

1. It will meet the minimum standards for protection under the Georgia Planning Act and the Mountain and River Corridor Protection Act. A good buffer ordinance will not only adhere to state requirements, but will incorporate those requirements into a single set of local regulations, making it easy to administer.
2. It will provide for flexibility and variance procedures. In many cases, it is possible to slightly reduce the width of a portion of the buffer to accommodate the needs of a landowner while not significantly affecting buffer performance. This can be incorporated into an ordinance through rules for "minor exceptions" or "buffer averaging." In extreme cases, a variance that significantly reduces the buffer width will need to be issued to provide regulatory relief to property owners. The buffer ordinance should include variance criteria and procedures that are stringent but fair.
3. It will provide an exception for existing land uses. In other words, properties are only affected by the buffer ordinance when they

change use—for example, when agricultural land is developed for residences.

4. It will provide exceptions for certain activities. Agriculture is traditionally outside the regulatory domain of local governments and may be exempted (although certain restrictions on pesticide and fertilizer application are appropriate). Forestry is acceptable within limits, although cutting within 50 feet of the stream should not be allowed. Structures such as boat ramps, which by their nature need to be on or near a stream, are also excepted.
5. It will include guidelines for buffer crossings, which should be minimized, and buffer restoration, which is sometimes necessary.

In administering a buffer ordinance, good communication with property owners is essential. This reduces the likelihood of opposition based on irrational fears and misunderstandings regarding the law. Proper enforcement is also a necessity, although previous experiences suggest that the enforcement burden need not be great. A simple and reliable system for determining buffer width—for those local governments with a variable-width ordinance—is also important. A model ordinance, an appendix to this paper, incorporates all of the provisions discussed here.

A buffer ordinance based on the recommendations contained in this paper and properly enforced should withstand any legal challenges based on property rights. One concern to local governments and land owners is the takings issue. Legally, a takings can occur when government regulates property to such a degree that little economic use is left to the landowner. However, a buffer ordinance will not usually preclude use of a property and will not necessarily reduce property values. In those cases where properties are severely impacted, the owner should receive a variance.

To analyze the impact of buffers on property rights, we examined the proportion of land parcels covered by buffers of various widths (50, 75, and 100 feet). The study showed that parcels of less than 1-2 acres can be significantly impacted by relatively narrow buffers. However, since parcels of this size or smaller have generally been dedicated to residential use and are unlikely to be converted to other uses, they are exempted from an ordinance. If they are not exempted, their owners would qualify for a variance. Large parcels of 70 acres or more usually lose less than 10 percent of their land area to buffers, a portion that should not significantly reduce their value (especially when the economic benefits of buffers are considered). Often,

Recommendations

Pass a riparian buffer ordinance based on the included model.

Develop a public information campaign explaining benefits and features of buffer ordinances.

Identify critical riparian areas in which existing land uses threaten water quality.

Identify wildlife areas, historic/prehistoric sites, and other areas meriting preservation.

Establish impervious surfaces limits.

Properly enforce erosion and sedimentation control statutes.

Amend existing floodplain ordinance to emphasize importance of limiting floodplain development and to prohibit certain activities harmful to water quality.

Set a 25 NTU turbidity standard.

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the riparian zone is the least suitable area for development and is left wooded anyway. For example, a land cover analysis showed that in Cherokee County, a typical urbanizing county, over 89 percent of the area along streams is still forested.

Although riparian buffers can reduce the useful area of properties, they can also increase property values and provide other economic benefits. Properties near healthy, protected streams are worth more than properties located farther away or near unhealthy, aesthetically unpleasant waterways. Buffers protect water quality, which has immense economic value. By keeping sediment out of rivers, for example, buffers reduce the expenses of drinking water treatment plants. Clean streams and rivers are also valuable for recreation and tourism, and are vital factors in attracting new businesses and residents. Finally, protecting streams with buffers is a low-cost way to enhance the survival of endangered aquatic species. In short, riparian buffers are not only essential tools for environmental protection, they are also important factors in the long-term economic health of a community.

Introduction

> **Key Terms**
>
> In its most basic definition, ***riparian*** refers to the land adjoining a body of water.
>
> A ***riparian buffer*** is an undisturbed naturally vegetated strip of land that lies along a stream, river, or lake and provides such functions as protecting water quality, providing wildlife habitat, and storing flood waters.

The health of streams and rivers depends to a great extent on the lands that surround them. Over the last two decades, researchers have shown that preserving naturally vegetated corridors along streams can "buffer" them from the degrading effects of nonpoint pollution while reducing the impact of floods, providing habitat for wildlife, and offering recreational benefits to people. Protected stream corridors or "riparian buffers" are now widely advocated by a range of federal and Georgia state agencies for protecting water quality on agricultural, forestry, and other lands (GSWCC 1994, GFC 1999, USEPA 1998). In Georgia, local governments are required to protect buffers along certain streams and rivers by the Georgia Planning Act and the Mountain and River Corridor Protection Act.

However, the minimum standards for riparian buffers issued by the Department of Natural Resources' Environmental Protection Division (EPD) are not based on current scientific research and do not provide a strong level of resource protection. Only certain streams and rivers are protected, and many activities that are harmful to water quality—such as mining—are exempted from regulation. Counties and municipalities intending to develop effective, comprehensive riparian buffer ordinances that provide sound protection for water quality and wildlife will find the minimum standards insufficient. Local governments have the authority to develop alternative, more effective ordinances, but thus far scientifically based guidelines for buffer ordinances have not been available to them. Many officials worry that without solid scientific support, a comprehensive buffer ordinance could face legal challenges from developers and other property owners.

The purpose of this paper is to serve as a resource for local governments that plan to develop comprehensive riparian buffer ordinances, by presenting scientifically based guidelines which evolved from an analysis of scientific literature published as *A Review of the Scientific Literature on Riparian Buffer Width, Extent and Vegetation* (Wenger 1999). Even with these guidelines, however, many local governments will face an uphill struggle in establishing stream buffer ordinances as they encounter property owners concerned that a buffer ordinance will infringe upon their rights. Local governments must decide which form an ordinance will take and how it will be administered. This paper is intended to help local governments make those decisions by reviewing existing buffer programs, discussing the different legal tools available and how to avoid a "takings" claim, and by including a model buffer ordinance that integrates its recommendations.

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Exceeding Minimum Standards

In Georgia, stream corridor protection is mandated by several laws: the Erosion and Sedimentation Act, the Georgia Planning Act, the Mountain and River Corridor Protection Act, and the Metropolitan River Protection Act. All require that affected local governments develop plans and ordinances consistent with the laws and with any minimum standards issued by the EPD. Because of this abundance of requirements, some local governments find themselves with a patchwork of protected stream corridors of varying width and extent, a situation that can be confusing and aggravating to property owners and officials alike. Such a system has little scientific basis and is unlikely to afford effective protection to aquatic resources. Complicating matters further, various federal and state agencies encourage the protection of stream buffers as best management practices (BMPs) on agricultural and forestry land. These buffers may be of greater or lesser width than those required by state laws.

Key Terms

As used in this paper, ***stream buffer*** and ***protected stream corridor*** are synonymous with riparian buffer.

A comprehensive riparian buffer ordinance can simplify these requirements by integrating them into one uniform set of rules. Such an ordinance—with a scientific foundation—will provide water quality and wildlife habitat insurance for the future. A buffer ordinance is essentially a land-use planning tool that directs new development away from streams and rivers. Generally, this is more cost-effective in controlling pollution than trying to retrofit engineering solutions once an area has developed. Federal environmental protection laws such as the Clean Water Act, the Safe Drinking Water Act, and the Endangered Species Act can impose significant costs on local governments that have not taken adequate steps to protect aquatic resources. For example, the recent listing of nine species of salmon as threatened or endangered is expected to impose major restrictions on certain activities in the Pacific Northwest—restrictions that could have been avoided had the fishes' habitat been better protected previously (Verhovek 1999).

The Functions and Characteristics of Riparian Buffers

Riparian buffers perform a range of functions with economic, social, and ecological value. These include the following:

- Trapping/removing sediment in runoff
- Reducing stream bank erosion
- Trapping/removing phosphorus, nitrogen, and other nutrients that can lead to eutrophication of aquatic ecosystems
- Trapping and removing other contaminants, such as pesticides
- Contributing leaves and other energy sources to the stream
- Storing flood waters, thereby decreasing damage to property
- Maintaining habitat for fish and other aquatic organisms by moderating water temperatures and providing woody debris
- Providing habitat for amphibious and terrestrial organisms
- Maintaining base flow in stream channels
- Maintaining good water quality
- Improving the aesthetic appearance of stream corridors (which can increase property values)
- Offering recreational and educational opportunities to residents and tourists

Because they provide all of these services, riparian buffers can be thought of as a "conservation bargain": a small investment that yields large returns. Preserving a relatively narrow strip of land along streams and rivers—land that is frequently less suitable for other uses—can help to maintain good water quality, provide habitat for wildlife, protect people and buildings against flood waters, and extend the life of reservoirs. "Vegetative buffer programs, however, are rarely developed to fully consider the multiple benefits and uses that they offer to resource managers and to the general public" (Desbonnet et al. 1994). Often, buffer programs are developed for a single goal, such as trapping sediment. However important this goal may be, programs with such a narrow focus inevitably undervalue buffers (and riparian zones in general) and may lose popular support if they don't meet this goal. On the other hand, programs that promote the multiple functions of buffers are likely to enjoy a wider and stronger base of support, especially when people recognize the economic benefits they can provide. We strongly recommend the establishment of multifunctional riparian buffer protection programs.

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Results of Riparian Buffer Research

A riparian buffer ordinance should be based on scientific research. To establish this scientific foundation, the authors reviewed the research that has been conducted on riparian buffers, carefully analyzing some 140 scientific articles and publications. From this review and the input of riparian buffer researchers and other scientists, we developed recommendations for buffer width, extent (i.e., what streams should be protected), and vegetation type (e.g., forest or grass). This section is organized by riparian buffer function. In a subsequent section, the guidelines for riparian buffer ordinances developed from this review are presented.

Reducing Erosion and Sedimentation

Sediment is the most significant pollutant in many streams and rivers. Research has shown that vegetative buffers are effective at trapping sediment from runoff and at reducing channel erosion. Studies have yielded a range of recommendations for buffer widths; buffers as narrow as 4.6 meters (15 feet) have proven fairly effective in the short term (less than one year). Studies suggest that long-term trapping of sediment requires much wider buffers. It appears that a 30-meter (100-foot) buffer is sufficiently wide to trap sediment under most circumstances, although buffers should be extended for steeper slopes. To be most effective, buffers must extend along all streams, including intermittent and ephemeral channels. Buffers must be augmented by limits on impervious surfaces and strictly enforced on-site sediment controls. Both grassed and forested buffers are effective at trapping sediment, although forested buffers provide other benefits as well.

Key Terms

A ***perennial*** stream is a stream or river that flows throughout the year, except during extreme droughts.

An ***intermittent*** stream flows at least six months out of the year—but does not flow during part or all of the summer.

An ***ephemeral*** stream flows less than six months out of the year, and may only carry water during or after a rainstorm.

Trapping/Removing Phosphorus, Nitrogen, and Other Contaminants

Phosphorus and nitrogen can be serious aquatic pollutants because they lead to eutrophication, or over-fertilization, of water bodies. Buffers are effective at trapping limited amounts of phosphorus. In many cases, phosphorus is attached to sediment or organic matter, so buffers sufficiently wide to control sediment should also provide adequate short-term phosphorus control. There are limits, however, to how much phosphorus a buffer can hold, and over the long term the soil can become saturated with the nutrient. For this reason, buffers should not be considered the primary method for controlling phosphorus runoff.

Buffers can provide very good control of nitrogen in runoff. Nitrogen that enters the buffer in the form of nitrate, ammonia, or organic nitrogen can be transformed into harmless nitrogen gas by microorganisms, allowing permanent removal of high concentrations of the nutrient. The widths necessary for removing nitrogen vary based on patterns of water flow, soil factors, slope, and other variables. In most cases, 30-meter (100-foot) buffers should provide good control, and 15-meter (50-foot) buffers should be sufficient under many conditions. It is especially important to preserve wetlands, which are sites of high nitrogen removal activity.

Other contaminants, including metals, pesticides, and biological pathogens, can also be trapped by buffers and in some cases transformed into less harmful forms. Although studies are limited, it appears that buffers should be at least 15 meters (50 feet) wide to remove these contaminants, and possibly much wider in some cases.

Protecting Wildlife Habitat

Riparian buffers are an essential component of aquatic habitat. They provide food for aquatic organisms in the form of leaves, debris, and invertebrates; they shade the stream, maintaining moderate water temperatures; and they contribute large woody debris, which adds to habitat diversity. The literature indicates that buffers from 10 to 30 meters (35 to 100 feet) wide are necessary for protecting aquatic habitat, depending on different factors. To be most effective, buffers must be preserved along as many streams as possible and composed of native forest.

Riparian buffers themselves constitute important terrestrial habitat, and the quality is directly correlated with width. While narrow buffers offer considerable habitat benefits to many species, protecting diverse terrestrial riparian wildlife communities requires some buffers of at least 100 meters (300 feet). To provide optimal habitat, buffers should consist of native forest.

Achieving Effective Buffer Extent, Vegetation, and Width

These are the recommendations for riparian buffer extent, vegetation, and width based on the literature review; they have been incorporated into the model ordinance, page 59.

Extent

It is very clear that riparian buffers must be preserved on as many stream miles as possible. We recommend that, at a minimum, all perennial and intermittent streams be protected by buffers. To define these streams, local governments should use whatever map type corresponds most closely

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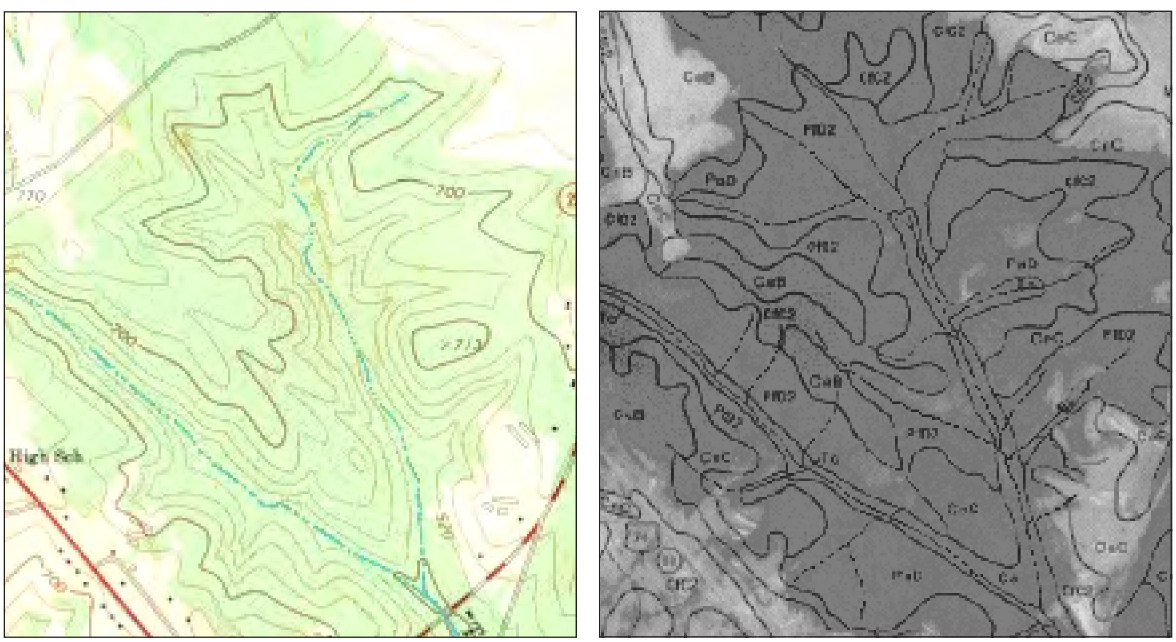
to field observations. For many parts of Georgia, the best option is the U.S. Department of Agriculture (USDA) Soil Survey maps, although recent versions are not available for all counties. U.S. Geological Survey (USGS) 1:24,000 scale topographic maps are a less acceptable alternative because they tend to omit many small-order tributaries (see Figure 1). Whichever map type is used, the administering authority for the ordinance should also be allowed to designate additional streams that are deemed worthy of protection, even if they do not appear on Soil Survey maps.

Ephemeral streams should also be protected when possible. However, because there is no lower boundary for the definition of an ephemeral stream—i.e., it is difficult to define what is an ephemeral stream channel and what is just a ditch—we recommend only that the banks of ephemeral channels be vegetated. [Note: Ephemeral streams may be considered streams under the Erosion and Sedimentation Act; therefore, land-disturbing activities may be subject to the restrictions of that law.]

Figure 1. Topographic Maps vs. Soil Survey Maps

These two maps show the same location in the Georgia Piedmont. The map on the left, a USGS topographic map, does not show many of the small intermittent streams that appear on the USDA soil survey map at right.



Vegetation

A riparian buffer covered by grass can adequately perform several functions, including trapping sediment and contaminants. However, effective performance of all functions, including protection of aquatic habitat, requires forested buffers. Therefore, we recommend that riparian buffers be preserved in a naturally vegetated state consisting of native forest. Restoration should be conducted when necessary.

Width

The literature review showed that most scientific recommendations for minimum buffer widths range from 15 meters (about 50 feet) to 30 meters (about 100 feet). It might be possible to determine the correct width from within this range by conducting additional research in the region of interest. Such research would be expensive and time consuming, however, and most local governments do not have funds for research or the time to wait for the results. In most cases, then, the choice of minimum width becomes a choice between margin of safety and acceptable risk. The greater the minimum buffer width, the greater the margin of safety in terms of water quality and habitat preservation. Accordingly, three options are proposed. The first is a variable-width buffer with a 100-foot base width, the second is a variable-width buffer with a 50-foot base width, and the third is a fixed-width buffer of 100 feet. The first can be considered the "conservative" option: it meets or exceeds many scientific buffer width recommendations; and, therefore, should ensure high water quality and support good habitat for native aquatic organisms. The second and third options are "riskier": they should, under most conditions, provide good protection to the stream and good habitat preservation, although heavy rain, floods, or poor management of contaminant sources could more easily overwhelm the buffer. All of these options are defensible given the literature reviewed. In choosing an option, government officials and other stakeholders must decide how much risk they can tolerate in the preservation of their aquatic resources.

Option One (variable width)

- Base width is 100 feet (30.5 meters) plus 2 feet (0.61 meters) per 1 percent of slope* of the stream valley.
- It is extended to edge of floodplain.

*Percent slope is the increase in elevation per unit of width. For example, if the stream valley rises by 20 feet over a width of 100 feet, slope is 20 percent.

- It is extended by the width of wetlands that lie within or partly within the buffer (as determined by slope and floodplain width).
- Existing impervious surfaces in the riparian zone do not count toward buffer width (i.e., the width is extended by the width of the impervious surface, just as for wetlands).
- Slopes over 25 percent do not count toward the width.
- The buffer applies to all perennial and intermittent streams.
- Ephemeral streams are not protected by buffers, but their banks must be vegetated.

Option Two (variable width)

- Base width is 50 feet (15.2 meters) plus 2 feet (0.61 meters) per 1 percent of slope of the stream valley.
- Entire floodplain is not necessarily included in the buffer, although potential sources of severe contamination should be excluded from the floodplain.
- Existing impervious surfaces in the riparian zone do not count toward buffer width (i.e., the width is extended by the width of the impervious surface, just as for wetlands).
- Slopes over 25 percent do not count toward the width.
- The buffer applies to all perennial and intermittent streams.
- Ephemeral streams are not protected by buffers, but their banks must be vegetated.

Figure 2 illustrates how Option Two is applied.

Variable-Width vs. Fixed-Width Buffers

Any of the three buffer options presented here would be a reasonable, scientifically defensible alternative for a local government in Georgia. Variable-width options, however, offer some significant benefits over fixed-width buffers. First, they are more scientifically defensible and more likely to provide adequate but not excessive protection. The variables that were used in the width formulas (slope, presence of wetlands, width of floodplain, and presence of impervious surfaces) were selected because they are highly correlated with buffer effectiveness and are easily measured in the field. Fixed-width buffers may not provide sufficient protection to ecologically sensitive areas or, conversely, may deprive landowners of areas more suited to development in ecological terms (Herson-Jones et al. 1995). Second, areas with different characteristics require different degrees of protection. Third, variable-width buffers can incorporate protection for other sensitive natural features such as floodplains, steep slopes, and wetlands. They do, however, have some potential drawbacks: they require slightly more staff time to administer, are less easily understood by the public, and may strike some landowners as unfair.

Option Three (fixed width)

- Fixed buffer width is 100 feet.
- The buffer applies to all perennial and intermittent streams.
- Ephemeral streams are not protected by buffers, but their banks must be vegetated.

For all three options, buffer vegetation should consist of native forest. Restoration should be conducted when necessary and possible.

Prohibited Activities

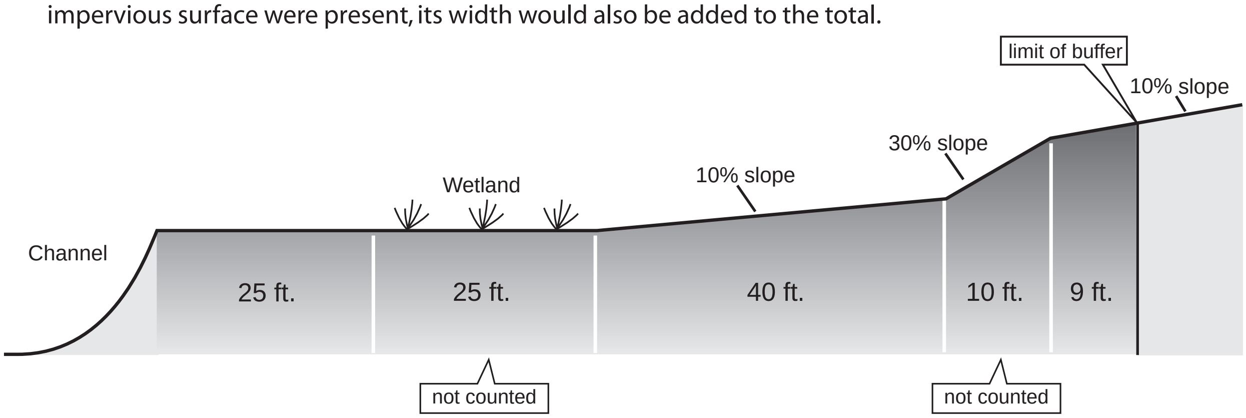
All significant sources of aquatic contamination and degradation should be excluded from buffers. These include construction resulting in land disturbance, impervious surfaces, logging roads, mining, septic tank drain fields, agricultural fields, waste disposal sites, stormwater detention ponds (except those designed as wetlands), access of livestock, and clear cutting of forests. Application of pesticides and fertilizers should also be prohibited.

Providing Additional Wildlife Habitat

All of the buffer options described above will provide habitat for many terrestrial wildlife species. To provide habitat for forest interior species, at least some riparian tracts 300 feet or wider should also be preserved. Identification of these areas should be part of an overall, countywide wildlife protection plan.

Figure 2. Applying a Flexible-Width Buffer

This diagram illustrates how Buffer Option 2 is applied to a hypothetical landscape. The average slope of the stream valley here is 12 percent, which means the buffer should be 50 + 24 = 74 feet wide. The width of the wetland and the steep slope are added to the total width, so the buffer actually covers some 109 feet. If an impervious surface were present, its width would also be added to the total.



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Effective Buffer Ordinances

A Selective Review

A number of Georgia counties and municipalities have established stream buffer ordinances. Most of these are modeled directly on EPD minimum standards, while others are more restrictive and a few even innovative. This section briefly presents several of the ordinances that exceed or differ from the minimum standards. It also describes a small sampling of local buffer protection programs from other states, primarily in the Southeast. Concluding the section are some results from a far more thorough survey of 36 local and state riparian buffer programs conducted by Heraty in 1993 (Schueler 1995).

Alpharetta

The city of Alpharetta maintains 100-foot buffers on all perennial streams as a requirement of its Erosion and Sedimentation Ordinance. According to Dee West, Director of Environmental Services, there was virtually no opposition to the buffer requirement because developers and the general public were invited to participate from the beginning of the ordinance development process (1998). The Alpharetta ordinance allows flexibility in buffer width, as long as a minimum of 50 feet and an average of 100 feet in width is maintained. In addition, there is an impervious surface setback that must average 150 feet in width and cannot be less than 75 feet in width. Septic tanks and septic tank drain fields are prohibited in this zone.

According to West, the only major enforcement difficulty the city experiences is that the EPD retains sole authority to issue variances for the riparian buffer requirements of erosion and sedimentation ordinances. Although Alpharetta rarely issues variances for the buffer requirements, the EPD routinely issues such exceptions. This is a potential drawback to buffer ordinances that only specify erosion and sedimentation control as the purpose of riparian protection.

Douglas County

Douglas County, Georgia, developed stream corridor zones in 1976 to protect the Dog River and Bear Creek basins, which serve as the county's public water supply (Dean 1997). With some revisions, these regulations are still part of the county's zoning code. There are actually three distinct classifications of stream corridors, two of which are independent zones and one of which is an overlay zone.

The Reservoir Open Space (ROS) zone protects the Bear Creek and Dog River Basins. Both rivers and all of their tributaries are protected by a 100-foot buffer of undisturbed natural vegetation, in addition to a 200-foot to 300-foot setback for construction (except wells), septic systems, and for maintaining animals. Moreover, there is a wider zone of 250 feet (small tributaries), 500 feet (large tributaries), or 1,000 feet (Bear Creek and Dog River mainstem) from the stream in which there can only be one house per five acres. Commercial, industrial, and high-density residential uses are prohibited.

The Open Space (OS) district is a subzone that can be established along other streams and rivers upon the recommendation of the county engineering department. The zone, which may be from 100 feet to 1,000 feet wide, also limits development to one house per five acres. The Reservoir Drainage Basin-Open Space (RDBOS) district is an overlay zone; i.e., each parcel within the RDBOS district is subject to the restrictions of both the RDBOS and the other zone it lies within. It does not follow stream corridors but rather serves to limit development on sensitive upland areas within the Bear Creek and Dog River basins. It is less protective than the ROS and OS zones: within the district, housing density is restricted to one unit per acre (for unsewered areas) or one dwelling unit per 30,000 square feet for areas served by sewers. Commercial development is likewise restricted to parcels of one acre or larger except in areas served by sewers (Douglas County Board of Commissioners 1998).

...Each parcel within the Reservoir Drainage Basin-Open Space district, an overlay zone, is subject to its restrictions as well as the zone it lies within.

Fulton County

In September 1998, Fulton County passed an ordinance to establish protected stream corridors for the unincorporated southern portion of the county. The impetus for the ordinance was twofold. First, Fulton County sought to expand the Camp Creek Wastewater Treatment Plant to compensate for the increased pollution, and the Georgia EPD required the county to reduce nonpoint pollution. Second, the Metropolitan River Protection Act (MRPA) was amended so that as of July 1, 1998, the protected zone along the Chattahoochee River was extended from Peachtree Creek (where it previously terminated) to the southwest border of Fulton County (Fulton County Board of Commissioners 1998). The MRPA requires buffers of 50 feet on the mainstem of the Chattahoochee River, 35-foot buffers on tributaries within 2,000 feet of the Chattahoochee, and 25-foot buffers on all other tributaries of the river (Cowie and Hardy 1997). Fulton County decided to exceed these minimum requirements by establishing a 75-foot-wide natural vegetated buffer on all perennial streams, with an additional 15-foot impervious surface setback and a further 10-foot-wide “improvement setback.”

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The ordinance effectively establishes an overlay zone on properties in the stream corridor, imposing additional restrictions in addition to those required by the primary zone. Within the protected corridor, which totals 100 feet in width, the following are prohibited:

- Septic tanks and septic tank drain fields
- Receiving areas for toxic or hazardous waste or other contaminants
- Hazardous or sanitary waste landfills
- Stormwater retention or detention facilities
- Accessory structures and buildings, parking lots, driveways, and other impervious surfaces

Utilities and transportation uses may be located within the corridor if a feasibility study is conducted to examine alternatives and if the project follows appropriate best management practices (BMPs) and will not diminish water quality. Timber harvesting is permitted except within 35 feet of the stream. Existing land uses are exempted, but no additions may be made to buildings and structures that sustain greater than 60 percent damage may not be rebuilt (Fulton County 1998).

The Fulton County ordinance has several interesting and significant aspects. First, it greatly exceeds state-mandated minimum requirements in a way that reflects scientific understanding of stream corridors. Second, in addition to the streams that appear as blue lines on United States Geological Survey (USGS) 7.5 minute topographic maps, protection may be applied to other perennial streams identified by Fulton County. The ordinance does not, however, protect intermittent or ephemeral streams; and this may reduce its effectiveness. Third, the ordinance does not exempt mining and other activities that may harm water quality, but which are sometimes exempted for political reasons. Finally, the ordinance provides clear and detailed rules for granting variances.

Madison County

Madison County passed a stream corridor protection ordinance in 1995 to protect the Broad and Hudson Rivers through creation of an overlay zone. Requirements are consistent with the minimum standards set forth by the Georgia Mountain and River Corridor Protection Act in nearly all respects, except that surface mining is specifically prohibited.

Winston–Salem/Forsyth County, North Carolina

Through ordinances established in the 1980s and 1990s, the city of Winston–Salem and Forsyth County, North Carolina, established a comprehensive watershed plan for Salem Lake, which provides 42 percent of the water supply for the region. As part of the plan, 100-foot-wide protected stream corridors were established along all perennial streams in the watershed. The only types of development permitted in the stream corridor are water-dependent structures, transportation infrastructure, utilities, and passive recreation structures. Land-disturbing activities are prohibited within 25 feet of the stream (Tyler et al. 1998).

Greensboro, North Carolina

On March 17, 1999, the Greensboro City Council approved a stormwater management ordinance that included riparian buffer provisions for all streams and natural channels draining at least 50 acres. The buffer consists of two zones: (1) a 15-foot-wide zone that is free of any development or soil disturbance and (2) a 35-foot-wide (or wider) zone that is free of occupied structures and has an impervious surface coverage of less than 50 percent. According to a University of North Carolina biologist (Rublee 1999), the buffer specifications were established through compromise among "developers" and "environmentalists." The primary purpose of the ordinance is to prevent flooding, rather than to provide water quality or habitat benefits.

Chester County, South Carolina

In 1994, South Carolina passed the Comprehensive Planning Act. It required counties that currently have zoning ordinances and comprehensive planning (a little more than half of the state's 46 counties) to update their plans and address natural resource protection by May, 1999. As a result, a number of local governments in the state are expected to develop stream corridor protection ordinances or zoning districts (Beasley, South Carolina Department of Natural Resources, 1998).

> ***South Carolina's 1994 Comprehensive Planning Act required that counties with zoning ordinances and comprehensive planning update them and address natural resource protection by May 1999.***

At this time, only two local governments have successfully introduced stream corridor zoning: Chester County and the city of Rock Hill. In 1998, Chester County adopted a zoning ordinance and shortly thereafter added a river preservation district, not as an overlay but as an independent zone. The district extends 100 feet on either side of the Catawba and Broad Rivers and 50 feet on either side of designated tributary streams. The only uses permitted in the river preservation zone are

- passive recreation;
- public boat landings, public water or wastewater treatment facilities, intakes, discharges, or other public uses; and
- agriculture and silviculture to include watering of livestock, tilling, and tree harvesting among other activities, provided any disturbed soil is maintained on-site until the buffer is revegetated.

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No private structures may be built in the zone, and housing within the buffer cannot be rebuilt if it is more than 50 percent damaged. Some members of the agricultural community expressed concerns about the establishment of the zone, but once they were assured that agricultural practices would still be permitted, opposition evaporated. The commissioners voted unanimously to pass the measure (Vead, Catawba Regional Planning Council, 1998).

Rock Hill, a city in York County, South Carolina, has established a 150-foot naturally vegetated buffer along the Catawba River. York County also attempted to establish a 100-foot riparian buffer through a free-standing river corridor ordinance, but the proposal failed at its second reading (three readings are required). Problems may have arisen because the proposed ordinance imposed some additional, although minor, restrictions in a 200-foot zone beyond the buffer, which apparently led to confusion and opposition among landowners who interpreted it as a 300-foot naturally vegetated buffer (Vead 1998).

Brown County, Wisconsin

Many local governments are understandably reluctant to impose regulations on the agricultural community, but a few counties have found it necessary and feasible to do so. One of these is Brown County, Wisconsin. In January 1998, the Brown County Board of Supervisors passed an ordinance establishing a 300-foot "agricultural shoreland management area" on all perennial and intermittent streams and rivers. Within this corridor, agricultural practices must be consistent with NRCS guidelines and erosion must be limited. Additionally, a 20-foot-wide vegetated buffer must be established along the banks of streams. Row cropping and tillage are prohibited in the 20-foot-wide buffer, although the land may serve as pasture if it meets technical guidelines (Brown County Board of Supervisors 1998).

Many local governments are reluctant to impose regulations on the agricultural community.

Charles County, Maryland

Charles County protects riparian buffers through a variable-width zoning district. The minimum width is based on the 100-year floodplain and is extended by the width of nontidal wetlands, plus 50 feet for 1st and 2d order streams and 100 feet for 3d order or larger streams.

When a 100-year floodplain and wetlands are not present, width is either 50 feet or 100 feet depending on stream order. In addition, if the slope of the stream valley is greater than 15 percent, the width of the buffer is doubled or extended to the top of the slope (whichever is less). Furthermore, the Charles County Planning Commission has the authority to extend the buffer to include important features. The complexity of the program makes it more difficult to administer than a fixed-width buffer. Because the buffer is a dedicated zoning district, changes to buffer width are considered changes to the zoning map and may only occur twice a year (Maryland Office of Planning 1993).

1993 Survey of Buffer Programs

In 1993, Heraty surveyed some 36 state and local urban riparian buffer programs nationwide. Responses indicated that protected buffers ranged in width from 20 feet to 200 feet, with an average of 92 feet. Sixty-five percent of the programs had variable-width buffers that extended width for slope (34 percent), certain classifications of streams/water bodies (15 percent), floodplain (8 percent), wetlands (12 percent), size of stream or water body (3 percent), type of development (6 percent), or some other condition (21 percent).

Eighty-six percent of the buffers required vegetation and limited disturbance of the buffer area. Sixty-six percent required vegetation to remain unaltered from predevelopment condition. Only 6 percent of programs permitted logging, although tree trimming, mowing, and tree removal were permitted by many programs. The restrictions on tree cutting no doubt reflect the urban focus of the survey.

Heraty reported that most buffer programs had strong citizen support. Over 80 percent of local governments agreed with the statement, "a majority of our citizens think that the community is better off having stream buffers." Ninety-four percent believed that buffers had a neutral or positive effect on adjacent land values.

Based on this survey, Schueler (1995) identified eight key points about riparian buffers:

1. *Buffer boundaries are largely invisible to local governments, contractors, and residents.* To be protected, buffers must be indicated on construction plans and marked at construction sites. Property owners must be informed of the presence and boundaries of buffers.
2. *Buffers are subject to extensive encroachment in urban areas.*
3. *Few jurisdictions have effective buffer education programs.*
4. *Allowable and unallowable uses are seldom defined.*

Points two, three, and four emphasize the need to communicate clearly with landowners about the boundaries of buffers, the benefits of buffers, and the permissible uses of buffers.

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5. *Few jurisdictions specified mature forest as a vegetative forest.* Schueler notes that "given the importance of riparian forests to the ecology of headwater streams, the adoption of a specific vegetative target for the stream buffer would be wise."
6. *Accuracy of buffer delineation is seldom confirmed in the field.* Heraty's study found that 50 percent of the buffer programs reported problems in buffer measurement by consultants. Twenty percent lacked a mechanism to inform the contractor about buffer boundaries during construction.
7. *Most buffers remain in private ownership.* Ninety percent of the buffers remained privately owned after development. Only 10 percent were acquired by the municipality or other government entity.
8. *The stream buffer program needs to be responsive to the interests of the development community.* This does not mean that buffer ordinances were necessarily too strict. Most developer concerns were directed at administration of the program rather than the restrictions in the buffer ordinance itself. This again suggests the need for open communication between the administrative agency and the developers and landowners who are impacted by the ordinance.

Tools to Protect Riparian Buffers

This section outlines the regulatory and nonregulatory tools that are available to local governments for protecting riparian buffers. In the first part, different types of riparian buffer ordinances are described. The second part outlines some related regulatory tools that can be used to support the riparian buffer ordinance. The final part describes nonregulatory approaches to riparian buffer protection, which are useful means of preserving land that is excepted from a riparian buffer ordinance.

Forms of Riparian Buffer Ordinances

Overlay Zoning Ordinances

For a county that already has a zoning ordinance in place, the most effective and expedient way to protect riparian buffers is through an amendment that adds a riparian buffer overlay zone. An overlay zone imposes restrictions on the affected portion of a property in addition to the restrictions placed on the property as a whole by the underlying zoning classification. It does not require changes to the current zoning map. Some local governments (e.g., Douglas County, Georgia; Chester County, South Carolina; and Charles County, Maryland) have used dedicated stream corridor zones rather than overlay zones. With this approach, a single property is split into two zoning districts—a riparian buffer zone district and the conventional zoning district. The model riparian buffer ordinance included at the end of this paper specifies overlay zones.

The model ordinance included at the end of this paper specifies overlay zones.

Freestanding Ordinances

For counties that do not have a zoning ordinance, a separate stream corridor protection ordinance is necessary. Several such ordinances were described in the preceding review of ordinances currently in place. However, because local governments are delegated specific zoning powers by the Georgia Constitution, they may have more flexibility in developing zoning-based riparian buffer ordinances than free-standing ordinances. For more information, see the section on “Meeting Minimum Standards,” page 29.

Floodplain Protection Ordinances

A floodplain protection ordinance can be a reasonable mechanism for riparian buffer protection. Historically, however, most floodplain ordinances are intended to minimize property damage, not to protect the ecological functioning of the floodplain or the river. There is now growing recogni-

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tion among government agencies that floodplains should be managed in a way that preserves their natural ecological functions:

> "Rivers and their floodplains are dynamic and complex natural systems that can provide important societal benefits, both economic and environmental. By adapting to the natural phenomenon of flooding, rather than trying to control floodwaters, we can reduce the loss of life and property, protect critical natural and cultural resources, and contribute to the sustainable development of our communities." (Federal Interagency Floodplain Management Task Force 1996)

The EPD Floodplain Management Office encourages local governments to include natural resource protection in drafting their floodplain ordinances (Brock, Environmental Specialist, 1998). Ideally, riparian buffers should be extended to the width of the floodplain, as proposed in riparian buffer width Option One, on page 11. At a minimum, local governments should incorporate language into their Flood Damage Prevention Ordinances to acknowledge the importance of preserving natural floodplain processes and to prohibit certain activities and structures that could cause serious environmental harm. These include animal waste lagoons, hazardous and municipal waste receiving and disposal sites, application of pesticides, and land application of animal waste or fertilizers. Because enforcement of such an ordinance would be difficult, compliance should be encouraged through a public information campaign.

Auxiliary Ordinances

Erosion and Sedimentation Control Ordinances

Local governments that have their own erosion and sedimentation control ordinances can be delegated the authority to administer the Erosion and Sedimentation Act of 1975 within their jurisdiction. This ordinance acts, in effect, as a buffer ordinance protecting a 25-foot (minimum) stream corridor on all streams and a 100-foot corridor on primary and secondary trout streams. Local officials are also authorized to pass ordinances that are more restrictive than the specifications of the state law. In the past, some local authorities have found difficulties in enforcing this ordinance because the EPD retains sole authority for issuing variances to the buffer provisions. The experiences of the city of Alpharetta were described in the previous section. While it can be argued that the local authority can overrule an EPD variance if it wishes, this legal issue can be avoided if the ordinance is properly worded to specify that buffers are protected for multiple purposes, not just erosion and sedimentation control.

Regardless of how buffers are protected, a properly enforced erosion and sedimentation control ordinance is essential in reducing the sediment in runoff and enhancing the performance of buffers. Riparian buffers alone are not enough to mitigate the effects of otherwise uncontrolled upland activities (Binford and Buchenau 1993). A broader approach of using various best management practices is more effective. As Barling (1994) notes, "Buffer strips should only be considered as a secondary conservation practice after controlling the generation of pollutants at their source." In many cases it may be easier, cheaper, and preferable to prevent sediments from mobilizing and moving off-site in the first place. For agriculture and forestry, soil is a valuable asset that is extremely difficult to replace. Erosion reduction efforts should focus on keeping soil in fields, where it is usable, rather than trapping it after it has left a field, where it is much more difficult to salvage. Numerous agricultural best management practices (BMPs) have been developed for this purpose. Producers should be strongly encouraged to implement the most effective BMPs, in addition to preserving riparian buffers. Additional information on BMPs and financial incentives for their use is available from the Natural Resources Conservation Service and the Georgia Soil and Water Conservation Commission.

For agriculture and forestry, soil is a valuable asset that is extremely difficult to replace.

Likewise, BMPs must be faithfully implemented and enforced in construction projects. A review by Brown and Caraco (1997) found that in many cases, half of all practices specified in erosion and sedimentation control plans were not implemented correctly and were not working. Contractors habitually saved money by cutting ESC installation and maintenance. Surveys also found that ESC practices rated as "most effective" by experts were seldom applied while those rated "ineffective" are still widely used. Further, a field assessment of silt fences found that 42 percent were improperly installed and 66 percent were inadequately maintained. While a substantial amount of money is now spent on ESC practices, Brown and Caraco (1997) concluded that "much of this money is not being well spent —practices are poorly or inappropriately installed, and very little is spent on maintaining them."

Effective enforcement of erosion and sediment control laws requires water quality monitoring and evaluation against a scientific standard. In 1996, a panel of scientists convened to make recommendations to the Georgia Department of Natural Resources (DNR) proposed establishing a turbidity standard of 25 NTU (nephelometric turbidity units), measured at the end of designated stream segments (Kundell and Rasmussen 1995). We recommend that local governments establish 25 NTU as a performance standard to monitor whether erosion and sedimentation control BMPs and riparian buffers are effective in controlling sedimentation in different stream segments. To pay for monitoring, a fee could be added to the erosion and sedimentation control permit application.

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Impervious Surface Limits

Riparian buffers cannot protect a stream from channel erosion if it is constantly scoured by high storm flows caused by runoff from impervious surfaces. In addition to protecting stream corridors, we strongly recommend that local governments pass an ordinance to minimize impervious surfaces and we encourage use of alternatives. There is solid scientific justification for such limits. In a natural forested watershed, surface runoff is quite rare, occurring only during the most severe rainstorms. Impervious surfaces, on the other hand, transfer most precipitation into runoff, leading to increased surface erosion, higher and faster storm flows in streams, and increased channel erosion. As a consequence, urban streams characteristically have greatly elevated sediment levels (Wahl et al. 1997). Flow from impervious surfaces also carries pollutants directly to streams, bypassing the natural filtration that would occur by passage through soil. Impervious surfaces are so closely correlated with urban water pollution that they are commonly used as an indicator of overall stream quality (Arnold and Gibbons 1996). May et al. (1997) note that impervious surfaces are the "major contributor to changes in watershed hydrology that drive many of the physical changes affecting urban streams." Trimble (1997) ascribed the cause of large-scale channel erosion in San Diego Creek to increased impervious surfaces in the watershed.

By transferring most precipitation into runoff, impervious surfaces lead to increased surface erosion…and increased channel erosion.

A stream may be considered to be impacted when more than 10-12 percent of its watershed is covered by impervious surfaces; when impervious surface levels reach 30 percent, the stream can be considered degraded (Klein 1979). While maintaining protected riparian buffers helps to stabilize banks and otherwise mitigate the effects of impervious surfaces, in many urban areas "as much as 90 percent of the surface runoff generated in an urban watershed concentrates before it reaches the buffer, and ultimately crosses it in an open channel or an enclosed storm drain pipe" (Schueler 1995). In these cases, buffers have little opportunity to intercept sediments and other pollutants carried to the stream (Note, however, that many studies have shown a good correlation between urban riparian buffers and water quality; e.g., May et al. 1997). Therefore, to protect streams in urban areas and to allow riparian buffers to properly perform their functions, it is necessary to minimize impervious surfaces across the whole watershed.

There are numerous ways in which local governments can reduce impervious surfaces and encourage the use of alternative, porous materials. These include the following:

- Relaxation of design standards that mandate excessive impervious surfaces. Minimum road widths are reduced, minimum parking re-

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quirements are lowered, and grassed swales are allowed as an alternative to concrete gutters.

- Smart Growth provisions that encourage clustered development. Development that is concentrated in a few areas creates less impervious surface area than sprawl.
- Use of pervious materials in government projects.
- Incentives for the use of pervious materials. Developers who use pervious alternatives or otherwise reduce impervious surface area are offered financial incentives.
- A stormwater utility fee. Developers are charged a fee based on the impervious surface area of new development to cover the impacts of increased stormwater generation. This acts as a disincentive for impervious surfaces.
- Impervious surface limits. The most comprehensive approach is to place actual limits on the amount of impervious surfaces that may be used on a site, in a watershed, or in a region.

According to Dr. Bruce Ferguson of the University of Georgia School of Environmental Design, it is possible to virtually eliminate impervious surfaces using existing technologies (1998). In addition to the water quality benefits, reducing impervious surfaces also can save a great deal of money—directly in construction costs and indirectly in flood mitigation (Arnold and Gibbons 1996). Appendix B lists various publications that discuss this topic further.

Nonregulatory Riparian Buffer Preservation Tools

A riparian buffer ordinance can be supplemented with a number of nonregulatory programs to increase its effectiveness and acceptance by landowners. Transferable development rights and density transfers provide a mechanism for compensating landowners who are affected by a buffer ordinance. Conservation easements and acquisition are ways to protect properties that are not affected by the ordinance. Conditional-use rezoning and developer exactions can increase the scope of the ordinance through additional requirements for developers. All of these are described in more detail here.

Transferable Development Rights

A local government that is serious about protecting water quality needs to look at the overall pattern of development in its jurisdiction. Not only does unplanned development adversely affect water quality, the cost of providing government services to sprawling development is very high. An essential tool for managing growth is a transferable development rights (TDR) program. In a TDR program, some areas are designated for preservation and low-density development, and others are marked for high-density development. The low-density areas—called “sending zones”—can be the more environmentally sensitive regions (or they may be the locations of agricultural production), while the high-density areas—“receiving zones”—are areas where it is most most cost-effective to provide services and provide infrastructure. Property owners in the receiving zones are allowed to buy development rights from property owners in the sending zones. Once the development right is sold from a sending property, that parcel may never be developed (in fact, it is usually protected from development by a permanent conservation easement). The owner of the receiving parcel can use those development rights to develop more densely and, presumably, more profitably.

Although TDRs appear complicated at first, they represent an invaluable mechanism, for equitably distributing the costs and benefits of development. Transferable development rights are a means of compensating landowners who are in low-density zones. Without TDRs, local officials will constantly face pressure to upzone properties to allow greater development, whether or not such development is in an appropriate location.

TDRs are invaluable in distributing the costs and benefits of development.

TDRs should be used in concert with overlay zoning or a freestanding stream corridor ordinance. It is possible to designate all protected stream corridors as “sending areas,” which would provide potential compensation for all impacted landowners. However, because this would create a market with hundreds or thousands of landowners holding a relatively small number of TDR credits apiece, this would only be practical if an effective TDR banking system were established. Floodplain areas that are not protected within riparian buffers should be classified as sending areas. Additionally, local governments should identify some wide (300 feet or greater) stream corridors that merit preservation as terrestrial wildlife habitat and designate these sites as sending areas.

Density Transfers

Density transfers are similar to TDRs in that they allow more dense development in one area in exchange for preservation of another area, but they are used to transfer development *within* a property rather than between properties. This can be used to compensate developers for the loss of land protected in the stream buffer by allowing them to develop more densely in the remainder of the property. A TDR ordinance can be written in such a way as to allow density transfers as a special type of TDR. Density transfers are also a common component of conservation subdivision regulations.

Conservation Easements

Regardless of the other stream corridor tools employed, conservation easements can be a useful mechanism for preserving tracts of riparian lands. Conservation easements are agreements in which landowners voluntarily agree to give up some of their development rights in exchange for tax benefits. Conservation easements require little oversight and virtually no expense on the part of the local government. On the other hand, initial participation of landowners is voluntary and therefore somewhat unpredictable. Many local land trusts are capable of accepting and enforcing conservation easements, sparing local governments the burden of handling paperwork and monitoring protected tracts.

Local governments can encourage the donation of conservation easements in several ways. First, they can establish a timely schedule for reassessing properties once easements have been donated, to provide landowners with property tax relief. Second, they can work with local land trusts to identify priority areas in which easements are most desirable. Third, they can promote the donation of easements through public information campaigns. Fourth, they can include a statement in their comprehensive plan or zoning ordinance that preserving riparian lands is in the public interest. This makes it easier for landowners to claim federal income tax deductions for placing conservation easements on their properties. (See Appendix B for further information sources on conservation easements.)

Acquisition

Acquisition is sometimes the best mechanism for protecting key parcels of land in the stream corridor. Generally, acquisition is reserved for special cases and cannot be the sole method for protecting riparian buffers. There are numerous sources of funds that can be applied toward riparian land acquisition. They are as follows:

- *Clean Water Act Section 319.* Funds for nonpoint source pollution control. Priority goes to watersheds ranked highly in Georgia's Unified Water Assessment Process (GA DNR EPD 1998).
- *The Heritage Fund.* Although this constitutional amendment failed in November, 1998, it will likely reappear at some point in the next few years. In its 1998 version, this amendment would have added $1.00 (on every $1,000 of home value) to the real estate transfer tax to create a fund dedicated to preservation of natural and historic sites. It is estimated that the fund would provide $30 to $32 million annually.
- *Georgia Environmental Facilities Authority.* This program, administered by the Department of Community Affairs, offers low-inter-

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est loans and grants for various purposes, including nonpoint source pollution control.

- *Impact Fees.* Local governments are authorized to charge fees to developers to pay for the infrastructure necessary to support the development (O.C.G.A. § 36-71-1 et seq). These fees can be applied to protect and produce water supplies, acquire and protect parks and open space, protect and improve shores (stream banks), and provide for flood control, among other purposes (Billingsley and Mizerak 1997).

An Effective Buffer Ordinance: The Components

An effective riparian buffer ordinance is the product of careful forethought. This section discusses some of the components that should be included in a riparian buffer ordinance. The model ordinance, Appendix A, provides an example for incorporating these guidelines into practice. Practical issues related to the administration and enforcement of a riparian buffer ordinance are also discussed here.

Meeting Minimum Standards

Local governments with water supply watersheds and large rivers within their jurisdictions must comply with the appropriate minimum standards issued by the EPD. If local governments choose to develop buffer ordinances that differ from the minimum standards, they must petition for EPD approval of alternate criteria. The model ordinance (Appendix A) is designed to meet the relevant minimum standards, except for one aspect. The minimum standards for river corridor protection, under the Mountain and River Corrider Protection Act, *prohibit* local governments from restricting construction of single family homes within the riparian buffer. While the proposed buffer ordinance provides an exemption for single family homes, it requires that they be located outside the buffer area if possible. This technically violates the minimum standards. For local governments with zoning, however, this may not be a problem. The local zoning powers established under the Georgia Constitution should allow local governments to supersede the restriction of the minimum standards in this respect. Nevertheless, this has never been legally tested, and local governments should still petition the EPD to allow this variation. Local governments without zoning ordinances may have less ground for using alternate criteria. In that situation, a stand-alone ordinance may have to comply precisely with the minimum standards and fully exempt single family homes from all buffer restrictions.

The model ordinance, Appendix A, includes the components discussed in this section.

In addition to buffer requirements, the minimum standards for water supply watersheds compel local governments to impose other restrictions, such as impervious surface limits. Local governments affected by these minimum standards must either add a new provision or enact a separate ordinance to meet these requirements. (See model ordinance, Appendix A, for more details.)

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Flexibility and Variance Procedures

Ensuring a degree of flexibility in delineating riparian buffers is an important strategy when creating an ordinance. It is very likely that cases will arise in which it is necessary and ecologically defensible to reduce the buffer width at certain points. This can be addressed by building a system of buffer averaging into the ordinance. This allows the buffer width to be reduced at certain points as long as the average buffer width remains the same along a parcel. Buffer averaging is incorporated into the attached ordinance as "Minor Exceptions." Buffer averaging would be inappropriate for a fixed buffer of less than 75 feet minimum width, because a reduction would bring the buffer to an unacceptably low level.

Although buffer averaging will address many concerns, in some cases landowners will need to request a formal variance from the provisions of the buffer ordinance. It is essential to clearly establish the conditions under which a variance may be issued. A variance should be considered in two cases:

1. When the buffer encroaches on a parcel to the degree that the remaining land is too small for the property owner to make reasonable economic use of it. In other words, there are grounds for a takings lawsuit. In this case, the buffer should be reduced only as much as necessary to allow for reasonable activity, and never less than 25 feet.
2. When the property is too small for the landowner to construct a single family dwelling without encroaching on the buffer. Again, the buffer should be reduced only as much as necessary to allow for the construction of an average-sized home for a single family.

An appeals process should be established to provide recourse to landowners in the event that a variance request is denied.

Exceptions and Prohibitions

Local governments can, as shown in the model ordinance, make an exception for existing land uses. These are defined as uses that, prior to the effective date of the ordinance, are either completed, ongoing (as in the case of agricultural activity), under construction, fully approved by the governing authority, or the subject of a fully completed application for any construction-related permit that has been submitted for approval. However, an existing use that occurs in the parcel but not currently in the buffer should not be exempted. For example, an agricultural operation that does not currently use the riparian area could not plant the area, spread manure, allow grazing, or otherwise use the corridor in nondesignated ways after the law takes effect.

Normal repairs, restoration, and renovation may be performed upon structures in the stream corridor, but expansion of buildings or impervious areas should be prohibited. Any work that involves disturbance of soils should be subjected to rigorous enforcement of the Erosion and Sedimentation Ordinance. Local governments may also wish to consider prohibiting the reconstruction of buildings that have suffered severe damage. This is not included in the proposed ordinance but is a part of some riparian buffer regulations.

Forestry activities can be permissible on a limited basis. No logging should occur within 50 feet of the stream. No logging roads may be built within the buffer, and buffer crossings should follow the latest best management practices (BMPs) issued by the Georgia Forestry Commission. There are substantial differences between the new and the 1995 BMPs (Georgia Forestry Commission 1995, 1999).

Agricultural operations constitute a special concern because they are often sources of water contamination and have been traditionally exempted from many land-use regulations. Because such operations are generally existing uses, they are also exempted from the proposed ordinance. However, protecting water quality requires addressing issues such as cattle watering in streams and the land application of waste from concentrated animal feeding operations (CAFOs). It is therefore recommended that certain agricultural activities be banned from the floodplain because they pose a direct threat to water quality, even though they may have preexisted. These include application of fertilizers and pesticides, the spreading of animal wastes, and the construction of waste lagoons. Other activities, such as allowing cattle direct access to the stream, should be discouraged and restricted but not necessarily banned.

There are numerous programs to help farmers preserve riparian buffers.

On the positive side, the Natural Resources Conservation Service (NRCS) administers several programs to assist farmers in preserving riparian buffers. The Conservation Reserve Program (CRP), which provides incentives for farmers to retire erodible or sensitive lands, now targets 4 million acres for the establishment of riparian buffers (USEPA 1998). This program has been underused in Georgia, with less than 1,000 acres of buffer land enrolled, compared to more than 15,000 acres in South Carolina (Johnson 1999). The Wetlands Reserve Program (WRP) pays farmers the appraised value of wetland acreage, as well as all costs of restoration, if they place permanent conservation easements on the land. It also provides cost-share funds if 30-year easements are placed on wetlands (Johnson 1999). The Conservation Reserve Enhancement Program (CREP) is a new initiative that awards additional funds for conservation projects that address critical water quality, soil erosion, and wildlife habitat needs (USEPA 1998). Each state can submit a proposal for CREP funds to enroll up to 100,000

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acres. States that have been funded have received an average of $200 million to acquire or obtain easements on riparian buffers and wetlands (Johnson 1999). The Environmental Quality Incentives Program (EQIP) provides technical assistance, incentive payments, and up to 75 percent cost-sharing for establishing conservation practices, including buffer strips. Although 50 percent of funds are reserved for livestock producers, CAFOs are specifically excluded (USDA NRCS 1997). Finally, the Wildlife Habitat Incentives Program offers funds to help improve wildlife habitat. Taken together, these programs offer hundreds of millions of dollars in assistance to preserve and restore riparian buffers on agricultural lands.

Local governments can take an active role in setting priorities and coordinating water protection efforts with farmers and representatives of the NRCS, the local Soil and Water Conservation District, and the local Resource Conservation and Development Agency. A cooperative approach will allow local governments to work toward their water quality goals while minimizing the regulatory burden on the agricultural community.

Good Communications

Riparian buffer width, extent, and vegetation should be based on science, not political expediency.

Local governments should involve landowners and developers in the process of developing riparian buffer ordinances. This will greatly reduce the possibility of legal challenges and make enforcement substantially easier. To reach landowners, clear and concise informational materials should be prepared to inform them of the requirements of the proposed ordinance, the benefits of buffers, and the fact that the ordinance respects their rights as landowners. Once the ordinance has been approved, these materials can be updated for permanent use.

The purpose of involving developers and landowners is to ensure that the ordinance respects property rights and is responsive to the needs of affected parties concerning variance procedures and administrative methods. It should not be viewed as a process for making watered-down compromises on stream buffer protection. Stream buffer width, extent, and vegetation should be based on science, not political expediency.

Determining Clear Variables

If a variable-width buffer option is used, it is necessary to develop expedient procedures for determining buffer width. The variables incorporated into the variable-width options presented here were chosen partly because they are readily measured in the field. Most commonly, buffer delineation will occur when a site is initially surveyed for development. On small parcels of land with fairly uniform topography, it may be possible to establish a uniform buffer width for the entire property. To accurately reflect the environmental conditions on larger properties, the width of the buffer should be determined at regular intervals along the stream. Slope can be determined by measuring the difference in elevation between the stream bank and a point approximately 100 feet inland, perpendicular to the stream bank. Wetlands should be identified and delineated using the criteria of the U.S. Army Corps of Engineers (1991).

How impervious surfaces are handled depends on their nature. If a road parallels the stream and lies within the buffer area, then the buffer should be increased by its average width. A decision must be made, however, on whether small areas of impervious surface will require an increase in buffer width. For example, if a small paved parking area exists within the buffer, is the buffer width to be increased just at that point? We recommend that local governments exempt impervious surfaces smaller than a predetermined area.

Additionally, there is a technical problem of how to handle impervious surfaces, wetlands, and steep slopes that lie partly within and partly outside the buffer. The normal procedure is to first determine the buffer width based on slope (and, for Option One, the width of the floodplain). Then, a check is made to determine whether any wetlands, very steep slopes, or impervious surfaces lie within this buffer. If they do, the width is increased by the width of the feature that is within the buffer. If the feature extends beyond the buffer, then the width is extended by the total width of the feature. For example, using Option Two, a stream running through a valley with a 10 percent slope would have a 70-foot buffer. A wetland lies within the outer 20 feet of the buffer and extends an additional 30 feet beyond. The buffer width is increased by all 50 feet of the wetland.

Ordinance Enforcement

A buffer ordinance is only as good as its enforcement. Enforcement costs time and money, but for many local governments the increased demands are relatively low (Herson-Jones 1995). In many cases, enforcement will be handled by an existing staff member, such as a building inspector. No matter who enforces the ordinance, he or she cannot do so without clear guidelines.

As indicated by the Heraty (1993) survey, discussed previously, it is essential to indicate accurately the boundaries of stream corridors on all site evaluation/design base maps. Such maps will generally be required as part of the development review policy.

> Thorough mapping is the only way to ensure that contractors responsible for various stages of the development project are unlikely

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to disturb or damage the buffer area during construction. In addition, site inspectors are able to verify that buffer regulations have been followed (Herson-Jones 1995).

Boundaries should be clearly indicated at construction sites, and temporary fencing should be used to ensure that there is no accidental intrusion in the buffer area. Site inspections should be made prior to construction to verify that buffer boundaries are accurately delineated and clearly marked. At least one subsequent inspection should be made during construction to ensure that the buffer is respected.

Minimizing the Effects of Riparian Buffer Crossings/Bypasses

Road crossings and other breaks in the riparian buffer reduce buffer width to zero and allow sediment and other contaminants to pass directly into the stream (Swift 1986). Buffer crossings may, in fact, be where the majority of sediment is transported to the stream. All buffer crossings should be avoided if possible, but when they are necessary Schueler (1995) suggests that

- crossing width should be minimized;
- direct (90 degree) crossing angles are preferable to oblique crossing angles;
- construction should be capable of surviving 100-year floods;
- free-span bridges are preferable to encasing the stream; and
- banks must be properly stabilized.

As in the attached model ordinance, local governments should exempt necessary road and utility crossings from buffer restrictions. These exemptions, however, require justification for such crossings and the use of all appropriate best management practices (BMPs). Crossings should be regularly monitored, especially after severe storms and floods, to determine if excessive sedimentation is occurring. Sewer lines that cross streams should also be inspected to ensure that they are not leaking or damaged in any way.

It is also essential to minimize practices that cause water flow to bypass the riparian zone. Drain tiles used to improve drainage from agricultural fields discharge flow directly into the stream (Fennessy and Cronk 1997, Osborne and Kovacic 1993, Vought et al. 1994). Jacobs and Gilliam (1985) compared fields drained by a riparian buffer with fields drained by ditches and drain tile. They observed high nitrate reduction in the riparian buffer, but much lower nitrate loss in drainage ditches and very little nitrate loss for fields drained by tile. Osborne and Kovacic (1993) recommend constructing riparian wetlands at the outflow of the drain tile to intercept nutrients and allow them to be processed and slowly infiltrate into the stream.

Similarly, in urban areas, storm drains carry contaminant-laden water from impervious surfaces directly into streams. This practice should be avoided, if not banned. Ideally, runoff should be allowed to infiltrate into the soil as close as possible to the source. If some drainage is required, outflow should either be directed in the form of sheet flow across a suitably wide riparian buffer or into stormwater detention ponds or constructed wetlands. When necessary, constructed wetlands may be incorporated into the riparian buffer if they are properly located and do not harm existing wetlands or other critical riparian features (Schueler 1995).

Supporting Restoration

To properly perform their functions, stream corridors should be maintained in a naturally vegetated state consisting of native trees and understory plants. If the buffer does not currently support this type of forest community, restoration is necessary. Sometimes restoration can be achieved simply by leaving the site alone and allowing it to naturally revert to forest; in other cases, streambanks must be stabilized, native trees need to be planted, or other forms of management may be necessary.

In their ordinances, local governments may require developers to perform any necessary riparian restoration work as a condition for issuing site development permits. At the least, restoration should be encouraged on all sites. Many restoration projects do not require a great deal of technical expertise and can be conducted by volunteer organizations such as scout troops and Adopt-a-Stream organizations. There are numerous technical publications available that provide guidance for stream corridor restoration. (See Appendix B.)

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Buffers and Private Property Rights

Perhaps the biggest impediment to establishing riparian buffer ordinances is concern for private property rights. Yet, a well-written ordinance that is administered fairly will balance protection of water quality and wildlife habitat with the rights of property owners. It is entirely possible to provide strong protection for riparian buffers while respecting the rights of property owners.

Buffers protected by a riparian buffer ordinance remain in the ownership of the property owner. This is in contrast to greenways, which are generally publicly owned. A buffer ordinance should never mandate public access to private property, nor should it restrict activities on a property to such an extent that the owner cannot make use of it. These conditions would be grounds for a takings lawsuit (discussed here). If a local government cannot provide adequate buffer protection along a stream segment without infringing on property rights, then the government must either acquire the parcels in question or try to offset the lack of protection with controls (whether regulatory or voluntary) somewhere else in the stream basin.

The Issue of Takings

Today, any discussion of land-use management must include the takings issue. Originally, the word "taking" referred to cases when the government physically appropriated private property for public works projects and was required to offer "just compensation" under the Fifth Amendment. Later, the courts determined that it is possible for laws to regulate properties to such an extent that the effect is virtually the same as a physical taking. Relatively few laws have been found to have this effect, however (Witten 1997, Zoeckler 1997).

Under the U.S. Constitution, a taking will occur

a. if the law fails to advance legitimate state interests *or*
b. deprives a property of all or nearly all viable economic use *or*
c. constitutes an invasion or mandates open access to the property.

Courts have clearly demonstrated that laws designed to protect water quality or even the environment in general are justified in the interest of public health, safety, and welfare (Witten 1997, Zoeckler 1997). In the case of *Lucas v. South Carolina Coastal Council* (1992), the U.S. Supreme Court noted that uses of property may be denied if they constitute a public nuisance, in accordance with long-established common law (Patterson 1993). Since nonpoint source pollution of water may constitute a public nuisance and riparian buffers are effective at preventing such pollution, the buffers may be protected from takings claims on these grounds as well.

In most cases, loss of some—but not all—economic value does not constitute a taking. In other words, the courts have determined that landowners do not have an absolute right to the most economically valuable use of their land. They do, however, have the right to exclude others from their land. Any law that requires landowners to allow public access to their property runs the risk of being declared a taking. Witten (1997) notes that the courts have determined that such access exactions must be justified by the activity being permitted by the ordinance; i.e., they must be "roughly proportional" (*Dolan v. City of Tigard* [1994]).

It is possible for an ordinance to be a taking under Georgia, but not federal, law.

An ordinance can also be declared a taking under the Georgia Constitution. Georgia courts consider similar criteria as federal courts in making such a determination, but there are some significant differences. In Georgia, government regulations are presumed to be valid unless it is proven that

a. the regulation causes "significant detriment" *and*
b. there is an "insubstantial relationship" between the regulation and the public interest.

Although both these tests must be met, it is possible for an ordinance to be a taking under Georgia law but not federal law. However, Georgia courts have upheld the validity of riparian buffer protection programs. In a unanimous decision in *Threatt v. Fulton County* (1996), the Georgia Supreme Court ruled that the county's riparian buffer ordinance, based on the Metropolitan River Protection Act, did not constitute a taking: "[T]here has been no showing that the buffer area or any other applicable regulation has deprived the condemnees of any or all economically viable or beneficial use of their property… nor is this a situation in which it can be argued that fairness and justice dictate that the burden imposed by the regulation be borne by the public as a whole" (Zoeckler 1997).

It is not clear what, if any, negative effects riparian buffers have on property values as a whole. On the one hand, buffers reduce the permissible uses on portions of properties, which would tend to reduce their value. On the other hand, studies have shown that home buyers will pay a premium for land that includes or is adjacent to protected stream corridors (National Park Service 1995). This issue will be discussed further.

An ordinance established in accordance with the recommendations that we have presented should run very little risk of being declared a taking of property. However, it is wise to anticipate potential problems and

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establish systems that reassure landowners that their rights will not be violated. This requires three components, discussed earlier:

1. A degree of flexibility in administering the buffer program
2. Fair, understandable, but strict procedures for variances
3. Open communication with landowners

How Much Land Is Affected by Riparian Buffers

Those concerned with property rights frequently suggest that riparian buffers will deprive small landowners of the use of most or all of their land. Buffer proponents counter that these concerns are greatly exaggerated. However, both parties frequently lack information to resolve this dispute. Several questions arise:

- How much of a land parcel of a given size is taken up by a buffer of a given width?
- Is there a property size threshold, beneath which buffers take up an inordinate percentage of the property area?
- What proportion of properties are affected by buffers in a typical developing county or municipality?
- What is the total area taken up by buffers in a typical county or municipality?

We can find simple answers to some of these questions with a few basic mathematical calculations. For example, a square one-acre lot is about 200 feet on each side. If the lot borders a stream, a 100-foot buffer will take up 50 percent of the lot. A square quarter-acre lot that borders a stream would lie entirely within the buffer. Of course, a lot that has been subdivided to a quarter-acre probably has a house on it (or will have one soon), which would earn it an exemption as a preexisting activity under the buffer ordinance proposed here. But what is the effect of buffers on larger lots that have not yet been subdivided, or on lots of unusual shape?

We conducted a study to determine the area of actual properties covered by a riparian buffer of various widths. We used a Geographic Information System (GIS) to draw buffers onto a tax parcel map. A tax map from Cherokee County was used as an example because the county lies within an environmentally sensitive region, is rapidly growing, and includes parcels of varying size. In addition, the study examined some countywide effects of riparian buffer protection.

Tax Parcel Map Analysis

The first part of the study used a tax parcel map from Cherokee County to examine the effects of a riparian buffer ordinance on individual properties. The map that was selected depicted parcels ranging in size from 1 acre to 120+ acres, including some that have been recently developed and some that are expected to be developed soon. Those about to be developed are of most interest because they are the ones most likely to be affected by the riparian buffer ordinance. Figure 3 shows the tax parcel map with buffers of 50 feet, 75 feet, and 100 feet, respectively. Although riparian buffers are indicated around all ponds, only those water bodies that cross property boundaries will be affected by the ordinance. Therefore, only the two ponds in the left center of the maps are included in calculations.

Thirty-eight percent of the parcels on the map could theoretically be affected by riparian buffers because they include or are adjacent to a stream or protected pond (again, however, recall that existing uses are "grandfathered," so most parcels would not be affected by a buffer ordinance in the near future, or possibly ever). Among affected parcels, a 50-foot buffer covers an average of 10.86 percent of the property area. A 75-foot buffer covers an average of 16.32 percent of affected properties, and a 100-foot buffer covers an average of 21.59 percent of affected properties.

Figure 3. Area of Tax Parcels Covered by Riparian Buffers of Different Widths

This figure shows 50-foot buffers. Numerals 1-7 indicate parcels that are described in the text and in Table 2.

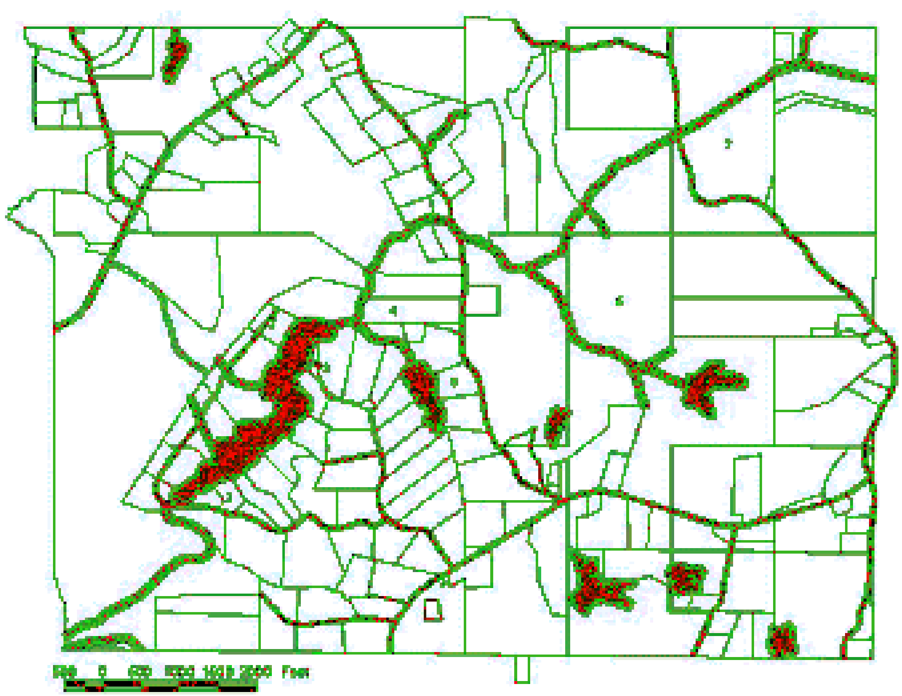

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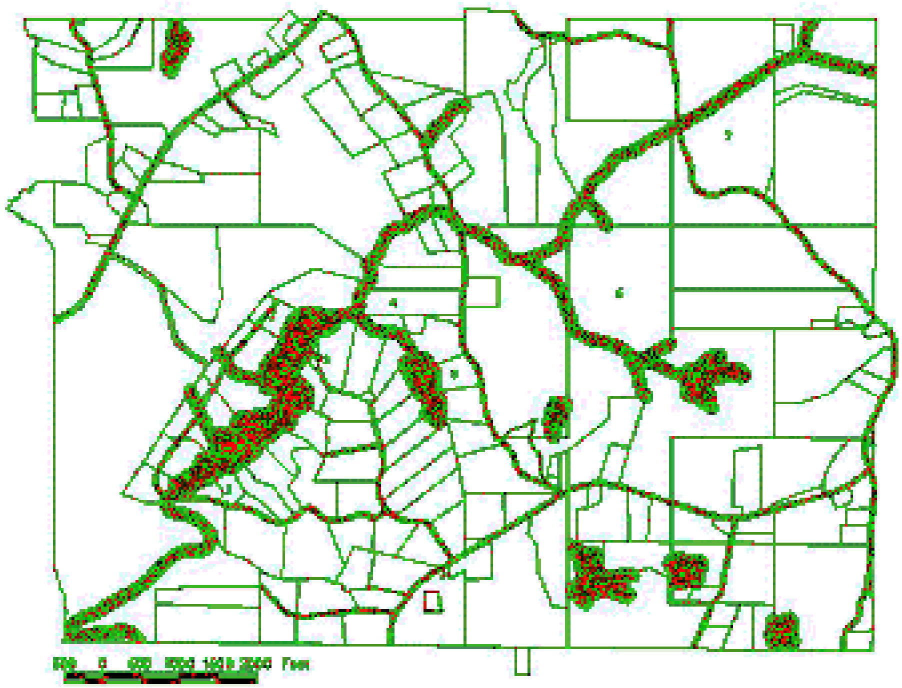
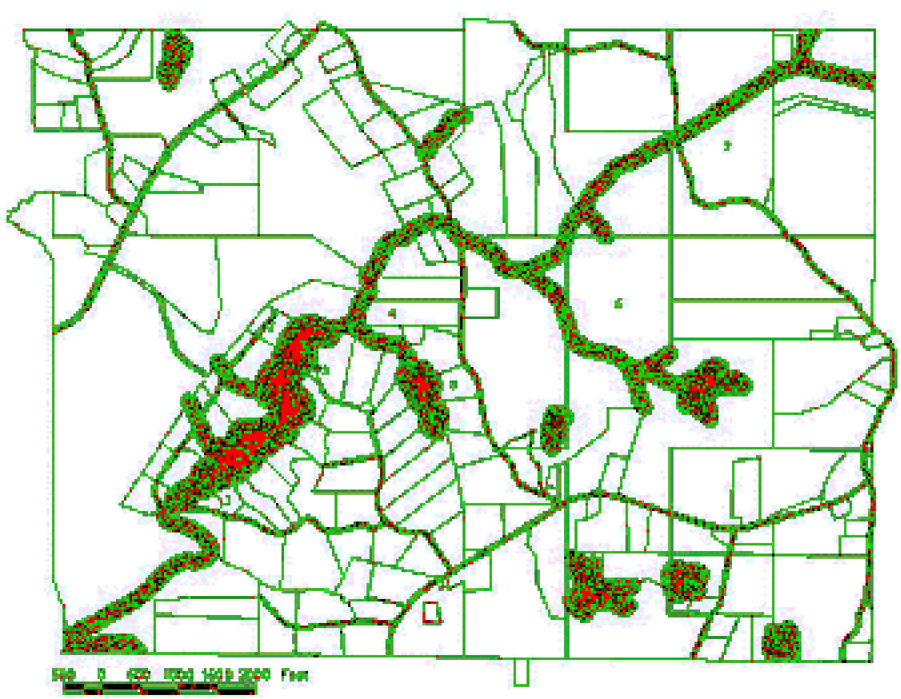
Figure 3 (*continued*). Area of Tax Parcels Covered by Riparian Buffers of Different Widths

The top figure shows 75-foot buffers, while the bottom figure shows 100-foot buffers. Numerals 1-7 indicate parcels that are described in the text and in Table 2.





Seven parcels, indicated on the maps by numerals, have been selected as examples. The characteristics of these parcels are shown in Table 1. Property 1 is slightly less than 3 acres. A 50-foot buffer covers 11.7 percent of the property, while a 100-foot buffer covers 23.16 percent. While this area is significant, there is clearly sufficient area left on the parcel (2.2 acres) for constructing a house or other structure. Property 2 is larger but loses a similar proportion of its area to the buffer because it has a longer section of shoreline (note that the areas on both sides of the road are included in this parcel). Property 3 is a smaller lot (1.2 acres) with a relatively long section of shoreline. Even a 50-foot buffer takes up almost half of the property, and a 100-foot buffer covers 85 percent of its area. If this parcel were not exempted, the owner would clearly have grounds for a variance to a 75- or 100-foot buffer. Due to the property's shape, the owner might even qualify for a variance from a 50-foot buffer.

Properties 4 and 5 are further examples of medium-sized properties that lose appreciable land area to the buffer but are clearly still quite usable. Property 6 is a 76-acre lot that is crossed by a stream and two small tributary creeks. Even with 100-foot buffers, however, the property only loses 10.70 percent of its area. Property 7 is a 120-acre lot that loses 6.12 percent of its land area when covered by 100-foot buffers.

Although it is not possible to generalize too much from these few examples, some observations can reasonably be made. For large properties of 70 acres or more, the effect of even wide buffers is likely to be minimal to developers. To a farmer, the losses could be significant, but agricultural operations are almost always existing activities and would therefore be

Table 1. Proportion of Parcels Covered by Riparian Buffers of Different Widths

ID numbers in this table indicate parcels shown on the tax maps (Figure 3).

Parcel		Percent of Property Covered by Buffer		
ID Number	Size (acres)	50 feet	75 feet	100 feet
1	2.8	11.7	17.4	23.1
2	5.0	10.5	15.6	20.8
3	1.2	47.3	68.0	85.3
4	10.4	4.2	6.4	8.5
5	4.9	8.2	12.8	16.6
6	76.4	5.2	7.9	10.7
7	120.1	3.1	4.6	6.1

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exempted. Medium-sized parcels of 3 to 70 acres will be affected but not generally to the point where they are not able to be developed. Many properties in this size class have been created as large-lot subdivisions and will likely be exempted as existing activities. But if they are not, the land lost to even a 100-foot buffer will almost always be less than 25 percent, which is not sufficient to preclude reasonable use.

On the other hand, small parcels of less than 3 acres are likely to be significantly impacted by wide (100-foot) buffers, and parcels of 1 acre or less will be significantly impacted by 50-foot buffers. Lots of a quarter acre or less may be swallowed up by riparian buffers. Again, it must be noted that such lots will generally be exempted because they have already been subdivided for residential or commercial purposes.

As discussed previously, the major effect of a riparian buffer is to alter patterns of future development away from streams and rivers. This means that mostly large properties are affected, and as was shown here, the effect on large properties is not excessive. Incorporating a buffer ordinance into the subdivision site plan should not have a negative economic effect on the developer; indeed, as will be discussed, the effect can even be positive.

Countywide Analyses

To examine the effect of a buffer ordinance on the county scale, digital maps of streams, rivers, and lakes derived from USGS topographic maps were used along with a map that showed land cover for Cherokee County derived from satellite images. Results showed that if 50-foot riparian buffers were applied to every stream, river, and lake that appeared on the map, a total of 5.9 percent of the county would be covered by buffers. For 75-foot buffers, 8.6 percent would be covered and for 100-foot buffers 11.3 percent would be included within buffer boundaries. On one hand, this is an underestimate because topographic maps do not include all streams and are not recommended for defining protected streams (they were used in this study solely because they were readily available in digital form). On the other hand, however, this is a gross overestimate of the impact that buffers would have in the short term, because it does not account for any exceptions or variances.

Land cover within 100-foot (30 meters) buffers is summarized in Table 2. Deciduous forest is the most common land cover within riparian buffers in Cherokee County (56.45 percent), followed by mixed forest (25.07 percent) and evergreen forest (8.07 percent). If all forest classes and wetland classes are combined, 91.39 percent of county riparian corridors are covered in some type of natural vegetation. The remainder of the riparian zones are in pasture/hay (4.57 percent), low-intensity residential (1.45 percent), or other uses (2.59 percent).

Table 2. Frequency of Land Cover Types in Riparian Zones in Cherokee County

Land Cover Type	Percent of Riparian Zone in Land Cover Type	
	100 foot (30 meter) zone	50 meter zone
Low-Intensity Residential	1.45	1.45
Hi-Intensity Residential	0.08	0.08
Hi-Intensity Commercial/Industrial	0.63	0.59
Bare Rock/Sand	0.01	0.01
Quarries/Mines/Pits	0.04	0.04
Transitional Barren	0.81	0.91
Deciduous Forest	56.45	53.89
Evergreen Forest	8.07	9.56
Mixed Forest	25.07	25.16
Pasture/Hay	4.57	5.58
Row Crops	0.81	0.91
Other Grasses	0.21	0.26
Woody Wetlands	0.98	0.92
Herbaceous Wetlands	0.82	0.64
Total	100.00	100.00

These results indicate that the vast majority of riparian corridors have the potential to serve as effective buffers. At present, these areas are not heavily utilized for agriculture or development, and in most areas protecting 100-foot buffers would not have an effect on existing land uses. Nevertheless, we still expect that local governments will exempt existing uses to ensure that the ordinance is politically acceptable.

Conclusions

Riparian buffers can cover a very significant portion of small properties. Those that are not exempted from a buffer ordinance will require variances. However, in most cases these properties will be exempted because they constitute existing uses. The effect of riparian buffers on medium to large properties is not sufficient to cause a major negative economic effect on landowners in any but exceptional cases, and even a 75-foot to 100-foot riparian buffer ordinance should not impose an unreasonable burden on property owners. In the case of Cherokee County, more than 90 percent of the riparian zones are covered by forest or wetlands, indicating a high potential for effective riparian buffer protection.

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Economic Considerations Regarding Buffers

Streams and riparian zones have economic value. This value can be broken down into a number of components, some of which are obvious and some of which are not. For example, an obvious value is that of the timber in a riparian zone that can be cut and sold. A less obvious value is that of an endangered species living in a river, which could become extinct if the riparian zone is not protected. The obvious values are what economists call "market values" because we can measure them in actual prices, while the less obvious ones are "nonmarket." They are real, but are harder to measure because they don't correspond to things that are commonly bought and sold. A riparian buffer ordinance offers economic benefits by preserving both market and nonmarket values. However, it also carries some economic costs, most of which are related to the costs of administration and the loss of unrestricted use of properties. Table 3 summarizes many of these costs and benefits.

It is important to note that most of the actual costs of having buffer ordinances relate to market values, while many of the benefits are nonmarket. If these nonmarket values are ignored, people will tend to undervalue riparian buffers, which can lead to poor protection and negative impacts on both the environment and the economy (Bollman 1984). The purpose of this section is to call attention to the economic benefits of riparian buffers so that they can be included in peoples' decisions. No attempt is made to quantify the actual economic benefits or costs of buffers, because such an assessment is beyond the scope of this project. The purpose here is to show that riparian buffers *do* have economic benefits, and these can be equal to or greater than the economic costs of a buffer ordinance.

As discussed previously, it is helpful to think of the riparian buffer as a land-use planning tool. In deciding to protect the riparian buffer, we are determining how best to use land in a riparian zone. Bollman (1984) summed up the situation:

> In making a decision as to how much, if any, of a riparian system is to be given up for the development of homesites, the administrator should take into account the relative scarcity of this resource or the relative scarcity of the wildlife and fish it supports and the amenities and recreation it makes available, and compare this with the relative scarcity of homesites in this vicinity or close by. Are there substitute opportunities for such homesites?

Table 3. Economic Costs and Benefits of a Riparian Buffer Ordinance

Costs	Benefits
Local Government	
Staff time	Increased property values
Staff training	Bank stabilization and erosion control
Technical assistance to developers and landowners	Low-maintenance stormwater management
Public education efforts	Reduction in flood damage
	Groundwater recharge
	Preservation of wildlife habitat
	Increased recreational opportunities and revenues
	Preservation of drinking water quality
Developers and Property Owners	
Technical surveys and reports	Increased property values
Buffer delineation	Low maintenance stormwater management
Loss of developable land	Bank stabilization and erosion control
Buffer restoration	Increased diversity of wildlife
Buffer protection during construction	Increased recreational opportunities
	Direct economic uses of buffer (e.g., logging)

Most of Georgia has no shortage of substitute sites for homes. Providing substitutes for the functions of the riparian buffer, however, is not easy and could require considerable expense. This expense represents the economic value of the buffer. When this value is fully considered, it becomes clear that in most cases the best land use for a riparian zone is as a functional riparian buffer.

The Costs

As shown in Table 3, a buffer ordinance imposes costs on a local government in the form of staff time, staff training, public education efforts, and technical assistance to landowners and developers. For most local govern-

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ments, the greatest expense is staff time (Herson-Jones 1995). Although these costs should be relatively easy to quantify, telephone calls to local government officials revealed that most governments do not track the expenses of their buffer programs. Therefore the actual staff time dedicated to buffer program administration is not known.

For landowners, the most significant cost of the ordinance is likely to be the loss of full use of the land covered by the riparian buffer. Any negative impact that this has on property values is offset to some degree by the positive effects of improved aesthetics, discussed in the next section. Other costs include time spent delineating the riparian buffer and completing necessary documentation to submit to the local government authority. Protecting the riparian buffer during construction might also add slightly to construction costs. If the stream channel is degraded, the local government could require the landowner to take measures to stabilize the banks and restore vegetation.

The Benefits

Direct Economic Uses

A protected riparian buffer is not without economic value. For example, selective logging is acceptable within the riparian zone, provided it is not conducted immediately adjacent to the stream and appropriate best management practices (BMPs) are observed. Rob Miller, the owner of a diversified agriculture business in Oregon, installed riparian buffers for bank stabilization and water quality purposes, but found that the system could also be profitable. He was quoted as saying, “We’ve found that if we use trees in the riparian buffer that produce profitable wood, we can help the environment *and* make a profit…we can make this system pay for itself” (USDA Forest Service 1997). Other nondestructive uses of buffer land include hunting, hiking, and water-based recreational activities.

The Value of Recreation and Tourism

Rivers and streams are natural magnets for recreational activities. A protected riparian buffer acquired by the local government can serve as a public park or greenway, a function with significant economic value. Of course, most buffers protected by an ordinance will remain in the ownership of individuals, and it is usually not legal or desirable for a government to mandate access to these lands. Still, these buffers can contribute positively to recreation and tourism by improving water quality and by improving the aesthetics of stream corridors, both of which are important for water-based recreational activities. Determining the economic value of stream recreation gives us an indication of the value of riparian buffers.

Buffers can contribute positively to recreation and tourism by improving water quality and the aesthetics of stream corridors.

There are several ways to calculate this. Crandall et al. (1992) used three techniques to quantify the economic value of The Nature Conservancy's Hassayampa River Preserve in Arizona: the Contingent Valuation Method (CVM), the Travel Cost Method (TCM), and local economic impact analysis. CVM is a survey-based method used to quantify the nonmarket value of resources. It has become an accepted standard among federal agencies, and even though it has its share of detractors, the method has been shown to produce reliable results (Carson and Mitchell 1993, Loomis and White 1996). Using CVM, researchers asked visitors how much they would be willing to pay to ensure that there were adequate instream flows to maintain a healthy river system. Respondents were willing to pay an average of \$65, or a total of \$520,000. For the TCM, the river preserve was valued based on the amount of money and time visitors spent to visit it. The TCM estimated the value of the preserve at \$613,360. Local economic impact analysis determined that visitors who came to the area specifically to visit the preserve contributed \$88,240 to the local economy (Crandall et al. 1992).

These methods have been used to value parks in Georgia as well. Visitors to state parks spend as much as \$13.26 per visit (Bergstrom et al. 1990). Recreationalists on one segment of the Broad River near Athens, Georgia, contribute \$88,200 in total output to the local economy each year. Visitors further responded that if the Broad River were officially protected, their number of annual visits would nearly double, yielding another \$79,772 in economic output (Bradford 1991). Whitewater rafting on the Chattooga River in North Georgia contributes some \$2.29 million in total economic output to the state (English and Bowker 1996).

Property Value Increases

A protected stream or river corridor is an aesthetic amenity that can increase property values in the nearby community. Quantifying the effect of a single factor on property values requires an economic method known as the hedonic price technique. Kulshreshtha and Gillies (1993) used this method to analyze the value of the South Saskatchewan River to the residents of the city of Saskatoon, Canada. They found that houses closer to the river were worth \$1,044 to \$33,363 more than otherwise similar homes in the same neighborhood. Rental properties close to the river were valued at \$34 per month more. Based on this research, the authors calculated the total aesthetic value of the river at \$1.2 million.

For a developer, a riparian buffer ordinance has the effect of requiring subdivision projects to take the form of conservation subdivisions. That is, the property is subdivided in such a way that individual lots are clustered together and a significant area of land is preserved in a natural

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state. Studies have shown that home buyers will pay more to live in a well-designed conservation subdivision (National Park Service 1995). In addition, clustering homes allows the developer to save money on infrastructure costs, which itself can offset the costs of development. Georgia developer Steve MacCaulay, who specializes in conservation subdivisions, says that he can make the same profits off of conservation subdivisions as he can from conventional designs (1999). In "The Economics of Watershed Protection," Schueler (1997) concludes that buffers and certain other watershed protection tools "all maintain the equity value of a parcel since they increase the value of developed properties."

Whether or not the increase in property value is large enough to cancel out the negative effect buffers can have on regulated properties depends on factors such as the size of the parcel and the nature of the land use. Cases will vary widely, but the following patterns appear likely:

- Small- to medium-sized parcels directly affected by the buffer may experience a slight decrease in property value. Landowners who would suffer significant economic hardship would qualify for a variance under the proposed buffer ordinance.
- For large properties that are subdivided for housing development, the effect is likely to be neutral.
- Properties near a protected riparian buffer but not directly affected by the buffer may experience a slight increase in property value.

The net effect across a county is likely to be neutral, yielding no net increase or decrease in property tax revenue for a local government (Schueler 1997).

The Value of Clean Water

Perhaps the most important purpose of riparian buffers, as far as local governments are concerned, is to maintain good water quality. Of course, it is very difficult to determine the precise contribution of buffers to clean water without extensive (and expensive) monitoring. Nevertheless there are methods available to determine the value of the water quality services of a buffer as well as to determine the value of clean water itself.

The most straightforward way to measure a buffer's water quality services is to determine how much it would cost to provide similar services using technological approaches. The Congaree Bottomland Hardwood Swamp in South Carolina is estimated to provide ecosystem services equivalent to a $5 million water treatment plant (Floodplain Management Association 1994). A study in Maryland determined that using riparian buffers and nonstructural controls was more cost-effective than engineered solutions in reducing nutrient pollution by 40 percent. The nonstructural approach was estimated to cost some $2.2 million, while equivalent structural techniques would cost $3.7 million to $4.3 million per year (Palone and Todd 1998). The city of Boulder, Colorado, decided that the services provided by Boulder Creek and its riparian zone were more valuable than those provided by a new nitrification tower, and chose to restore the stream system rather than to construct the technological solution (National Park Service 1995). Riparian buffers can also eliminate the need for engineered stormwater management systems, which can cost from $500 to $10,000 per acre (Palone and Todd 1998).

The value of buffers can also be determined by the costs saved in the treatment of drinking water. For many contaminants, including sediment, there is a direct relationship between quantity of pollutant and cost of treatment. The city of Roswell, Georgia, has seen its water treatment costs increase by 50 percent over the course of three years, due mainly to increased turbidity in the water (Moring 1999). Preventing sedimentation (and other forms of contamination) by establishing buffers upstream of water intakes and reservoirs may be more cost-effective than paying to remove the pollutants once they have entered the water. This was the approach that New York City used in acquiring lands in its watershed rather than constructing a new treatment facility. Water treatment is not only the business of municipalities, but of industry as well. To fully value clean water, one should also consider the amount spent by water-dependent manufacturers (such as breweries) to treat water for their production processes.

> ***One way to value buffer functions is to determine how much people are willing to pay for clean water.***

A riparian buffer ordinance is a planning tool: it prevents stream degradation before it happens. Therefore, a buffer's value can further be estimated from the amount of money people are willing to pay for stream restoration once damage has occurred. Montgomery County, Maryland, is spending $20,000 to $50,000 *per housing lot* in some areas to restore degraded streams and riparian zones. In an equally extreme case, Fairfax County, Virginia, is spending $1.5 million to restore two miles of degraded stream and riparian area (Palone and Todd 1998).

Another approach to valuing buffer functions is to determine how much people are willing to pay for clean water, using the Contingent Valuation Method. Carson and Mitchell (1993) determined that people are willing to pay an average of $275 per household per year (in 1990 dollars) to achieve the goals of the Clean Water Act. Based on this, total benefits provided by clean water in the United States (not counting the benefits of drinking water) were approximately $46.7 billion in 1990. This exceeds the Department of Commerce's estimates of the costs of the Clean Water Act for 1988 ($37.3 billion) but is lower than the projected costs of the Clean Water Act in 2000 and beyond.

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A 1986 CVM study found that Chicago residents would pay $30–$50 to improve the quality of the city's streams and rivers (Croke et al. 1986). The authors suggested that this relatively low value was due to the fact that residents relied mostly on Lake Michigan for recreational purposes, so there was less demand for stream services. Lant and Tobin (1989) used CVM to determine the value of services provided by riparian wetlands in Iowa river basins. In the Edwards basin, the value of wetland services was found to be roughly equivalent to the value of the land as cropland. In the Skunk River Basin, the riparian zones were found to be worth 10 times as much as functioning wetlands than as farmland. The Skunk River riparian zones were highly valued because wetlands were relatively scarce and their services were valued by the population of the nearby metropolitan area of Ames, Iowa. Because such services have not been measured by market value, however, riparian zones are often misallocated to farming purposes. This represents a net economic loss to all citizens.

Fox et al. (1995) calculated the economic benefit of improved water quality from agricultural soil conservation practices, based on water treatment costs and the value of sport fishing. The researchers determined that narrow buffer strips on agricultural land in a 8,155 acre watershed will produce a water quality benefit of more than $36,000. The cost of sacrificing agricultural income from the land used for these narrow buffer strips was $481. Of course, such buffer strips are not the same as wide riparian buffers, but even if the land lost from production were 20 times as great as the authors suggested, the cost would still be under $10,000—less than a third of the benefits.

The Value of Endangered Species

Studies have shown that people will pay to preserve habitats for various endangered species.

Threatened and endangered species have value to people even when they provide no direct economic benefits. Economists have used CVM to determine how much people are willing to pay to ensure that these organisms survive. This represents the existence value of species (how much people value the continued existence of these organisms), as well as the bequest value (the value of leaving some of these organisms for future generations) and option value (the value of having an option to do something with species in the future, even if we have no direct economic uses for them at present). Studies have shown that people will pay $3–$9 per year to preserve habitat for relatively obscure nongame species such as the Colorado Squawfish (*Ptychocheilus lucius*) and the Striped Shiner (*Notropis chrysocephalus*). They will pay considerably more ($30–$60 per year) for higher profile species such as the Chinook Salmon (*Oncorhynchus tshwytscha*) (Loomis and White 1996). One study found that Washington households would pay $73 per year to remove dams and restore the Elwha River to improve salmon populations (Loomis 1998). Studies such as this can serve as a guide in determining the economic benefits of habitat protection tools such as riparian buffers. For example, if each of the almost 100,000 residents of Cherokee County were willing to pay just $5 per year to protect threatened and endangered fish species, the estimated value of the county's aquatic habitat would be $500,000. At least a few studies of this sort should be conducted in Georgia to determine the economic value of nongame wildlife, currently valued very little.

Regional Quality of Life Benefits

Protecting riparian buffers can have other long-term positive impacts on the economy of a region. Clean water, like clean air, can be a significant economic asset. A community that protects its natural resources through the use of buffer ordinances and other laws may find that it is easier to attract both businesses and employees. Respondents to a 1995 survey by *Money* magazine ranked clean air and water as the two most important factors in choosing a place to live—even above low crime rates and low taxes (US EPA 1996). On the state level, it has been shown that the states with the highest levels of environmental protection also have the best economies (Fodor 1999). An aesthetically pleasing environment can improve the efficiency level of the workforce and reduce turnover (Kulshreshtha and Gillies 1993). Therefore, a local government that protects its natural environment also protects its economic future.

Conclusions

This section has shown that there are concrete economic benefits of riparian buffers and that economic tools exist to quantify these benefits. However, there is still the need for a detailed study on the economic costs and benefits of a specific riparian buffer ordinance. Such a study should include such elements as

- a determination of the costs of actual administration and enforcement of a buffer ordinance,
- a study of the hedonic effects of a buffer ordinance on property values, and
- a contingent valuation study of people's willingness to pay for protected and improved water quality.

A thorough economic analysis of this sort would provide information to resolve some of the debate that surrounds buffers and to help local governments create buffer programs that provide the greatest economic and environmental benefits.

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Even without such a study, it is apparent that the economic benefits of buffers are at least of a magnitude comparable to their costs. In the future, we can expect the economic balance to tilt even more in favor of protecting riparian zones and other natural resources. Technological advances are steadily reducing the costs of agricultural and industrial goods, but the same cannot be said of natural features such as riparian zones. Therefore, in terms of goods and services produced from the agricultural and industrial sectors, the natural environment is becoming increasingly valuable (Bollman 1984). It makes economic sense to preserve these areas and locate extractive or destructive uses elsewhere when possible (Bollman 1984).

Summary of Recommendations

Over the course of this paper, we have endeavored to supply the reader with sufficient information to create an effective, legally and politically defensible program for protecting riparian buffers. However, we recognize that by including this amount of information—and a number of relevant digressions—we run the risk that the major points might be lost. To ensure that does not happen, we summarize here the key steps to developing an effective riparian buffer ordinance.

- Pass a riparian buffer ordinance that protects all perennial and intermittent streams based on the model included in this publication. The buffer ordinance should emphasize the multiple formations of riparian buffers and should specify that buffers be maintained in a naturally forested state.
- Develop a public information campaign to explain the benefits of a riparian buffer ordinance, the restrictions of the buffer ordinance, and procedures for seeking variances.
- Identify critical riparian areas in which existing land uses may pose a threat to water quality. Such areas include cattle watering spots, areas where chicken waste is applied to fields, older homes with septic drain fields, etc. Develop a program to work with landowners and other government entities (e.g., Natural Resources Conservation Services) to minimize stream impacts in these areas.
- Identify high-priority wildlife habitat areas, historic or prehistoric sites, and other exceptional areas in the county that merit preservation. All floodplain lands that are not included in a protected stream corridor should automatically be included in this list. Some riparian corridors of 300-foot width or greater should also be included. These high-priority areas should be designated "sending areas" under a transferable development rights (TDR) program, if present. Funding should be pursued to acquire high-priority areas that otherwise cannot be preserved.
- Establish limits on impervious surfaces to control runoff.
- Properly enforce erosion and sedimentation control statutes.
- Amend the jurisdiction's existing flood damage prevention ordinance to include language that emphasizes the importance of limiting floodplain development for purposes of flood storage, water quality protection, and wildlife habitat preservation. Prohibit activities in the floodplain that could directly threaten water quality, including application of fertilizers and pesticides, siting of animal waste lagoons, and disposal of hazardous materials, including motor oil.

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- Establish a 25 NTU turbidity standard to monitor erosion and sedimentation control and riparian buffer effectiveness in different stream segments.

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Appendix A: Model Riparian Buffer Ordinance

This is a sample riparian buffer ordinance, using a fixed width, written as an amendment to an existing zoning ordinance. It creates a new buffer overlay zone along all perennial and intermittent streams. Local governments that have not adopted a zoning ordinance may use a stand-alone version, available from the University of Georgia Institute of Ecology Office of Public Service and Outreach. A variable-width buffer ordinance is also available. Call 706-542-3948 or email *lfowler@arches.uga.edu* for further information.

This ordinance complies with the state minimum standards for river corridor protection as well as the minimum standards for water supply watershed protection that relate to riparian buffers. Some local governments may be subject to additional requirements for water supply watershed protection. These requirements are summarized at the end of this document.

Language that is optional or variable is indicated by brackets and/or parentheses. The name of the local government should be inserted for [*county/municipality*].

ARTICLE [X] RIPARIAN BUFFER ZONE

1. INTENT AND PURPOSE.

The streams and rivers of [*county/municipality*] supply much of the water required by [*county/municipality*] citizens for drinking and other municipal and industrial uses [*alternatively, for regions that rely on groundwater*]. The quality of the groundwater that is used for drinking, agricultural and industrial purposes in [*county/municipality*] is connected with the quality of the surface water in the streams and rivers of [*county/municipality*]. Furthermore, the people of [*county/municipality*] use the surface waters for fishing, canoeing, and other recreational and economic purposes. The [*county/municipality*] Board of Commissioners finds that the protection of the streams and rivers of [*county/municipality*] is vital to the health, safety and economic welfare of its citizens.

This section establishes the justification for the ordinance. It should be tailored to emphasize the important aquatic resources of the local area.

For example, if endangered species of fish are present, insert a sentence that says "In addition, the [local river] and its tributaries provide habitat for a number of threatened and endangered species of fish." If these terms are defined previously in the zoning ordinance then they may not have to be redefined here.

It is therefore the intent of this ordinance to amend the Zoning Ordinances of [*county/municipality*] to establish a new riparian buffer zone of restricted development and limited land use adjacent to all perennial streams and rivers in [*county/municipality*]. The purposes of the riparian buffer zone are: to protect public and private water supplies, to trap sediment and other pollutants in surface runoff, to promote bank stabilization, to protect riparian

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wetlands, to minimize the impact of floods, to prevent decreases in base flow, to protect wildlife habitat, and to generally maintain water quality.

The standards and regulations set forth in this ordinance are created under the authority of the [*county/municipality*]'s Home Rule and zoning powers defined in the Georgia Constitution (Article IX, Section 2). In the event of a conflict between or among any provisions of this ordinance, or any other ordinances of [*county/municipality*], the requirement that is most restrictive and protective of water quality shall apply.

2. TITLE.

This Ordinance shall be known as "The Riparian Buffer Zone Requirements of [*county/municipality*]" and may be referred to generally as "Riparian Buffer Requirements."

3. DEFINITIONS.

"Existing land use" means a land use which, prior to the effective date of this ordinance, is either:

(1) completed; or
(2) ongoing, as in the case of agricultural activity; or
(3) under construction; or
(4) fully approved by the governing authority; or
(5) the subject of a fully completed application, with all necessary supporting documentation, which has been submitted for approval to the governing authority or the appropriate government official, for any construction-related permit.

"Impervious surface" means any paved, hardened or structural surface which does not allow for complete on-site infiltration of precipitation. Such surfaces include but are not limited to buildings, driveways, streets, parking lots, swimming pools, dams, tennis courts, and any other structures that meet the above definitions.

"Land-disturbing activity" means any grading, scraping, excavating or filling of land, clearing of vegetation and any construction, rebuilding, or significant alteration of a structure.

"Protected area" means any land and vegetation that lies within the riparian buffer zone, as defined herein.

"Riparian Buffer Zone" or "RBZ" is an overlay zone that encompasses all land within 100 feet [*or other fixed width, but never less than 50 feet*] on either side of all streams in [*county/municipality*], measured as a line extending perpendicularly from the stream bank.

The width of the riparian buffer zone is first defined here. Naturally, this width must be consistent throughout the ordinance. We recommend a width of 100 feet, which is consistent with state minimum standards. If

"Second order stream or higher" means any stream that is formed by the confluence of two or more other streams, as indicated by solid or dashed blue lines on the United States Geological Survey 7.5 minute quadrangle maps, of the most recent edition.

"Stream" or "River" means all of the following:

(a) any perennial stream or river (or portion thereof) that is portrayed as a solid line on a United States Department of Agriculture Soil Survey Map of the most recent edition; and

(b) any intermittent stream or river (or portion thereof) that is portrayed as a dashed line on a United States Department of Agriculture Soil Survey Map of the most recent edition; and

(c) any lake or impoundment that does not lie entirely within a single parcel of land; and

(d) any other stream as may be identified by [*county/municipality*].

a width narrower than 100 feet is specified, a separate ordinance or section of this ordinance must be added to cover those stream segments governed by minimum standards (water supply watersheds and large rivers). "Stream bank" means the uppermost limit of the active stream channel, usually marked by a break in slope.

This ordinance specifies the use of soil survey maps, which may be the most accurate maps for determining affected streams. In some areas other map types may be preferable. This section should be changed to refer to the most accurate map available for the jurisdiction, with accuracy determined by field evaluations.

4. DISTRICT USE AND REGULATIONS.

4.1. The Riparian Buffer Zone District (RBZ) is an overlay zone that encompasses all land within 100 feet [*or width defined above*] on either side of all streams in [*name of county/municipality*], measured as a line extending from the stream bank. The RBZ must be maintained in a naturally vegetated state. Any property or portion thereof that lies within the RBZ is subject to the restrictions of the RBZ as well as any and all zoning restrictions that apply to the tax parcel as a whole.

4.2. The following land uses are prohibited within the protected area:

(a) any land-disturbing activity;
(b) septic tanks and septic tank drain fields;
(c) buildings, accessory structures, and all types of impervious surfaces;
(d) hazardous or sanitary waste landfills;
(e) receiving areas for toxic or hazardous waste or other contaminants;
(f) mining;
(g) storm water retention and detention facilities, except those built as constructed wetlands that meet the approval of the Office of Planning and Zoning of [*county/municipality*].

5. EXCEPTIONS.

5.1. The following land uses are excepted from the provisions of Section 4:

Local governments with port facilities may wish to except these facilities provided they meet certain requirements.

(a) Existing land uses, except as follows:

1. when the existing land use, or any building or structure involved in that use, is enlarged, increased, or extended to occupy a greater area of land; or

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2. when the existing land use, or any building or structure involved in that use, is moved (in whole or in part) to any other portion of the property; or

3. when the existing land use ceases for a period of more than one year.

(b) Agricultural production, provided that it is consistent with all state and federal laws, regulations promulgated by the Georgia Department of Agriculture, and best management practices established by the Georgia Soil and Water Conservation Commission.

(c) Selective logging, except within 50 feet [*or other distance, but never less than 25 feet*] of a stream and provided that logging practices comply with the best management practices set forth by the Georgia Forestry Commission.

(d) Crossings by transportation facilities and utility lines. However, issuance of permits for such uses or activities is contingent upon the completion of a feasibility study that identifies alternative routing strategies that do not violate the RBZ, as well as a mitigation plan to minimize impacts on the RBZ.

(e) Temporary stream, stream bank, and vegetation restoration projects, the goal of which is to restore the stream or riparian zone to an ecologically healthy state.

(f) Structures which, by their nature, cannot be located anywhere except within the riparian buffer zone. These include docks, boat launches, public water supply intake structures, facilities for natural water quality treatment and purification, and public wastewater treatment plant sewer lines and outfalls.

(g) Wildlife and fisheries management activities consistent with the purposes of Section 12-2-8 (as amended) of the Official Code of Georgia Annotated.

Important Note:

Section 5.1(h)-1 exceeds the state minimum standards by requiring the residence to be located outside of the riparian buffer if possible. As of this writing, such a provision may require EPD approval. Contact the University of Georgia, Institute of Ecology Office of Public Service and Outreach, for more information on this issue.

(h) Construction of a single family residence, including the usual appurtenances, provided that:

1. based on the size, shape or topography of the property, as of the effective date of this ordinance, it is not reasonably possible to construct a single-family dwelling without encroaching upon the Riparian Buffer Zone; and

2. the dwelling conforms with all other zoning regulations; and

3. the dwelling is located on a tract of land containing at least two acres. For purposes of these standards, the size of the tract of land shall not include any area that lies within the protected river or stream; and

4. there shall be only one such dwelling on each two-acre or larger tract of land; and

5. septic tank drain fields shall not be located within the buffer area, although a septic tank or tanks serving such a dwelling may be located within the RBZ.

(i) Other uses permitted by the Georgia DNR or under Section 404 of the Clean Water Act.

5.2. Notwithstanding the above, all excepted uses, structures or activities shall comply with the requirements of the Erosion and Sedimentation Act of 1975 and all applicable best management practices and shall not diminish water quality as defined by the Clean Water Act. All excepted uses shall be located as far from the stream bank as reasonably possible.

6. MINOR VARIANCES.

6.1. A minor variance is a reduction in buffer width over a portion of a property in exchange for an increase in buffer width elsewhere on the same property such that the average buffer width remains 100 feet [*or width specified above*]. No minor variance can decrease buffer width to less than 75 feet [*or 25 feet less than the buffer width*]. A property owner may request a minor variance from the requirements of the RBZ by preparing the appropriate application with the [*county/municipality*] Office of Planning and Zoning.

Minor variances allow for "buffer averaging," which gives the landowner a fast and easy method for reducing the width of the RBZ by small amounts, if necessary.

6.2. Each applicant for a minor variance must submit documentation that issuance of the variance will not result in a reduction in water quality. All minor variances shall adhere to the following criteria:

(a) the width of the RBZ shall be reduced by the minimum amount possible, and never to less than 75 feet [*or 25 feet less than the buffer width*] at any point; and

(b) reductions in the width of the RBZ shall be balanced by corresponding increases in the RBZ elsewhere on the same property, such that the total area included in the RBZ is the same as if it were 100 feet [*or width specified above*] wide; and

(c) land-disturbing activities must comply with the requirements of the Erosion and Sedimentation Act of 1975 and all applicable best management practices.

7. MAJOR VARIANCES.

7.1. A major variance is a reduction in RBZ width that is not balanced by a corresponding increase in buffer width elsewhere on the same property, or else a reduction in buffer width to less than 75 feet [*or as specified*

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above]. A property owner may request a major variance from the requirements of the RBZ by preparing the appropriate application with the [*county/municipality*] Office of Planning and Zoning. Such requests shall be granted or denied by application of the criteria set forth below in section 24.7.3 and will be subject to the conditions set forth below in section 24.7.4. Under no circumstances may an exception be granted which would reduce the buffer to a width less than the minimum standards established by state or federal law.

7.2. Each applicant for a major variance must provide documentation that describes:

(a) existing site conditions, including the status of the protected area; and

(b) the needs and purpose for the proposed project; and

(c) justification for seeking the variance, including how buffer encroachment will be minimized to the greatest extent possible; and

(d) a proposed mitigation plan that offsets the effects of the proposed encroachment during site preparation, construction, and post-construction phases.

Section 7.3a is designed to ensure that any landowner who might have grounds for a claim of "takings" can qualify for a variance. Section 7.3b is designed to ensure that even those landowners with lots smaller than two acres, as of the effective date of the ordinance, can construct a single-family dwelling within the buffer if necessary to prevent extreme hardship. Landowners with lots of two acres or larger who must encroach on the buffer in order to construct a home are excepted in section 5.1(h)-1.

7.3. No major variance shall be issued unless the [*county/municipality*] Zoning Board of Appeals determines that:

(a) the requirements of the RBZ represent an extreme hardship for the landowner such that little or no reasonable economic use of the land is available without reducing the width of the RBZ; or

(b) the size, shape, or topography of the property, as of the effective date of this ordinance, is such that it is not possible to construct a single-family dwelling without encroaching upon the Riparian Buffer Zone.

7.4. Any major variance issued by the [*county/municipality*] Zoning Board of Appeals will meet the following conditions:

(a) the width of the RBZ is reduced only by the minimum extent necessary to provide relief; and

(b) land-disturbing activities must comply with the requirements of the Erosion and Sedimentation Act of 1975 and all applicable best management practices. Such activities shall not impair water quality, as defined by the federal Clean Water Act and the rules of the Georgia Department of Natural Resources, Environmental Protection Division; and

(c) as an additional condition of issuing the variance, the [*county/municipality*] Zoning Board of Appeals may require water quality monitoring downstream from the site of land-disturbing activities to ensure that water quality is not impaired.

8. REPEAL CLAUSE.

The provisions of any ordinances or resolutions or parts thereof in conflict herewith are repealed, save and except such ordinances or resolutions or parts thereof which provide stricter standards than those provided herein.

9. SEVERABILITY.

Should any section, subsection, clause, or provision of this Article be declared by a court of competent jurisdiction to be invalid, such decision shall not affect the validity of this Article in whole or any part thereof other than the part so declared to be invalid.

10. AMENDMENT.

This Article may be amended from time to time by resolution of the Board of Commissioners of [*county/municipality*]. Such amendments shall be effective as specified in the adopting resolution.

11. EFFECTIVE DATE.

This article shall become effective upon its adoption.

ADDITIONAL WATER SUPPLY WATERSHED REQUIREMENTS.

The above ordinance meets the riparian buffer provisions of the state minimum standards for water supply watershed protection. However, the minimum standards place other restrictions on small and large water supply watersheds in addition to riparian buffer requirements. A water supply watershed is the drainage basin upstream of governmentally owned drinking water supply intake; a small water supply watershed is less than 100 square miles, while a large water supply watershed is 100 square miles or larger. A water supply reservoir is a governmentally owned impoundment of water for the primary purpose of providing water to one or more governmentally owned public drinking water systems.

Within a seven-mile radius upstream of a water supply reservoir, no impervious surfaces, septic tanks or septic tank drain fields may be installed within 150 feet of a stream bank. *Note: The EPD can approve alternate criteria for protecting drinking water standards. Because the ordinance above is generally stricter than the state minimum standards, the EPD may allow local governments to waive certain criteria, such as the 150-foot impervious surface/septic setbacks. We do not recommend waiving the other requirements described here.*

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In both large and small water supply watersheds, new facilities which handle hazardous materials of the types and amounts determined by the Department of Natural Resources must perform their operations on impermeable surfaces having spill and leak collection systems as prescribed by the Department of Natural Resources.

In small water supply watersheds only, new hazardous waste treatment or disposal facilities are prohibited, and new sanitary landfills are allowed only if they have synthetic liners and leachate collection systems. The impervious surface area (including all public and private structures, utilities or facilities) of the entire water supply watershed shall be limited to twenty-five percent (25%) of the area of the watershed or existing use, whichever is greater.

Appendix B: Additional Riparian Buffer Resources

For more information, see the following resources, categorized by topic. Publications data for this additional material can be found in the References.

Riparian Buffers

Chesapeake Bay Riparian Handbook:
A Guide for Establishing and Maintaining Riparian Forest Buffers.
R. S. Palone and A. H. Todd, eds., 1998.
Available on the Internet at *http://www.chesapeakebay.net/facts/forests/handbook.htm*.

Site Planning for Urban Stream Protection.
T. Schueler, 1995.
Available from the Center for Watershed Protection at 410-461-8323.

State and Federal Laws Affecting Streams and Rivers

Environmental Management Requirements for Stream and River Corridors in Georgia.
G. Cowie and P. Hardy, 1997.
Available from the EPD at 1-888-EPD-5947 (Atlanta: 404-657-5947).

Floodplain Protection

Protecting Floodplain Resources: A Guidebook for Communities.
Federal Interagency Floodplain Management Task Force, 1996.
Available from the EPD floodplain management office at 404-656-6382.

Conservation Easements

A Landowner's Guide: Conservation Easements for Natural Resource Protection (second edition).
L. Fowler and H. Neuhauser, 1998.
Available from the Georgia Environmental Policy Institute at 706-546-7507.

Reducing Impervious Surfaces and Other Local Environmental Provisions

Land Development Provisions to Protect Georgia Water Quality.
University of Georgia School of Environmental Design, 1997.
Available from the EPD at 1-888-EPD-5947 (Atlanta: 404-657-5947).

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Reducing the Impacts of Storm Water Runoff through Alternative Development Practices

A. E. Miller and A. Sutherland, 1999

Available from the Institute of Ecology, University of Georgia, Athens, GA 30602-2202; call 706-542-2968; or email *lfowler@arches.uga.edu*.

Stream Restoration

Stream Corridor Restoration: Principles, Practices and Processes

USDA interagency document, 1998.

Available on the Internet at *http://www/hqnet.usda.gov/streams_restoration.htm*.

Guidelines for Stream Bank Restoration

Georgia Soil and Water Conservation Commission, 1994.

Available from GSWCC at 706-542-4242.

Takings

Counties and the Takings Issue: How Far Can Government Go in Regulating Private Property?

J. Witten, 1997.

Available from the Association County Commissioners of Georgia at 404-522-5022.

A Summary of Takings Law

R. L. Zoeckler, 1997.

Available from the Georgia Environmental Policy Institute at 706-546-7507.

Transferable Development Rights (TDRs)

An Introduction to Transferable Development Rights

M. Bledsoe et al.

Available from the Institute of Ecology at 706-542-2968.

For Other Model Ordinances for Natural Resources Protection, Contact:

Office of Public Service and Outreach

Write to Institute of Ecology, University of Georgia, Athens, GA 30602-2202; call 706-542-2968; or email *lfowler@arches.uga.edu*.

NPDES PHASE I DATA

MS4

Municipal Separate Storm Sewer System

Office University of Alabama , Center of Watershed Protection Date Jul-03
Prepared by: UA - CWP

States: AL, AZ, CA, CO, GA, ID, KA, KY, MA, MD, MN, NC, OR, PA, TN, TX, VI
EPA Regions:

Municipalities Included:
Huntsville, Jefferson County, Mobile, Montgomery. Maricopa County, Tucson. Alameda, Caltrans, Colorado Springs, Denver Metro
Atlanta, Clayton County, Cobb County, Fulton County, Ada County Highway District, Topeka, Wichita, Jefferson County - Louisville, Lexington
Boston, Anne Arundel County, Baltimore County, Baltimore City, Carroll County, Charles County, Harford County, Howard County
Montgomery County, Princes Georges County, State Highway, Minneapolis, Charlotte, Fayetteville, Greensboro, Raleigh
Clackamas County, Eugene, Gresham, Portland, Salem, ODOT, Philadelphia, Knoxville, Memphis,
Arlington, Dallas, Dallas County, Forth Worth, Gargland, Harris County, Houston, Irving, Mesquite, Plano, Tarrant County
Arlington County, Chesapeake County, Chesterfield County, Fairfax County, Hampton County, Henrico County, Newport News County
Norfolk County, Portsmouth County, Virginia Beach County

Site Identification:

Description of the projects:

ITEMS

	ITEM	DESCRIPTION	EXAMPLE
SITE DESCRIPTION	Order	Key to identify the event, numeric, integer	1
	Landuse	Landuses that represent most of the watershed RE: Residential, CO: Comercial, ID: Industrial, IS:Institutional, OP: Open Space, FW: Freeway, UNK: Unknown Category	RE_CO
	Season	Season: WI: Winter (Dec-Jan-Feb); SP: Spring (Mar-Apr-May); SU: Summer (Jun-Jul-Aug); FA:Fall (Sep-Oct-Nov)	FA
	Season_WI_1	WI = 1; SP = 2; SU = 3; FA = 4	4
	COM_FF_XX	Composite, Flush or grab sample	COM
	LOCATION_ID	Key to identify state, jurisdiction and site. The key has characters in the following order. Two capital letters for the state, two for the jurisdiction or municipality. The last characters identify the discharge.	ALBHA001
	Jurisdiction	Name of the Jurisdistiction or Municipality. If spaces are necessary use _ instead.	San_Marcos
	Site_ID	Use the ID used by the community. This is the last part of the ID that were used in LOCATION_ID	A001
	Contact	Identify the name and phone number or e-mail of the office that create the record.	Gepeto@epa.gov
	PLU_Residential	Percentage of Landuse residential in the drainage area	45
	PLU_Institutional	Percentage of Landuse institutional in the drainage area	5
	PLU_Commercial	Percentage of Landuse commercial in the drainage area	15
	PLU_Industrial	Percentage of Landuse industrial in the drainage area	0
	PLU_Open_Space	Percentage of Landuse open space in the drainage area	25
	PLU_Freeway	Percentage of Landuse freeway in the drainage area	10
	PLU_Water	Percentage of Landuse water in the drainage area	15
	PLU_UNK	Percentage of Landuse unknown category in the drainage area	10
	Drainage_Area	Drainage Area in acres	1.25
	Status	Data base code name etc	BMP Test Site ID Code: 1011073569
	Latitude	Approximated Latitude North of the site in dd_mm_ss	38_54_09.09
	Longitude	Approximated Longitude West of the site in dd_mm_ss	77_09_13.00
	EPA_Rain_Zone	Zones according to: Methodology for Analyisis of Detention Basins for control of Urban Runoff Quality Prepared for the U.S. Environmental Protection Agency, Office of Water. 1986 [55 FR 48073 Nov 16 1990] 40 CFR part 122 appendix E	2
	Per_Impervious	Percentage of impervious in the drainage area. Use 100 for complete impervious	45

	Runoff_Vol_Coef	Volumetric runoff coefficient in the drainage area	0.25
	Curve_Number	Curve number	75
	Aged_Development	Age of the development in years	10.5
	Type_Conveyance	Use 2 capital letters in this field. CG for curb and gutter/seal drainage; GS for grass swale or OT for others. Use the comments column to add more information	CG
	Controls	Structure Control located above the discharge. Use WP for detention pond, DP for Dry Ponds, DT for detention structutes or OT for others. Use the comments field to add more information	WP
	Comments	Include all the comments that you consider relevant in the site.Don't use colons, semicolons, or commas. Use double underline instead period.	Low_Density_residential_in_Arlington_terms__Density_is_about_5_dwelling_units/acre__Garden_apts_and_low_rise_buildings
EVENT DESCRIPTION	EVENT_ID	use the code used for the community to identify the event	2001001
	Precipitation_Depth (in)	Precipitation depth of the EVENT_ID in inches.	1.6
	Q	Indicates where the precipitation was measured.	On Site
	Start_Date (mm/dd/yy)	Identify the start day of the EVENT_ID	4/12/1999
	Start_Time (min of day)	Identify the start time of the EVENT_ID	08_45
	End_Date (mm/dd/yy)	Identify the end day of the EVENT_ID.	4/13/1999
	End_Time (min of day)	Identify the end time of the EVENT_ID. **NOTE: If you don't have this information but have the duration, assign the start time at 00_00 of the storm day and assign the duration as end time. Additionally assign the start day as the end day.	23_30
	Maxr15	Maximum precipitation intensity in 15 minutes. (units in/hr)	0.85
	Runoff (in)	Total runoff of the EVENT_ID in inches.	0.89
	Q	Indicates if the runoff has base flow or not.	E_Base
	3H_TOT	Total runoff was evaluated for the complete event or the first 3 hours.	TOT
	FF_COM (First Flush or composite)	Identify with FF if the record corresponds to First Flush or COM for Composite	FF
	Type_Sample	MA: Manual; AU: Automatic	AU
	Type_Sampler	Indicate if the sample was time or flow weighted composite.	FLOW_COMP
	Type_Sa_An	DI: use for discrete analysis; COM: Used for composite analysis	DI
	BOD5 (mg/l)	Assign the value for each parameter in the corresponding units.	25.3
	Q	Qualifiers. Assign The following qualifiers according to the case: ND: Not Detected, don't assign any value to the cell value; NA: Not Available. The sample for this parameter was not available, please try to explain why in the comments; NZ: Not Analyzed; E:Estimated; C:Calculated	ND

		PARAMETER	X if included	Total Observations	Percentage Detected
Conventional Parameters	Commonly Used	Conductivity (uS/cm @ 25C)			
		DO (mg/L)			
		Hardness (mg/L CaCO3)			
		Oil and Grease (mg/L)			
		pH			
		Temperature (C)			
		Turbidity (NTU)			
	Sol	TDS (mg/L)			
		TS (mg/L)			
		TSS (mg/L)			
	O	BOD5 (mg/L)			
		COD (mg/L)			
	Bac	Fecal Coliform (colonies/100 ml)			
		Fecal Streptococcus (colonies/100 ml)			
		Total Coliform (colonies/100 ml)			
		Total E. Coli (colonies/100 ml)			
	Nutrients	Ammonia (mg/L)			
		N02+NO3 (mg/L)			
		Nitrogen Dissolved (mg/L)			
		Nitrogen Total (mg/L)			
		Nitrogen Kjeldahl Total (mg/L)			
		Phosphate Ortho (mg/L)			
		Phosphorous Dissolved (mg/L)			
		Phosphorous Total (mg/L)			
	Metals and Toxicants	Antimony Total (ug/L)			
		Antimony Dissolved (ug/L)			
		Arsenic Total (ug/L)			
		Arsenic Dissolved (ug/L)			
		Beryllium Total (ug/L)			
		Beryllium Dissolved (ug/L)			
		Cadmium Total (ug/L)			
		Cadmium Dissolved (ug/L)			
		Chromium Total (ug/L)			
		Chromium Dissolved (ug/L)			
		Copper Total (ug/L)			
		Copper Dissolved (ug/L)			
		Cyanide Total (ug/L)			
		Cyanide Dissolved (ug/L)			
		Lead Total (ug/L)			
		Lead Dissolved (ug/L)			
		Mercury Total (ug/L)			
		Mercury Dissolved (ug/L)			
		Nickel Total (ug/L)			
		Nickel Dissolved (ug/L)			
		Selenium Total (ug/L)			
		Selenium Dissolved (ug/L)			
		Silver Total (ug/L)			
		Silver Dissolved (ug/L)			
		Thallium Total (ug/L)			
		Thallium Dissolved (ug/L)			
		Toxicity Test Total (I25% RED)			
		Toxicity Test Dissolved (I25% RED)			
		Zinc Total (ug/L)			
		Zinc Dissolved (ug/L)			
	Volatiles	Acrolein (ug/L)			
		Acrylonitrile (ug/L)			
		Benzene (ug/L)			
		Bromoform (ug/L)			
		Carbon Tetrachloride (ug/L)			
		Chlorobenzene (ug/L)			
		Chlorodibromomethane (ug/L)			
		Chloroethane (ug/L)			
		2-Chloroethylvinyl ether (ug/L)			
		Chloroform (ug/L)			
		Dichlorobromoethane (ug/L)			
		1,1-Dichloroethane (ug/L)			
		1,2-Dichloroethane (ug/L)			
		1,1-Dichloroethylene (ug/L)			
		1,2-Dichloropropane (ug/L)			
		1,3-Dichloropropylene (ug/L)			

	Ethylbenzene (ug/L)
	Methylbromide (ug/L)
	Methylchloride (ug/L)
	Methylenechloride (ug/L)
	1,1,2,2-Tetrachloroethane (ug/L)
	Tetrachloroethylene (ug/L)
	Toluene (ug/L)
	1,2-Trans-dichloroetylene (ug/L)
	1,1,1-Trichloroethane (ug/L)
	1,1,2-trichloroethane (ug/L)
	Trichloroethylene (ug/L)
	Vinylchloride (ug/L)
Extra Parameters	Alkalinity, total as CaCO3 (mg/l)
	pH Field (S.U.)
	Fecal Coliform/Fecal Strep Ratio
	Oil and Grease Hidrocarbon (mg/l)
	Total_hydrocarbon_fingerprint (mg/l)
	Total_Petroleum_hydrocarbon (mg/l)
	Total_Organic_Carbon (mg/L)
	Chloride (mg/l)
	trans-1,3-Dichloropropene
	Bromomethane
	Chloromethane
	Trichlorofluoromethane
	Tetrachloroethene(ug/l)
	BOD5 Carbonaceous (mg/l)
	Hardness as calcium(mg/L)
	Hardness, Magnesium(mg/L)
	Nitrogen_Nitrate (mg/l)
	Nitrogen_Nitrite (mg/l)
	Nitrogen_Total_Organic (mg/l)
	Barium, total as Ba (ug/l)
	Iron, total as Fe (ug/l)
	Iron, Dissolved as Fe (ug/l)
	Days since last rain

ORDER	Landuse	Season	Database	LOCATION_ID	Jurisdiction (County)	Jurisdiction (City)	Site_ID	Rain Zone
1321	FW	WI	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1322	FW	SU	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1323	FW	WI	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1324	FW	SU	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1325	FW	SU	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1326	FW	SU	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1327	FW	SU	BMP	VA	Albemarle	Charlottesville	29 North Swale B_Inflow	2
1328	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1329	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1330	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1331	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1332	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1333	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1334	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1335	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1336	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1337	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Buffer Strip_EOP	2
1338	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1339	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1340	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1341	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1342	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1343	FW	SP	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1344	FW	SP	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1345	FW	SP	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1346	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1347	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1348	FW	WI	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1349	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1350	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1351	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1352	FW	WI	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1353	FW	SP	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1354	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1355	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1356	FW	FA	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2
1357	FW	SU	BMP	VA	Albemarle	Charlottesville	29 South Swale_Inflow	2

ORDER	Contact	PLU_Residential	PLU_Institutional	PLU_Commercial	PLU_Industrial	PLU_Open_Space
1321		0	0	0	0	0
1322		0	0	0	0	0
1323		0	0	0	0	0
1324		0	0	0	0	0
1325		0	0	0	0	0
1326		0	0	0	0	0
1327		0	0	0	0	0
1328		0	0	0	0	0
1329		0	0	0	0	0
1330		0	0	0	0	0
1331		0	0	0	0	0
1332		0	0	0	0	0
1333		0	0	0	0	0
1334		0	0	0	0	0
1335		0	0	0	0	0
1336		0	0	0	0	0
1337		0	0	0	0	0
1338		0	0	0	0	0
1339		0	0	0	0	0
1340		0	0	0	0	0
1341		0	0	0	0	0
1342		0	0	0	0	0
1343		0	0	0	0	0
1344		0	0	0	0	0
1345		0	0	0	0	0
1346		0	0	0	0	0
1347		0	0	0	0	0
1348		0	0	0	0	0
1349		0	0	0	0	0
1350		0	0	0	0	0
1351		0	0	0	0	0
1352		0	0	0	0	0
1353		0	0	0	0	0
1354		0	0	0	0	0
1355		0	0	0	0	0
1356		0	0	0	0	0
1357		0	0	0	0	0

ORDER	PLU_Freeway	PLU_Water	PLU_UNK	Drainage_Area
1321	100	0	0	0.8648654
1322	100	0	0	0.8648654
1323	100	0	0	0.8648654
1324	100	0	0	0.8648654
1325	100	0	0	0.8648654
1326	100	0	0	0.8648654
1327	100	0	0	0.8648654
1328	100	0	0	0.805560344
1329	100	0	0	0.805560344
1330	100	0	0	0.805560344
1331	100	0	0	0.805560344
1332	100	0	0	0.805560344
1333	100	0	0	0.805560344
1334	100	0	0	0.805560344
1335	100	0	0	0.805560344
1336	100	0	0	0.805560344
1337	100	0	0	0.805560344
1338	100	0	0	0.805560344
1339	100	0	0	0.805560344
1340	100	0	0	0.805560344
1341	100	0	0	0.805560344
1342	100	0	0	0.805560344
1343	100	0	0	0.805560344
1344	100	0	0	0.805560344
1345	100	0	0	0.805560344
1346	100	0	0	0.805560344
1347	100	0	0	0.805560344
1348	100	0	0	0.805560344
1349	100	0	0	0.805560344
1350	100	0	0	0.805560344
1351	100	0	0	0.805560344
1352	100	0	0	0.805560344
1353	100	0	0	0.805560344
1354	100	0	0	0.805560344
1355	100	0	0	0.805560344
1356	100	0	0	0.805560344
1357	100	0	0	0.805560344

ORDER	Status	Latitude	Longitude	Per_Impervious
1321	Checked Nov 23, 2007			62
1322	Checked Nov 23, 2007			62
1323	Checked Nov 23, 2007			62
1324	Checked Nov 23, 2007			62
1325	Checked Nov 23, 2007			62
1326	Checked Nov 23, 2007			62
1327	Checked Nov 23, 2007			62
1328	Checked Nov 23, 2007			100
1329	Checked Nov 23, 2007			100
1330	Checked Nov 23, 2007			100
1331	Checked Nov 23, 2007			100
1332	Checked Nov 23, 2007			100
1333	Checked Nov 23, 2007			100
1334	Checked Nov 23, 2007			100
1335	Checked Nov 23, 2007			100
1336	Checked Nov 23, 2007			100
1337	Checked Nov 23, 2007			100
1338	Checked Nov 23, 2007			57
1339	Checked Nov 23, 2007			57
1340	Checked Nov 23, 2007			57
1341	Checked Nov 23, 2007			57
1342	Checked Nov 23, 2007			57
1343	Checked Nov 23, 2007			57
1344	Checked Nov 23, 2007			57
1345	Checked Nov 23, 2007			57
1346	Checked Nov 23, 2007			57
1347	Checked Nov 23, 2007			57
1348	Checked Nov 23, 2007			57
1349	Checked Nov 23, 2007			57
1350	Checked Nov 23, 2007			57
1351	Checked Nov 23, 2007			57
1352	Checked Nov 23, 2007			57
1353	Checked Nov 23, 2007			57
1354	Checked Nov 23, 2007			57
1355	Checked Nov 23, 2007			57
1356	Checked Nov 23, 2007			57
1357	Checked Nov 23, 2007			57

ORDER	Q	Runoff_Vol_Coef	Age_of_Development	Type_Conveyance	Controls	Comments
1321		0.949999988				
1322		0.949999988				
1323		0.949999988				
1324		0.949999988				
1325		0.949999988				
1326		0.949999988				
1327		0.949999988				
1328						
1329						
1330						
1331						
1332						
1333						
1334						
1335						
1336						
1337						
1338		0.730000019				
1339		0.730000019				
1340		0.730000019				
1341		0.730000019				
1342		0.730000019				
1343		0.730000019				
1344		0.730000019				
1345		0.730000019				
1346		0.730000019				
1347		0.730000019				
1348		0.730000019				
1349		0.730000019				
1350		0.730000019				
1351		0.730000019				
1352		0.730000019				
1353		0.730000019				
1354		0.730000019				
1355		0.730000019				
1356		0.730000019				
1357		0.730000019				

ORDER	EVENT_ID_Conventional	Precipitation_Depth (in)	Q	Start_Date (mm/dd/yy)	Start_Time (min of day)	End_Date (mm/dd/yy)	End_Time (min of day)
1321	11/12/92	0.360000002		11/12/92			
1322	05/31/93	0.416259841		05/31/93			
1323	11/05/92	0.416259841		11/05/92			
1324	07/12/93	0.645236218		07/12/93			
1325	07/12/93	0.416259841		07/12/93			
1326	07/19/93	0.468503922		07/19/93			
1327	07/12/93	0.468503922		07/12/93			
1328	10/23/94	0.350393686		10/23/94			
1329	10/23/94	0.468503922		10/23/94			
1330	10/09/94	0.468503922		10/09/94			
1331	10/23/94	0.610000055		10/23/94			
1332	10/23/94	0.468503922		10/23/94			
1333	09/25/94	0.610000055		09/25/94			
1334	10/23/94	0.350393686		10/23/94			
1335	09/25/94	0.350393686		09/25/94			
1336	10/09/94	0.760000034		10/09/94			
1337	10/09/94	0.929921218		10/09/94			
1338	07/17/94	1.429921248		07/17/94			
1339	10/30/93			10/30/93			
1340	07/23/94	0.760000034		07/23/94			
1341	06/26/94	0.939999978		06/26/94			
1342	07/17/94			07/17/94			
1343	04/13/94			04/13/94			
1344	03/27/94			03/27/94			
1345	03/27/94			03/27/94			
1346	06/26/94	2.150000024		06/26/94			
1347	06/26/94	0.929921218		06/26/94			
1348	12/04/93	1.429921248		12/04/93			
1349	10/30/93	0.760000034		10/30/93			
1350	07/23/94	0.700000027		07/23/94			
1351	07/17/94			07/17/94			
1352	11/17/93	0.929921218		11/17/93			
1353	03/27/94	1.429921248		03/27/94			
1354	10/30/93	0.929921218		10/30/93			
1355	07/23/94	1.429921248		07/23/94			
1356	10/30/93			10/30/93			
1357	07/23/94	2.150000024		07/23/94			

ORDER	Maxr15	Runoff (in)	Q	3h or Total event? 3H - TOT	FF_COM (First Flush or composite)	Type_Sampler	Type_Sa_An
1321		0.332305962					
1322		0.033340832					
1323							
1324		0.061102362					
1325		0.061102362					
1326		0.055163105					
1327		0.061102362					
1328							
1329							
1330							
1331							
1332							
1333		0.107458577					
1334							
1335		0.107458577					
1336							
1337							
1338		0.111516352					
1339		0.132867977					
1340		0.565310855					
1341							
1342		0.111516352					
1343		0.010260374					
1344							
1345							
1346							
1347							
1348		0.923409497					
1349		0.132867977					
1350		0.565310855					
1351		0.111516352					
1352		0.022039998					
1353							
1354		0.132867977					
1355		0.565310855					
1356		0.132867977					
1357		0.565310855					

ORDER	Days since last rain	Conductivity (uS/cm @25ºC)	Q	DO (mg/l)	Q	Hardness (mg/L CaCO3)	Q	Oil and Grease Total (mg/l)	Q
1321									
1322									
1323									
1324									
1325									
1326									
1327									
1328									
1329									
1330									
1331									
1332									
1333									
1334									
1335									
1336									
1337									
1338									
1339									
1340									
1341									
1342									
1343									
1344									
1345									
1346									
1347									
1348									
1349									
1350									
1351									
1352									
1353									
1354									
1355									
1356									
1357									

ORDER	pH	Q	Turbidity (NTU)	Q	Temperature (C)	Q	TDS (mg/l)	Q	TS (mg/l)	Q
1321										
1322										
1323										
1324										
1325										
1326										
1327										
1328										
1329										
1330										
1331										
1332										
1333										
1334										
1335										
1336										
1337										
1338										
1339										
1340										
1341										
1342										
1343										
1344										
1345										
1346										
1347										
1348										
1349										
1350										
1351										
1352										
1353										
1354										
1355										
1356										
1357										

ORDER	TSS (mg/l)	Q	BOD5 (mg/l)	Q	COD (mg/l)	Q	Fecal Coliform (colonies/100 ml)	Q	Fecal Streptococcus (colonies/100 ml)	Q
1321	15.5				48					
1322	17				97					
1323	14.80000019				64					
1324	14				16					
1325	15				18					
1326	13				56					
1327	19				22					
1328	23									
1329	20									
1330	33				43					
1331	40									
1332	18									
1333	205				200					
1334	24									
1335	65				50					
1336	220				145					
1337	180				35					
1338	19				98					
1339	16.5				61					
1340	13.5				40					
1341	20				67					
1342	17				87					
1343	36				72					
1344	28.5				46					
1345	28				59					
1346	15				75					
1347	65				93					
1348	42				72					
1349	28				71					
1350	15				23					
1351	15				73					
1352	41.5				64					
1353	28.5				64					
1354	31				74					
1355	34.5				56					
1356	23				57					
1357	15				30					

ORDER	Total Coliform (colonies/100 ml)	Q	Total E. Coli (colonies/100 ml)	Q	Ammonia (mg/l)	Q	N02+NO3 (mg/l)	Q	Nitrogen Total (mg/l)
1321									
1322									
1323									
1324									
1325									
1326									
1327									
1328									
1329									
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ORDER	Q	Nitrogen Kjeldahl Total (mg/l)	Q	Phosphate Ortho (mg/l)	Q	Phosphorous Dissolved (mg/l)	Q	Phosphorous Total (mg/l)	Q
1321								0.479999989	
1322									
1323								2.079999924	
1324								0.129999995	
1325								0.150000006	
1326								0.709999979	
1327								2.470000029	
1328									
1329								0.07	
1330								0.870000005	
1331								1.200000048	
1332								0.850000024	
1333								4.340000153	
1334								0.239999995	
1335								1.5	
1336								2.829999924	
1337								0.829999983	
1338								2.140000105	
1339								3	
1340								1.820000052	
1341								1.50999999	
1342								2.190000057	
1343								3.599999905	
1344								0.340000004	
1345								0.469999999	
1346								1.519999981	
1347								2.50999999	
1348								1.899999976	
1349								3.200000048	
1350								0.949999988	
1351								1.629999995	
1352								1.350000024	
1353								0.860000014	
1354								3.200000048	
1355								2.470000029	
1356								3	
1357								1.25	

ORDER	Antimony Total (ug/l)	Q	Antimony Dissolved (ug/l)	Q	Arsenic Total (ug/l)	Q	Arsenic Dissolved (ug/l)	Q	Beryllium Total (ug/l)	Q
1321										
1322										
1323										
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ORDER	Beryllium Dissolved (ug/l)	Q	Cadmium Total (ug/l)	Q	Cadmium Dissolved (ug/l)	Q	Chromium Total (ug/l)	Q	Chromium Dissolved (ug/l)	Q
1321										
1322										
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ORDER	Copper Total (ug/l)	Q	Copper Dissolved (ug/l)	Q	Cyanide Total (ug/l)	Q	Cyanide Dissolved (ug/l)	Q	Lead Total (ug/l)
1321									
1322									
1323									
1324									
1325									
1326									
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ORDER	Q	Lead Dissolved (ug/l)	Q	Mercury Total (ug/l)	Q	Mercury Dissolved (ug/l)	Q	Nickel Total (ug/l)	Q	Nickel Dissolved (ug/l)
1321										
1322										
1323										
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ORDER	Q	Selenium Total (ug/l)	Q	Selenium Dissolved (ug/l)	Q	Silver Total (ug/l)	Q	Silver Dissolved (ug/l)	Q	Thallium Total (ug/l)	Q
1321											
1322											
1323											
1324											
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ORDER	Thallium Dissolved (ug/l)	Q	Zinc Total (ug/l)
1321			
1322			439.9999976
1323			50.00000075
1324			180.0000072
1325			100.0000015
1326			79.99999821
1327			119.9999973
1328			250
1329			129.9999952
1330			519.9999809
1331			519.9999809
1332			319.9999928
1333			769.9999809
1334			219.9999988
1335			750
1336			1009.99999
1337			280.0000012
1338			70.0000003
1339			100.0000015
1340			29.99999933
1341			230.0000042
1342			29.99999933
1343			219.9999988
1344			70.0000003
1345			90.00000358
1346			
1347			270.0000107
1348			90.00000358
1349			129.9999952
1350			50.00000075
1351			29.99999933
1352			59.99999866
1353			70.0000003
1354			129.9999952
1355			70.0000003
1356			119.9999973
1357			50.00000075

RB-AR34127

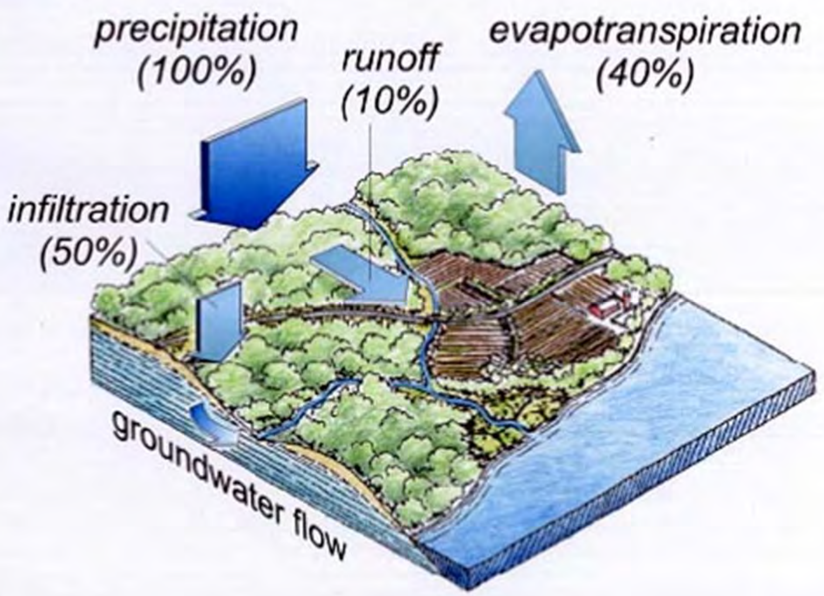
Low Impact Development
LID

* Effective Site Design
* Natural Stormwater Management Practices

Smart Growth / Smart Energy Toolkit

The Problem

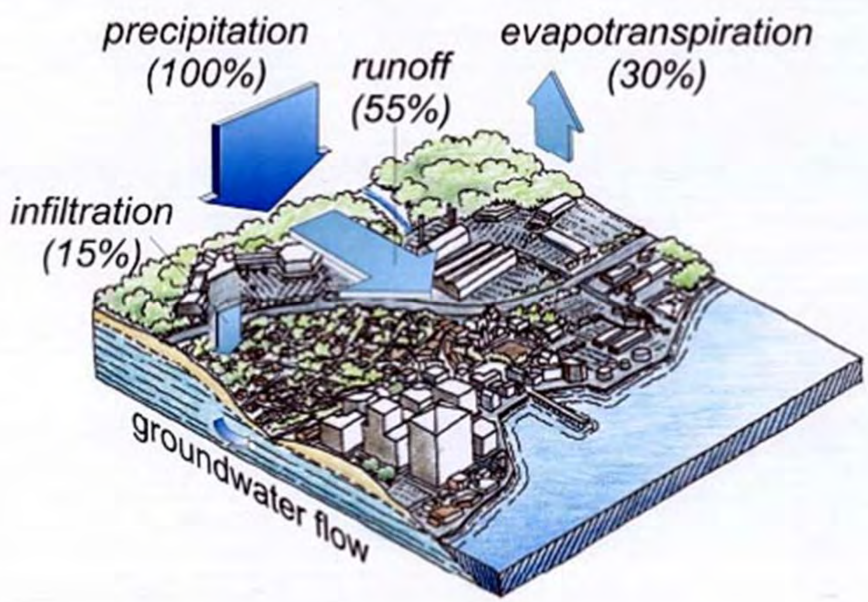
Conventional Development



- Loss of natural land or open space
- Depleted drinking water supply
- Reduced quantity and quality of water resources
- Increased infrastructure costs & maintenance

The Solution

Smart Development



- Less land clearing and grading costs
- Reduced infrastructure costs
- Protection of regional water quality
- Reduced stormwater runoff

"Conventional" Planning & Design

- Style of suburban development over the past 50 years
- Generally involves larger lots
- Clearing and grading of significant portions of a site
- Wider streets and larger cul-de-sacs
- Enclosed drainage systems for stormwater conveyance
- Large detention ponds

Site Design Planning Process

#1 AVOID IMPACTS – Preserve Natural Features and Use Conservation Design Techniques

#2 REDUCE IMPACTS – Reduce Impervious Cover

#3 MANAGE IMPACTS – Utilize Natural Features and Natural Low-Impact Techniques to Manage Stormwater

- Conservation of natural hydrology, trees, and vegetation
- Minimized impervious surfaces
- Dispersal of stormwater runoff
- Conservation of stream & wetland buffers
- Ecological landscaping

LID Site Design

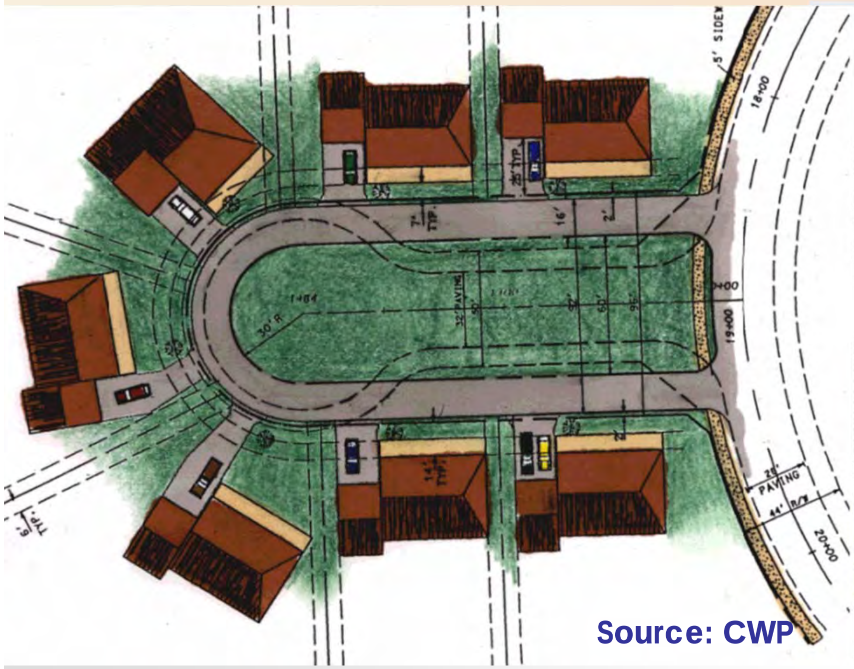
Site Design Practices

- Reduce storm pipes, curbs and gutters
- Preserve sensitive soils
- Cluster buildings and reduce building footprints
- Reduce road widths
- Minimize grading
- Limit lot disturbance
- Reduce impervious surfaces

Better Site Design on Roadways and Driveways

- Narrower streets
- Alternative cul-de-sacs
- Shared driveways

Source: City of Portland, OR



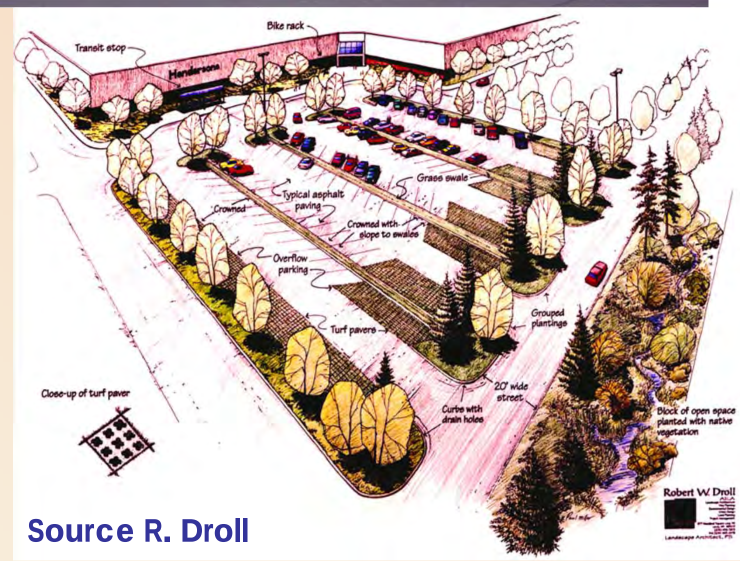
Source: CWP

Source: R. Claytor

Better Parking Lot Design

- Incorporate green strips and buffers
- Create multiple small lots
- Reduce requirements near transit
- Allow shared parking
- Require compact spaces
- Set parking maximums
- Alternative permeable pavers in overflow areas

West Farms Mall, W. Hartford, CT



Source R. Droll

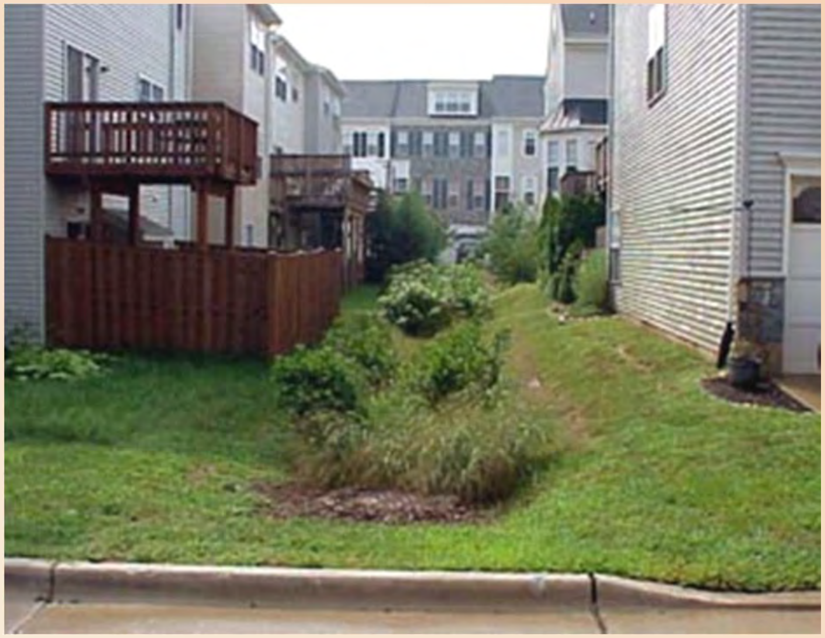
Low Impact Development LID

*Natural Stormwater Management Practices

- Small-scale stormwater controls
- Distributed throughout site
- Maintain flow patterns, filter pollutants, and recreate or maintain hydrology

LID Stormwater Techniques

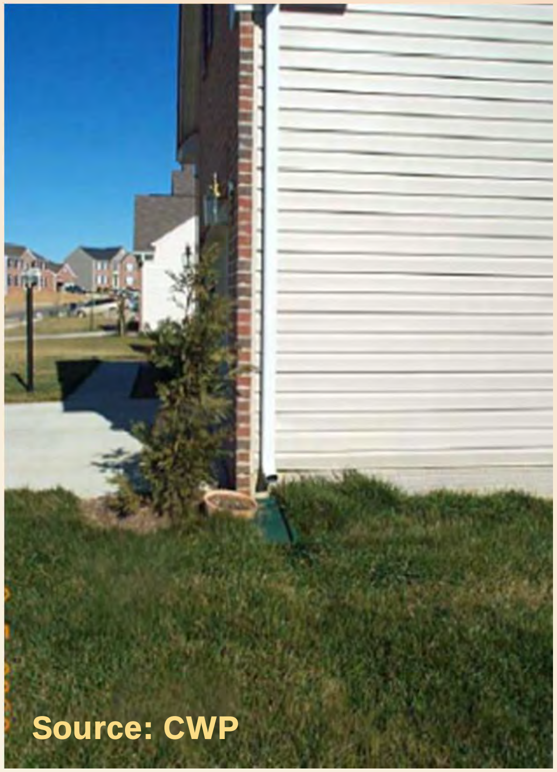
- Rain Barrels and Cisterns / Water Re-use
- Stormwater Planters, Tree Planting
- Permeable Paving
- Open Channels
- Bioretention
- Stormwater Wetlands
- Green Rooftop Systems
- Vegetative Buffers
- Infiltration



Rain Barrels and Cisterns
Runoff Reduction & Water Conservation

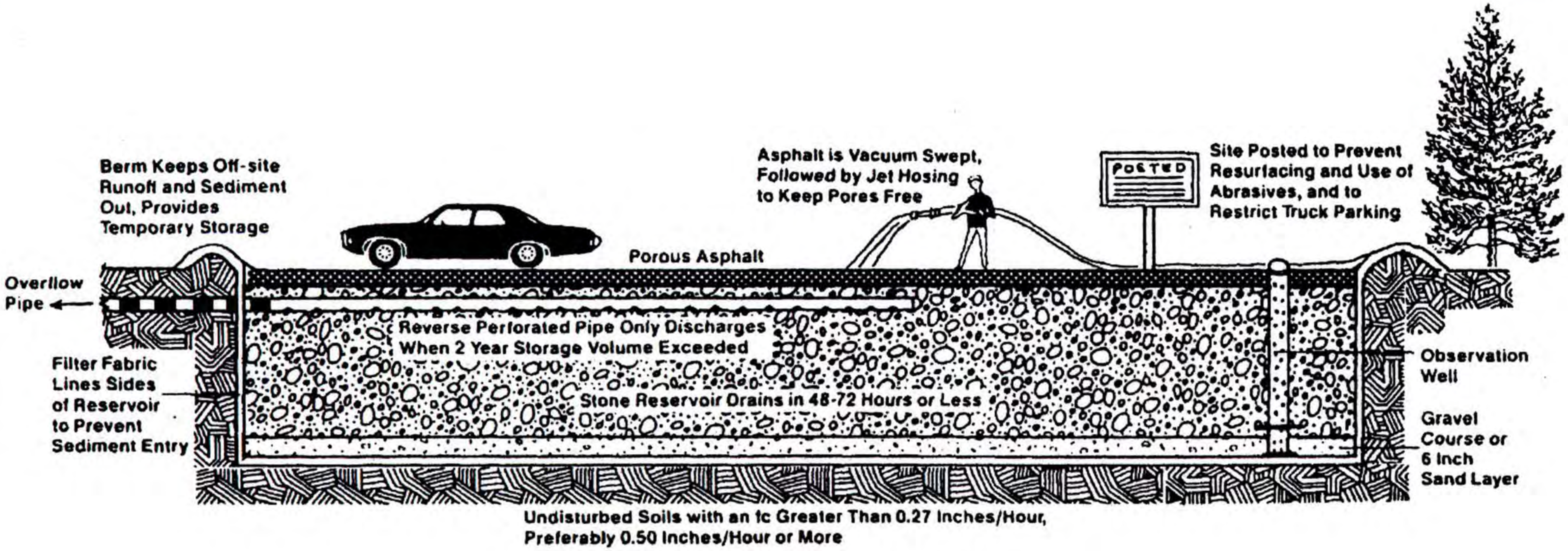
- Downspouts directed to tanks or barrels
- 50 –10,000 gallons
- Excess diverted to drywell or rain garden
- Landscaping, car washing, other non-potable uses

Dry Well Infiltration of Roof Runoff



Disconnection of Rooftop Runoff to Vegetated Swale

Permeable Pavement



Copyright 2000, Center for Watershed Protection

Permeable Pavement @ Work

Vegetated Swales

Conveyance, Treatment, Infiltration

- Roadside swales ("country drainage") for lower density and small-scale projects
- For small parking lots
- Mild side slopes and flat longitudinal slopes
- Provides area for snow storage & snowmelt treatment

Bioretention Applications

- Parking lot islands
- Median strips
- Residential lots
- Office parks

Source: Larry Gavin

Source: City of Portland, OR

Source: LID Center

Bioretention Applications

- Urban retrofits
- High-density areas

Vegetated Filter Strips

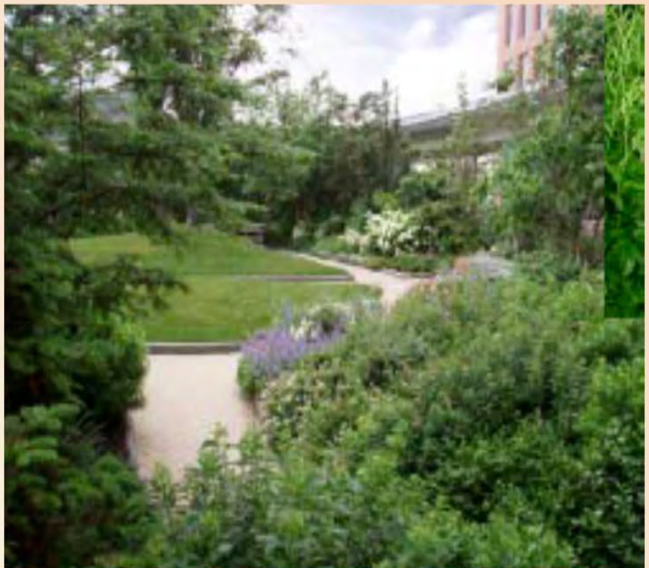
Pretreatment and Attenuation

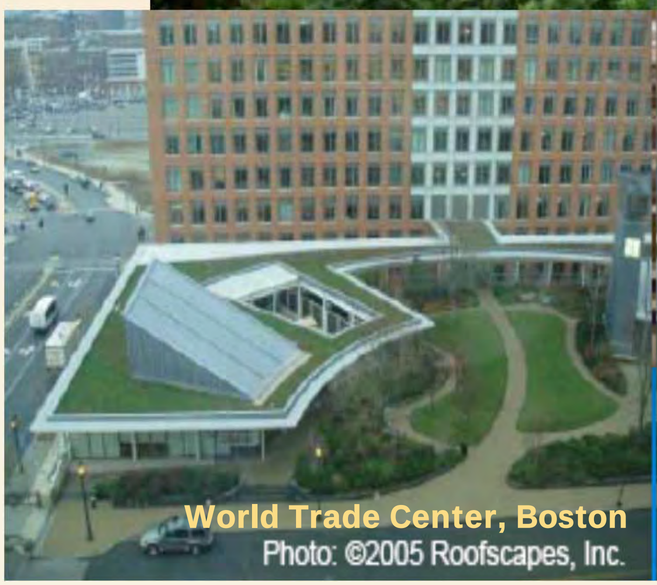
- Mild vegetated slopes
- Adjacent to small parking lots and roadways
- Another opportunity for snow storage

Source: City of Portland, OR

Source: City of Portland, OR

Green Roofs





- Stormwater Runoff absorption/collection
- Reduced flooding of and damage to urban streets
- Interior heating and cooling benefits of 10 degrees or more
- Air purification
- Recreational amenity
- Improved aesthetics
- Extended roof life, estimated at 40 years

Stormwater Planters

- Vegetative uptake of stormwater pollutants
- Pretreatment for suspended solids before they reach water-treatment facilities
- Aesthetically pleasing
- Reduction of peak discharge rate

LID BENEFITS

Environmental and Community

- Protects unique or fragile habitats
- Reduces the pollution impacts of stormwater runoff
- Promotes aquifer recharge
- Provides opportunities to link wildlife habitats
- Conservation values are part of the planning process
- Can further goals of open space and community development plans

The planning process inherently protects natural resources and promotes recharge to underlying aquifers.

Local Authorities

Better Site Design will—

- Identify and preserve natural features
- Maintain natural hydrology
- Help respect abutter's properties
- Retain property values
- Augment groundwater supplies
- Maintain high water quality
- Provide new green space as a amenity

Local Authorities

- Green strips in parking lots provide shade, serve stormwater collection and treatment needs, and reduce the need for large unsightly detention basins
- Reduction in overall parking area reduces runoff volumes
- Shared parking allows for more retail tax revenue
- Enhanced aesthetics can increase retail traffic and sales revenue

Local Authorities

- Infiltration replenishes groundwater supplies, increases aquifer recharge, and maintains base flows to streams and wetlands
- Less runoff and sediment going into public drainage systems = lower maintenance costs, more overall capacity, and a longer lifespan for drainage systems
- Reduced frequency and severity of Combined Sewer Overflow (CSO) events improves water quality and public health

LID BENEFITS

For Developer and Realtor

- Streamlines the plan review process, reduces time and costs
- Adds valuable amenities that can enhance marketing and sale prices
- Decreases site development costs by designing with the terrain

The permitting structure encourages smart growth and facilitates a process that is clear, easy to understand, and cost-effective to developers.

Developer and Realtor

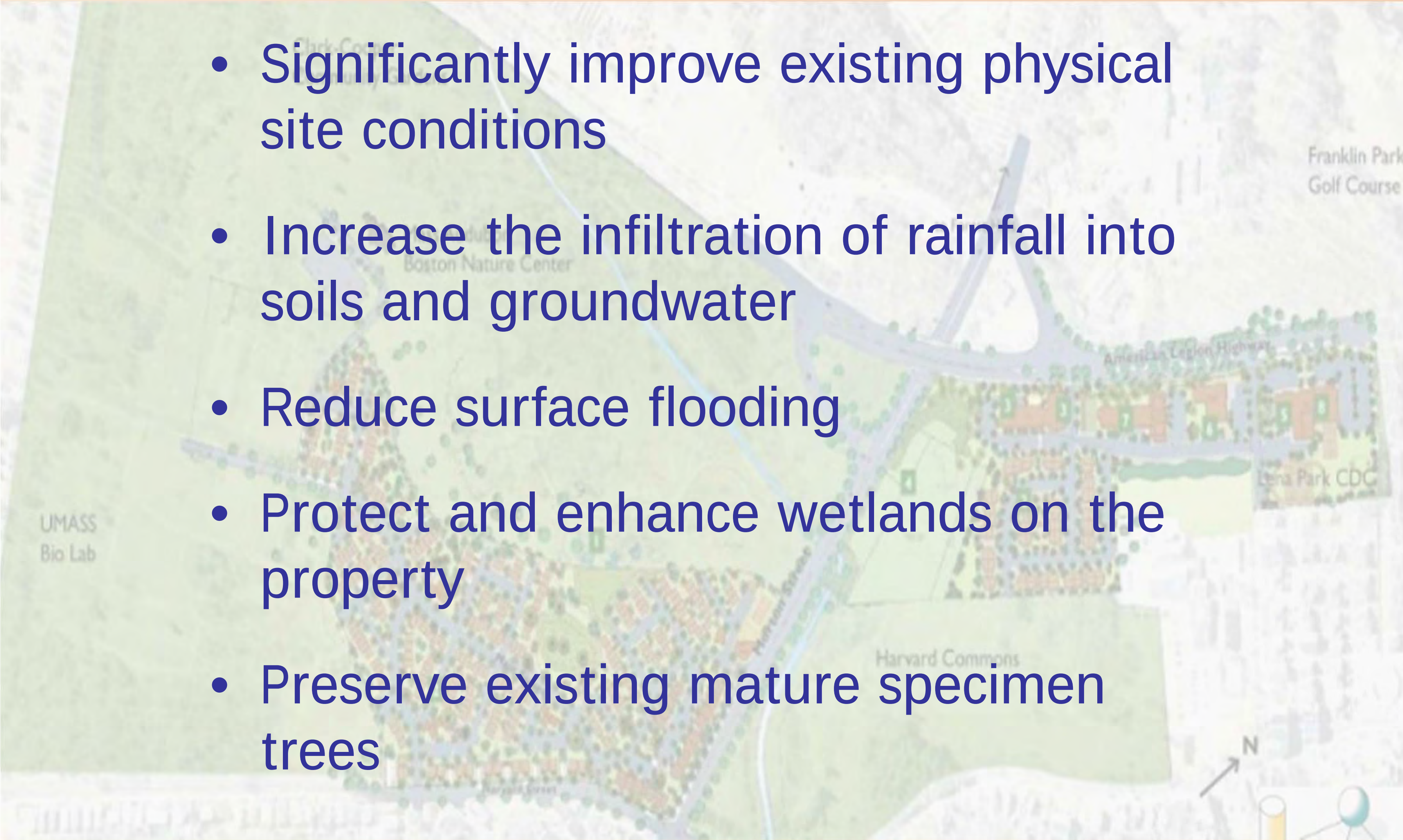
- Low Impact Development practices can cost less than conventional drainage techniques
- LID can reduce the size and number of detention facilities and the size and cost of drainage infrastructure
- Systems designed to mimic nature can enhance aesthetics and property home values
- Surface vegetative systems are more visible, thereby facilitating routine maintenance and requiring less maintenance than underground practices

Genzyme Corp. Headquarters Cambridge

- Green roof
- Recycled roof runoff for "make up" water for cooling system
- Moisture sensors in green areas to minimize irrigation needs

Olmsted Green, Boston

- Significantly improve existing physical site conditions
- Increase the infiltration of rainfall into soils and groundwater
- Reduce surface flooding
- Protect and enhance wetlands on the property
- Preserve existing mature specimen trees



Olmsted Green, Boston

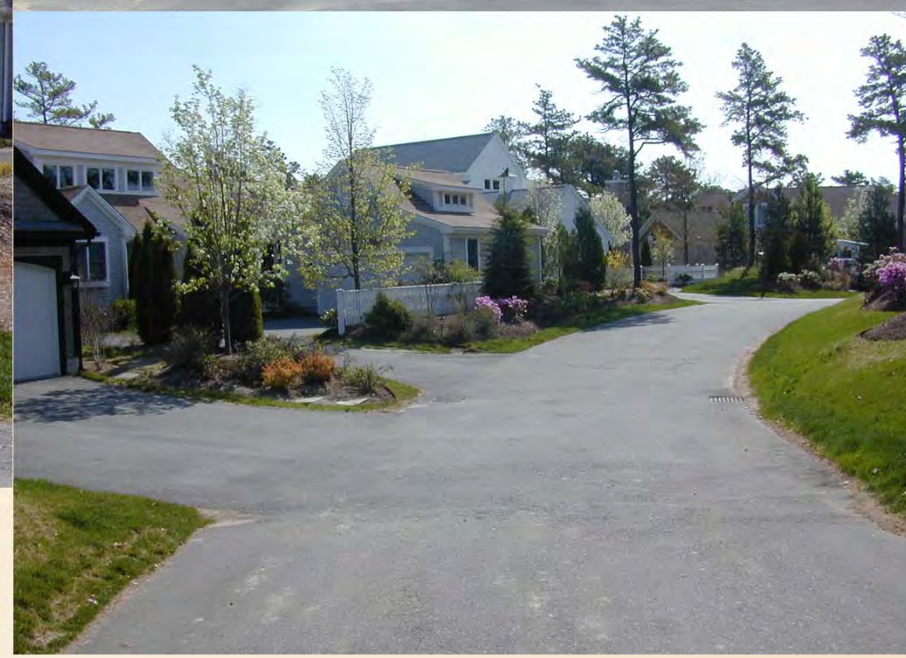
LID methods will include—

- Tree preservation
- Soil amendents to improve vegetative growth and erosion control
- Vegetated swales and rain gardens
- Subsurface infiltration
- Permeable pavers and pavements
- Stormwater System Operations & Management Plan

Pinehills, Plymouth

* Small clusters * Natural features retained
* Minimum impervious surfaces * Narrow roads

* Shared driveways
* Houses sited with natural terrain
* Vegetation retained



* Narrow roads
* "Country drainage"

LID Model Bylaw

- Provides incentive for conservation site planning
- “Stormwater Credits” reduce the size and number of conventional practices
- Requirement to treat stormwater
- Expands upon Massachusetts Stormwater Policy by including all land areas (beyond Wetland Protection Act jurisdiction)

Links for More Information

- The Low Impact Development Center
  www.lowimpactdevelopment.org
- ECONorthwest applies economic analysis to better understand the benefits of low-impact developments including a presentation by Ed MacMullan
  www.econw.com/casestudies/casestudy?study=low-impact-development
- Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewers Overflows
  www.nrdc.org/water/pollution/rooftops/contents.asp
- Low Impact Development, Buzzard's Bay National Estuary Program
  www.buzzardsbay.org/lid.htm
- The University of New Hampshire Stormwater Center
  www.unh.edu/erg/cstev/
- Greenscapes
  www.nsrwa.org/greenscapes/default.asp

Links for More Information

- Low Impact Development Center: Urban Design Tools
  www.lid-stormwater.net/
- Massachusetts Low Impact Development Toolkit, developed by the Metropolitan Area Planning Council (MAPC)
  www.mapc.org/LID.html
- Green Roofs for Healthy Cities
  www.greenroofs.net/index.php
- Heat Island Effect – Trees and Vegetation
  www.epa.gov/hiri/strategies/vegetation.html
- Building Better II: A Guide to America's Best New Development Projects
  www.sierraclub.org/healthycommunities/buildingbetter/

RB-AR34161

SOIL QUALITY – URBAN TECHNICAL NOTE No. 2

Urban Soil Compaction

USDA NRCS

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

Soil Quality Institute
411 S. Donahue Dr.
Auburn, AL 36832
334-844-4741
X-177
Urban Technical
Note No. 2

March, 2000

This is the second note in a series of Soil Quality-Urban technical notes on the effects of land management on soil quality.

Introduction

Soil is a crucial component of rural and urban environments, and in both places land management is the key to soil quality. This series of technical notes examines the urban activities that cause soil degradation, and the management practices that protect the functions urban societies demand from soil. This technical note will focus on urban soil compaction.

Healthy soil includes not only the physical particles making up the soil, but also adequate pore space between the particles for the movement and storage of air and water. This is necessary for plant growth, and for a favorable environment for soil organisms to live. Compaction occurs when soil particles are pressed together, thereby reducing the amount of pore space. Examples of compaction in urban settings are traffic pans resulting from repeated trips across lots with trucks and machinery and excessive trampling by people, bicycles, etc. Soils are particularly susceptible to compaction if these activities occur when the soil is wet. The primary impacts of soil compaction are changes in the soil's physical properties (Schuler et al., 2000):

- Strength increases with compaction. Soil strength is the ability to resist penetration by an applied force and is desirable under roads and buildings.
- Bulk density increases with compaction. Bulk density is the weight of soil per volume. It is commonly reported as grams of oven dry soil per cubic centimeter.
- Porosity decreases with compaction. Porosity is the ratio of the volume of pores to the bulk volume of the soil.
- With compaction, the distribution of pores shifts toward smaller pore sizes. Pore size distribution is the array of pores, from very small to large, making up the soil's overall porosity.

These changes influence the movement of air and water in the soil, ease of root growth, and the biological diversity and activity in the soil. For proper plant growth, void space must be available for air and water movement. Typically a medium textured soil has about 50 % solids and 50 % pore or void space. Compaction increases bulk density and reduces the number of large pores in the soil. (Schuler et al., 2000).

Compared to agricultural land, compaction in urban areas can be more permanent because of the difficulty in bringing in equipment to loosen the soil, due to the presence of utilities and the prevalence of perennial vegetation.

Causes of Soil Compaction in Urban Areas

Causes of compaction in urban areas are generally of two types:

1. Deliberate compaction during construction activities.
    - Compacting of entire areas in order to increase strength for paving and housing foundations without consideration for leaving non-constructed areas (landscaping areas and lawns) in a more natural state.
    - Use of heavy equipment for reshaping and sloping banks along roads and hillsides.
    - Grading lots and placing sod on hard soil or soil denuded of topsoil.
2. Unintentional compaction of the soil after construction is completed.
    - Allowing uncontrolled traffic (both vehicles and foot traffic)
    - Allowing vehicles on lawn areas around homes or businesses, especially when the soil is wet.

Impacts of Soil Compaction

For individual homeowners and businesses, soil compaction makes it difficult to establish and maintain lawns and landscaping due to:

- Restricted root growth.
- Reduced plant uptake of water and nutrients.
- Reduced available water capacity.
- Reduced soil biological activity.

For communities, excessive levels of soil compaction lead to environmental problems due to:

- Increased storm water runoff as a result of low infiltration rates of compacted soils.
- Increased flooding due to runoff.
- Increased erosion from construction sites.
- Increased water pollution potential, especially nitrates and phosphorus, in local rivers, streams, lakes, and ponds.

Detection of Soil Compaction

Generally compaction is a problem within the top 12 inches of the soil surface. Detection of compaction can be by:

- Observing discolored or poor plant growth.
- Probing with a firm wire (survey flag) or welding rod (18” in length) into the compacted area.
- Digging down to plant roots and finding lateral root growth with little if any penetration of compacted layers.
- Taking bulk density samples (Table 2).
- Using commercially available cone penetrometers that indicate force required to penetrate the soil in terms of pressure (pounds per square inch). Roots are unable to penetrate soil compacted to 300 psi or more. This varies with soil type and moisture content of the soil when tested (Schuler et al., 2000).

Table 2. General relationship of soil bulk density to root growth based on soil texture (NRCS Soil Quality Institute, 1999).

Soil texture	Ideal bulk densities (g/cm^3)	Bulk densities that may affect root growth (g/cm^3)	Bulk densities that restrict root growth (g/ cm^3)
Sands, loamy sands	<1.60	1.69	>1.80
Sandy loams, loams	<1.40	1.63	>1.80
Sandy clay loams, loams, clay loams	<1.40	1.60	>1.75
Silts, silt loams	<1.30	1.60	>1.75
Silt loams, silty clay loams	<1.10	1.55	>1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	>1.58
Clays (>45% clay)	<1.10	1.39	>1.47

Prevention of Urban Soil Compaction

Compaction problems during urban development can be avoided by proper planning. Working with local governments may help prevent total compaction in development areas. Divide large areas into sections to be consciously compacted for roads and foundations, and sections for lawns and landscaping. Disturb only areas needed for construction. Also, only manipulate soil when dry (less than field capacity).

Soil that will support lawns can be protected by subsoiling, and by stockpiling topsoil that will be returned to the site after construction. These two measures can restore water flow functions to near natural conditions. Establishing sod or seeding a lawn is much more successful on a loose soil with topsoil than on a compacted soil without adequate topsoil.

In parks and recreation areas, specific areas can be designated for heavy traffic (paved areas or trails). The remaining vegetated areas will benefit from less compaction because of controlled traffic. During special events, lay down metal or wood mats for better distribution of weight for vehicular traffic or involving high volume of people in concentrated areas. Mesh elements have been used for sporting fields (Beard and Sifers, 1990).

These measures may take a little more time initially, but will pay dividends in the long run. The benefits of planning and wise urban development are:

- Satisfied buyers of homes with soils that function well
- Soils that have good infiltration rates (less frequent irrigation)
- Reduced run-off (less chemical and fertilizer loss to water bodies)
- Lower mortality rates of perennial vegetation (lawns and trees)
- Better plant growth and quality for shrubs, flowers, trees, gardens, and lawns.

Management Practices for Compacted Urban Soil

Although prevention is more effective, the detrimental effects of compaction can be lessened after soils are compacted. Management practices to reduce the effects of urban compaction are:

- Subsoiling to alleviate compacted soils. Always have underground utilities and other underground plumbing or wires located and marked.
- Partial or total soil replacement. Replace dense soil with loose soil or haul in topsoil.
- Increasing organic matter. In gardens, go to residue management/no-till systems and/or cover crops.
- Use of mulch, compost, manures, and amendments.
- Annual aeration of turf grasses to improve infiltration.
- Aeration of soil using a metal tube and air compressor. This is usually used around tree roots. (Personal communication with John Lesenger. Used at the Alabama Shakespeare Festival.)
- Irrigation management. Frequent, low rates of water are necessary because compacted soil holds little water. Over-irrigation wastes water and may lead to environmental pollution from lawn chemicals, nutrients, and sediment.
- Cutting grass at higher heights, which reduces evapotranspiration losses (see local turf grass recommendations–Extension Service).

Summary

Compaction changes important physical properties of the soil. Soils with higher strength, higher bulk densities, and decreased pore space have lower infiltration rates, reduced water holding capacity, and more runoff. This degradation of soil quality results in the need for more irrigation, less healthy plants, higher plant mortality rates, and higher pollution potential from storm water runoff. Urban soil compaction is more complicated than in an agricultural setting. It is less convenient to alleviate urban compaction because soil cannot be disturbed easily around perennial vegetation, underground utilities, buildings, drive ways, etc. Planning will prevent many problems with compaction in developments and subdivisions. Preventive practices, including limiting the extent of disturbed areas, manipulating soil only when dry and restricting traffic, are more effective and less expensive than practices to alleviate compaction after it occurs. Preventing and managing compaction results in soils that function well and that benefit all of society.

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RB-AR34165

SOUTH ORANGE COUNTY HYDROMODIFICATION MANAGEMENT PLAN

December 2011

CONTENTS

TABLES

FIGURES

ACRONYMS

ACCCMP	Alameda Countywide Clean Water Program	OCHM	Orange County Hydrology Manual
BAHM	Bay Area Hydrology Model	PDP	Priority Development Project
BEHI	Bank Erosion Hazard Index	PLS	Pervious Land Surface
BMI	Benthic Macroinvertebrates Index	PWA	Philip Williams & Associates
BMP	Best Management Practice	S	Slope in Lane's equation
CASQA	California Stormwater Quality Association	Q or Qw	Flow
CCCWP	Contra Costa Clean Water Program	Qcrit - Qc	Critical flow
CEM	Channel Evolution Model	Qcp	Geomorphically critical flow – 10 percent of the 2-year flow
CEQA	California Environmental Quality Act	Qs	Sediment discharge in Lane's equation
D_{50}	Median grain size diameter	RWQCB	Regional Water Quality Control Board
Ep	Erosion potential index	SCCWRP	Southern California Coastal Water Research Project
ET	Evapotranspiration	SCVURPPP	Santa Clara Valley Urban Runoff Pollution Prevention Program
FSURMP	Fairfield-Suisun Urban Runoff Management Program	SMCWPPP	San Mateo Countywide Water Pollution Prevention Program
GIS	Geographical Information System	STOPPP	San Mateo County Stormwater Pollution Prevention Program
HEC-HMS	Hydrologic Modeling System; distributed by the US Army Corps of Engineers Hydrologic Engineering Center	SSMP	Standard Stormwater Mitigation Plan
HMP	Hydromodification Management Plan	SUSMP	Standard Urban Stormwater Mitigation Plan
HR	Hydraulic Radius	SWM SWMM	Stanford Watershed Model Storm Water Management Model; distributed by USEPA
HSPF	Hydrologic Simulation Program FORTRAN, distributed by USEPA	SWMP	Storm Water Management Plan
IMP	Integrated Management Practices	SWWM	Storm Water Management Model
LEED	Leadership in Energy and Environmental Design	TMDL	Total Maximum Daily Load
LID	Low Impact Development	USACE	United States Army Corps of Engineers
LSPC	Loading Simulation Program in C++	USEPA	United States Environmental Protection Agency
MHHW	Mean Higher High Water	USGS	United States Geological Survey
NOAA	National Oceanic and Atmospheric Administration		
NPDES	National Pollutant Discharge Elimination System		
NRCS	Natural Resource Conservation Service		

1.0 Introduction

Hydromodification refers to changes in the magnitude and frequency of stream flows due to urbanization and the resulting impacts on receiving channels, such as erosion, sedimentation, and potentially degradation of in-stream habitat. The degree to which a channel will erode or aggrade is a function of the increase or decrease in work (shear stress), the resistance of the channel bed and bank materials – including vegetation (critical shear stress), the change in sediment delivery, and the geomorphic condition (soil lithology) of the channel. Critical shear stress is the shear stress threshold above which motion of bed material load is initiated. Not all flows cause significant movement of bed material—only those that generate shear stress in excess of the critical shear stress of the bank and bed materials. Urbanization increases the discharge rate, amount and timing of runoff, and associated shear stress exerted on the channel by stream flows and can trigger erosion in the form of incision (channel downcutting), widening (bank erosion), or both. Depths that generate shear below critical shear stress levels have little or no effect on the channel stability.

Program Provision F.1.h of the San Diego California Regional Water Quality Control Board (SDRWQCB) Permit Order R9-2009-0002 (Permit) requires "…the Permittees to develop and implement a Hydromodification Management Plan (HMP) to manage increases in runoff discharge rates and durations from all Priority Development Projects." Where receiving stream channels are already unstable, hydromodification management can be thought of as a method to avoid accelerating or exacerbating existing problems. Where receiving stream channels are in a state of dynamic equilibrium, hydromodification management may prevent the onset of erosion, sedimentation, lateral bank migration, or impacts to in-stream vegetation.
The Permit contains certain requirements that strongly influence the methodology chosen in development of the HMP. The Permit requires the Permittees to develop an HMP for all Priority Development Projects (with certain exemptions) and develop a performance standard including a geomorphically-significant flow range that ensures the geomorphic stability within the channel. Supporting analyses must be based on continuous hydrologic simulation modeling. Similarly, the loss of sediment supply due to the development must be considered.

The SDRWQCB jurisdiction area covers the southern portion of Orange County. The northern portion of Orange County is under the jurisdiction of the Santa Ana Regional Water Quality Control Board (SARWQCB) and is not subject to this HMP. MS4 Permittees or dischargers directly or indirectly discharging runoff into waters of the United States within the San Diego Region include the Cities of Aliso Viejo, Dana Point, Laguna Beach, Laguna Hills, Laguna Niguel, Laguna Woods, Lake Forest, Mission Viejo, Rancho Santa Margarita, San Clemente, and San Juan Capistrano, as well as the County of Orange and the Orange County Flood Control District.

2.0 Permittee HMP Development Process

Although the County of Orange serves as the lead agency for development of the HMP, all 13 Permittees have participated in its development, both financially and through participation in HMP workshops scheduled over the course of the project at times corresponding with key decision points in developing the HMP. Participants in the HMP Workshops created a Permittee HMP Workgroup to provide input on the development of the HMP.

The Permittees will continue to meet to discuss and resolve any issues that may arise during the HMP implementation phase. The Permittee HMP Workgroup will also assist in refining and reinforcing methodologies, criteria, and standards established in the HMP.

The Permittee HMP Workgroup has met three times since August 2011. **Table 2-1** shows meeting dates, locations, and agenda items. In addition to the formal meetings, the Permittee HMP Workgroup coordinated via email to review and discuss technical documents, deliberate on specific HMP-related topics and concur on issues.

Table 2-1: HMP Workgroup Meetings

Date	Location	Agenda
August 8, 2011	Laguna Hills City Hall	Kickoff Workshop Discussion of the proposed South Orange County HMP (SOCHMP) Approach and Methodology
October 12, 2011	RBF Consulting Irvine/Webcast	Presentation of the San Diego Hydrology Model Tool by Clear Creek Solution (Doug Beyerlein) Presentation of the HMP Framework by RBF Consulting (Scott Taylor & Daniel Apt)
November 17, 2011	RBF Consulting Irvine	Draft HMP Document Review

No later than 90 days after receiving a finding of adequacy from the San Diego Regional Water Quality Control Board Executive Officer, the Final South Orange County HMP requirements will be incorporated into the Model Water Quality Management Plan (Model WQMP). The Permittees will use the revised Model WQMP to incorporate the HMP requirements into the local approval processes through their local WQMPs and municipal ordinances. This will also be completed within 90 days after receiving a finding of adequacy from the San Diego Regional Water Quality Control Board Executive Officer.

It should be noted that this HMP has in large part been based on the San Diego HMP, which was developed by the County of San Diego and the Permittees for San Diego County. The San Diego HMP was approved by the San Diego Regional Board and served as the starting point for development of the South OC HMP.

3.0 Literature Review

Pursuant to Permit Section F.1.h(1)(e), this section provides the results of a literature review conducted as a basis for the development of the HMP.

Hydromodification in the context of this Plan refers to changes in the magnitude and frequency of stream flows due to urbanization and the resulting impacts on the receiving channels in terms of erosion, sedimentation, and degradation of in-stream habitat. The processes involved in aggradation and degradation are complex, but are caused by an alteration of the hydrologic regime of a watershed due to increases in impervious surfaces, more efficient storm drain networks, and a change in historic sediment supply sources. The study of hydromodification is an evolving field, and regulations to manage the impacts of hydromodification must be grounded in the latest science available.

HMPs seek ways to mitigate erosion impacts by establishing requirements for controlling runoff from new development. In order to establish appropriate regulations, it is important to understand 1) how land use changes alter storm water runoff; and 2) how these changes can impact stream channels. These and other issues central to HMPs adopted in California have been addressed in numerous journal articles, books, and reports. This report builds upon previous literature reviews developed for the San Diego County HMP, including recent studies or information relevant to Southern California.

3.1 Managing Hydromodification

There are many different approaches to managing hydromodification impacts from urbanization and most HMPs provide multiple options for achieving and documenting compliance with National Pollutant Discharge Elimination System (NPDES) permit requirements. In general, hydrograph management approaches focus on managing runoff from a developed area to not increase instability in a channel, and in-stream solutions focus on managing the receiving channel to accept an altered flow regime without becoming unstable. This section briefly summarizes various approaches for HMP compliance.

Hydrograph Management Solutions

Facilities that detain or infiltrate runoff to mitigate development impacts are the focus of most HMP implementation guidance. They work by either reducing the volume of runoff (infiltration facilities) or holding water and releasing it below Q_c (detention facilities). These facilities, also referred to as BMPs, can range from regional detention basins designed solely for flow control, to bioretention facilities that serve a number of functions. A number of BMPs, including swales, bioretention, flow-through planters, and extended detention basins have been developed to manage storm water quality, and several resources describe the design of storm water quality BMPs (CASQA 2003; Richman et al. 2004). In many cases, these facilities can be designed to also meet hydromodification management requirements.

Many HMPs also provide guidance for applying LID approaches to site design and land use planning to preserve the hydrologic cycle of a watershed and mitigate hydromodification impacts. These plans typically include decentralized storm water management systems and protection of natural drainage features, such as wetlands and stream corridors. Runoff is typically directed toward infiltration-based storm water BMPs that slow and treat runoff. The following sections summarize how hydromodification management BMPs developed for existing HMPs have been designed and implemented.

Sizing Hydromodification BMPs

Hydromodification BMPs differ slightly from those used to meet water quality objectives in that they focus more on matching undeveloped flow-regimes than on removing potential pollutants, although these two functions can be combined into one facility. Various methods exist for sizing hydromodification BMPs.

- **Hydrograph Matching** uses an outflow hydrograph for a particular site that matches closely with the pre-project hydrograph for a design storm. This method is most traditionally used to design flood-detention facilities to mitigate for a particular storm recurrence interval (e.g., the 100-year storm). Although hydrograph matching can be employed for multiple storm recurrence intervals, this method generally does not take into account the smaller, more frequent storms where a majority of the erosive work in stream channel is done and is therefore not widely accepted for HMP compliance nor recommended for use as a part of this plan.
- **Volume Control** matches the pre-project and post-construction runoff volume for a project site. Any increase in runoff volume is either infiltrated on site, or discharged to another location where streams will not be impacted. The magnitude of peak flows and time of concentration is not controlled, so while this method ensures there is no increase in total volume of runoff, it can result in higher erosive forces during storms.
- **Flow Duration Control** matches both the duration and magnitude of a specified range of storms. The entire hydrologic record is taken into account, and pre-project and post-construction runoff magnitudes and volumes are matched as closely as possible. Excess runoff is either infiltrated onsite or discharged below Q_{cp} (Geomorphically critical flow – 10 percent of the 2-year flow).

The Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVUPPP) HMP reviewed each of these methods and concluded that a Flow Duration Control approach was the most effective in controlling erosive flows. Two examples were evaluated using this approach, one on the Thompson Creek subwatershed in Santa Clara Valley and one on the Gobernadora Creek watershed in Orange County. The evaluation approach used continuous simulation modeling to generate flow-duration curves, and then designed a test hydromodification management facility to match pre-project durations and flows.

In addition to the SCVURPP HMP, the flow duration control approach has been applied by the Alameda Countywide Clean Water Program (ACCWP), SMCWPPP, the Fairfield-Suisun Urban Runoff Management Program (FSURMP), Contra Costa Clean Water Program (CCCWP), and San Diego County. Among these agencies, different approaches have emerged on how to demonstrate that proposed BMPs meet flow-duration control guidelines. Both methods employ continuous simulation to match flow-durations, but differences exist in how continuous simulation is used (site-specific simulation vs. unit area simulation). Differences also exist in the focus of the two approaches (regional detention facilities vs. on-site LID facilities). Both approaches were evaluated by the different RWQCBs and deemed valid (Butcher 2007).

BAHM Approach

The Bay Area Hydrology Model (BAHM) is a continuous simulation rainfall-runoff hydrology model developed for ACCWP, SMCWPPP, and SCVURPP. It was developed from the Western Washington Hydrology Model, which focuses primarily on meeting hydromodification management requirements using storm water detention ponds alone or combined with LID facilities (Butcher 2007). The Western Washington Hydrology model is based on the Hydrologic Simulation Program – FORTRAN (HSPF) modeling platform, developed by the United States Environmental Protection Agency (U.S. EPA), and uses HSPF parameters in modeling watersheds.

Project proponents who want to size a hydromodification BMP select the location of their project site from a map of the county and BAHM correlates the project location to the nearest rainfall gauge and applies an adjustment factor to the hourly rainfall for the nearest gauge, to produce a weighted hourly rainfall at the project site. The user then enters parameters for the proposed project site describing soil types, slope, and land uses. BAHM then runs the continuous rainfall-runoff simulation for both the pre-project and the post-construction conditions of the project site. Output is provided in the form of flow-duration curves that compare the magnitude and timing of storms between the pre-project and the post-construction modeling runs.

If an increase in flow durations is predicted, the user can select and size mitigation BMPs from a list of modeling elements. An automatic sizing subroutine is available for sizing detention basins and outlet orifices that matches the flow duration curves between the pre-project scenario and a post-construction mitigation scenario. Manual sizing is necessary for other BMPs included in the program, such as storage vaults, bioretention areas, and infiltration trenches. The program is designed so that, once a BMP is selected and sized, the modeling run can be transferred to the local agency for approval. The model reviewer at the local agency can launch the program and verify modeling parameters and sizing techniques.

A HMP tool was also developed to support developers and applicants with the San Diego County HMP. The San Diego Hydrology Model (SDHM) derives from the BAHM, and integrates parameters that are specific to the San Diego region.

A similar approach will be used for the South Orange County HMP. The Western Washington Continuous Simulation Hydrology Model (WWHM) has been modified to include local rainfall and loss rate information, in addition to preferred local BMP selection to provide project proponents a user-friendly tool to develop a hydromodification mitigation strategy. The South Orange County Hydrology Model (SOCHM) allows the user to match the flow duration curve for the selected range of flows using locally preferred BMPs.

Contra Costa Clean Water Program (CCCWP) Approach

The CCCWP developed a protocol for selecting and sizing hydromodification BMPs, which are referred to as Integrated Management Practices (IMPs) in their guidebook. Instead of a project proponent running a site-specific continuous simulation to size hydromodification control facilities, the CCCWP provides sizing factors for designing site level IMPs. Sizing factors are based on the soil type of the project site and are adjusted for Mean Annual Precipitation. Sizing factors are provided for bioretention facilities, flow-through planters, dry wells and a combination cistern and bioretention facility.

Sizing factors were developed through continuous-simulation HSPF modeling runs for a variety of development scenarios. Flow-durations were developed for a range of soil types, vegetation and land use types, and rainfall patterns for development areas in Contra Costa County. Then, based on a unit area (one acre) of impervious surface, flow-durations were modeled using several IMP designs. These IMPs were then sized to achieve flow control for the range of storms required, (from 10 percent of the 2-year storm up to the 10-year storm). These sizing factors were then transferred to a spreadsheet form for use by project proponents.

The primary difference between the CCCWP approach and the BAHM approach is the level of modeling required. The CCCWP approach is simplified for the project proponent in that both hydromodification and water quality mitigation are incorporated into the IMP sizing factors. The BAHM allows for more flexibility in that regional BMPs may be used for hydromodification, and if desired, water quality, in addition to site level approaches. The South Orange County NPDES Permit allows for regional mitigation of hydromodification impacts. Therefore, an approach that uses continuous simulation to assess regional or neighborhood level BMP implementation is preferred for this Plan.

Sediment Management Solutions

Sediment discharge is one of the fundamental independent variables impacting stream stability. Lane (1955) described alluvial channel stability in the relation:

$$Q_s \times D_{50} \propto Q_w \times S$$

Where:

Q_s = Sediment discharge
D_{50} = Median sediment size
Q_w = Flow
S = Channel Slope

As seen by Lane's relationship, if any of the four variables are altered, one or more of the remaining variables must change. In the case of urbanization, runoff usually is increased, causing a reduction in channel slope (S) through downcutting or increased channel meander. Urbanization may also result in a change in sediment discharge (Q_s). Streambed material is derived from the channel bed and banks. If channels are altered by development in such a way as to reduce or increase sediment discharge, instability may occur.

Only a portion of the total sediment load in a channel is important for stream stability. Total channel sediment load may be classified by size or transport mechanism. The wash load commonly refers to the portion of the total sediment load that remains continuously in suspension (based on particle size). The wash load has a nominal impact on channel stability. Bed material load refers to the material that moves along the channel bed via saltation, and is continuously in contact or exchange with the channel bed. Bed material load is the critical portion of total sediment discharge for channel stability.

Urbanization can reduce the mass of bed material transported through the elimination of alluvial channel sections. This occurs in site development when first order and particularly larger streams are lined or placed into underground conduits. There are two general approaches for managing the bed material load relative to urbanization and channel stability. The first approach attempts to correct for the change in bed material load by increasing or decreasing the discharge rate as appropriate to generally maintain the balance described by Lanes relation. While theoretically a sound approach, this option requires a significant amount of detailed information that is difficult to obtain and requires good calibration of sediment models. Sediment transport models are non-linear and relatively sensitive to the rate of sediment supply and particle size distribution. Guidance for site specific analysis is provided in **Appendix D**.

The second approach to maintaining sediment supply is physically based, relying on a field assessment of site locations that may supply bed material load to the receiving channel, and protecting those sources during the site planning and development process. With this approach, the project proponent need only provide engineered solutions for flow mitigation. Protection of site bed material sources is the preferred approach since it is physically based and potentially less prone to error. Guidelines for field assessment of bed material sources are provided with the Sediment Supply Management approach, which is described in **Section 5.1**.

In-Stream Stabilization Solutions

In-stream solutions focus on managing the stream corridor to provide stability, modifying the stream channel to accept an altered flow regime. In cases where development is proposed in a watershed with an impacted stream it may be beneficial to focus on rehabilitating the stream channel to match the new independent variables of channel cross section, sediment discharge, flow discharge and channel slope rather than retrofitting the watershed or only controlling a percentage of the runoff with on-site controls. This type of approach can restore stream functions, beneficial uses, and values at a much more rapid pace, especially in locations that cannot physically be returned to their natural state due to changes in stream channel alignment and restrictions on the channel cross section due to adjacent development. In addition, in some cases where a master-planned watershed development plan is being implemented it may be more feasible to design a new channel to be stable under the proposed watershed land use rather than to construct distributed on-site facilities.

In-stream stabilization and restoration solutions are available as alternative compliance as a part of the South OC HMP. In-stream restoration projects are available if on-site controls are not feasible and it has been determined that the receiving water that the project discharges to has impacts due to hydromodification. Tiered benefits (benthic communities, morphology) of such in-stream restoration projects must offset the hydrologic and sediment changes induced by the associated PDP(s).

Other Methods

A number of methods exist for managing channels to accept altered flow regimes and higher shear forces. These have been covered in detail in a number of sources available to watershed groups and public agencies. (A few helpful sources include Riley 1998, Watson and Annable 2003, and FISRWG 1998.)

Stream Susceptibility - Domain of Analysis

Southern California Coastal Water Research Project (SCCWRP) has developed a series of screening tools that evaluate the susceptibility of a stream to hydromodification impacts (SCCWRP, 2010). These screening tools allow a project proponent to rate the susceptibility of the evaluated stream to erosion for a variety of geomorphic scenarios including alluvial fans, broad valley bottoms, incised headwaters, etc.

The development of HMPs in most Southern California counties is correlated to the ultimate findings of SCCWRP studies on hydromodification (SCCWRP, 2008 through 2011). It is generally acknowledged that SCCWRP's formulation of regional standards for hydromodification management may serve as a baseline for development of HMPs for specific regions in Southern California.

When evaluating the stream susceptibility though the SCCWRP screening tools, a domain of analysis is defined. This domain of analysis corresponds to the reach lengths upstream and downstream from a project from which hydromodification assessment is required. The domain of analysis determination includes an assessment of the incremental flow accumulations downstream of the site, identification of grade control points in the downstream conveyance system, and quantification of downstream tributary influences. The south Orange County program elected not to perform the extensive susceptibility mapping required to correlate channel reaches with variable low-flow discharge thresholds, since the return on investment for this type of analysis appears to be very low.

The effects of hydromodification may propagate for significant distances downstream (and sometimes upstream) from a point of impact such as a stormwater outfall. Accordingly, the domain of analysis serves as a representative buffer domain across which the susceptibility of a stream should be evaluated. This representative domain spans multiple channel types/settings, and is defined as follows in this HMP (SCCWRP, 2010):

- Proceed downstream until reaching the closest of the following:
  - at least one reach downstream of the first grade-control point (but preferably the second downstream grade-control location)
  - tidal backwater/lentic waterbody
  - equal order tributary (Strahler 1952)
  - a 2-fold increase in drainage area

OR demonstrate sufficient flow attenuation through existing hydrologic modeling.

- Proceed upstream to extend the domain:

- upstream for a distance equal to 20 channel widths OR to grade control in good condition – whichever comes first. Within that reach, identify hard points that could check headward migration, evidence that head cutting is active or could propagate unchecked upstream

Within the analysis domain there may be several reaches that should be assessed independently based on either length or change in physical characteristics. In more urban settings, segments may be logically divided by road crossings (Chin and Gregory 2005), which may offer grade control, cause discontinuities in the conveyance of water or sediment, etc.

The domain of analysis is discussed here since it may be relevant for use in site-specific analysis as discussed in **Appendix D**. It is not used in this HMP as a discriminator for HMP applicability to a specific project except in the case of urban infill projects.

3.2 Flow Control Approach

HMPs that have been developed in the San Francisco Bay Area, Northern California (Contra Costa, Santa Clara, and Alameda Counties and the Sacramento area), and San Diego County vary with regard to the emphasis placed on lower flow control thresholds as compared to other approaches, such as distributed low impact development (LID) methods. The South Orange County HMP was developed using the lower flow control threshold approach. There is consensus in that both the frequency and duration of flows must be controlled using continuous simulation hydrologic modeling (rather than the standard design storm approach used for flood control design) to mitigate for potential development impacts. It is also generally accepted that events more frequent than the 10-year flow are the most critical for hydromodification management, since flows within this range of return period (up to the 10-year event) perform the most work on the channel bed and banks.

The Santa Clara HMP focused on using detention basins for hydromodification management and emphasized the lower flow control limit for site runoff. Extended detention flow control basins can be constructed with multi-stage outlets to mitigate both the duration and magnitude of flows within a prescribed range. To avoid the erosive effects of extended low flows, the maximum rate (depth) at which runoff is discharged is set below the erosive threshold. Per the Santa Clara HMP, the lower flow control limit was defined as the flow rate that generates critical shear stress on the channel bed and banks. Both Santa Clara and Alameda Counties correlated the lower flow control limit to a value equal to 10 percent of the 2-year runoff event.

The Contra Costa HMP emphasized the importance of using LID methods to meet hydromodification management criteria. LID approaches to hydromodification management rely on site design and distributed LID Best Management Practices (BMPs) to control the frequency and duration of flows and to mitigate hydrograph modification impacts. By minimizing directly connected impervious areas and promoting infiltration, LID approaches mimic natural hydrologic conditions to counteract the hydrologic impacts of development. LID systems are sized to achieve flow control for the range of storms required (from 10 percent of the 2-year storm up to the 10-year storm).

The County of San Diego HMP defined an adaptive lower flow threshold based on the channel susceptibility rating (High, Medium, or Low). Receiving streams in San Diego County were individually classified by their susceptibility to channel erosion impacts using a critical flow calculator and a channel screening tool developed by Southern California Coastal Water Research Project (SCCWRP). This classification produced three lower flow thresholds which are 0.1Q2, 0.3Q2, and 0.5Q2. The upper range of the mitigation flow was considered the pre-project 10-year storm event.

The approach developed for the San Diego County HMP was approved by the SDRWQCB and selected as the base approach for the South Orange County HMP. However, the South Orange County program elected not to perform the extensive susceptibility mapping required to correlate channel reaches with variable low-flow discharge thresholds. The implementation of HMPs in Northern California and in San Diego has shown that numerically larger low flow thresholds generally have very limited applicability in practice. Accordingly, a base low flow threshold ($0.1Q_2$) was selected for this HMP. Nonetheless, the applicant may compute a site-specific low flow threshold at their option.

3.2.1 Previous Studies

Previous hydromodification literature reviews were conducted by Geosyntec Consultants (Mangarella and Palhegyi, 2002) for the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and by the Contra Costa Clean Water Program (CCCWP 2004). Mangarella and Palhegyi provide a detailed overview of the geomorphic and hydrologic processes involved in hydromodification (see **Section 3.2.3**) for additional details on the mechanics of stream erosion). Channel assessment methods described in Section 6 of this HMP rely heavily on those reviewed by Bledsoe et al. (2008) for SCCWRP.

To date, six approved HMPs have been published. These include HMPs for SCVURPPP (2005), the CCCWP (2005), the Fairfield-Suisun Urban Runoff Management Program FSURMP (2005), the Alameda Countywide Clean Water Program (ACCCMP 2005), the San Mateo Countywide Stormwater Pollution Prevention Program (SMCWPPP [formerly STOPPP] 2005), and the San Diego County Hydromodification Plan (2009). In addition, a number of HMPs were implemented while agencies developed their final plans. Interim HMPs are not detailed in this report because these plans have adopted findings from the above listed HMPs.

3.2.2 Hydrograph Modification Processes

The effects of urbanization on channel response have been the focus of many studies (see Paul and Meyer, 2001 for a review), and the widely accepted consensus is that increases in impervious surfaces associated with urbanizing land uses can cause channel degradation. Urbanization generally leads to a change in the amount and timing of runoff in a watershed, which increases erosive forces on channel bank and bed material and can cause large-scale channel enlargement, general scour, stream bank failure, loss of aquatic habitat and degradation of water quality.

Channel erosion, like most physical processes, is a complex system based on a variety of influences. Channel erosion is non-linear (Philips 2003), meaning the response of streams is not directly proportional to changes in land use and flow regimes. Small changes or temporary disturbances in a watershed may lead to unrecoverable channel instability (Kirkby 1995). These disturbances may give rise to feedback systems whereby small instabilities can be propagated into larger and larger instabilities (Thomas 2001).

A number of studies have sought to correlate the amount of urbanization in a watershed and stream instability (Bledsoe 2001; Booth 1990, 1991; Both and Jackson 1997; MacRae 1992; 1993; 1996; Coleman et al. 2005). Evidence from these studies suggests that below a certain threshold of watershed imperviousness, streams maintain stability. This threshold or imperviousness transition zone appears to be around seven to ten percent watershed urbanization for perennial streams (Schueler 1998 and Booth 1997), but may begin at a lower level for intermittent streams such as those found in Southern California. Studies done in Santa Fe, New Mexico (Leopold and Dunne 1978) suggest that changes occur at four percent impervious area of the watershed. Initial studies by Coleman et al. (2005) suggest that a response in the stream channel may begin to occur at two to three percent watershed imperviousness for intermittent streams in Southern California. It is important to understand that use of impermeable cover alone is a poor predictor of channel erosion due to differences in storm water detention and infiltration within regions. In highly urbanized watersheds returning a stream to a natural condition is infeasible due to existing development in the watershed. In these scenarios the focus should be on in-stream restoration to restore the beneficial uses of the receiving water.

Though it is well established that watershed urbanization causes channel degradation, a detailed understanding of how development alters runoff and how this altered runoff in turn causes erosion is still being developed. This section briefly describes these processes and summarizes methods used to quantify hydromodification impacts.

Effective Work

The ability of a stream to transport sediment is proportional to the amount of flow in the stream: as flow increases, the amount of sediment moved within a channel also increases. The ability of a stream channel to transport sediment is termed stream power, which integrated over time is work. Leopold (1964) introduced the concept of effective work, whereby the flow-frequency relationship of a channel is multiplied by sediment transport rate. This gives a mass-frequency relationship for erosion rates in a channel. Flows on the lower end of the relationship (e.g., two-year flows) may transport less material, but occur more frequently than higher flows, thereby having a greater overall effect on the work within the channel. Conversely, higher magnitude events, while transporting more material, occur infrequently so cause less effective work. Leopold found that the maximum point on the effective work curve occurred around the 1-to 2-year frequency range. This maximum point is commonly referred to as the dominant discharge. It corresponds roughly to a bankfull event (a flow that fills the active portion of the channel up to a well-defined break in the bank slope).

Urbanization tends to have the greatest relative impact on flows that are frequent and small, and which tend to generate less-than-bankfull flows. Change is greatest in these events because prior to urbanization, infiltration would have absorbed much or all of the potential runoff, but following urbanization, a high percent of the rainfall runs off. Thus, events that might have generated little or no flow in a non-urbanized watershed can contribute flow in urban settings.

These smaller less-than-bankfull events have been found to cause a significant proportion of the work in urban streams (MacRae 1993) due to their high frequency, and can lead to channel instability. Less frequent, larger magnitude flows (e.g., flows greater than Q_{10}) are less strongly affected by urbanization because during such infrequent storm events, the ground rapidly becomes saturated, and acts (for purposes of runoff generation) in a similar manner as impervious surfaces.

Estimating Critical Q_c

Due to the increase in impervious surfaces and fewer opportunities for infiltration of storm water, urbanization creates a higher runoff rate and more runoff volume than an un-urbanized watershed. Opportunities for infiltration of excess storm water exist in urbanized areas, but many times are infeasible due to cost, technical barriers or land use constraints. Therefore, some of the excess storm water must be discharged to a receiving stream. In order to achieve a comparable E_p to a pre-developed condition, this excess runoff volume must be discharged at a rate at which insignificant effective stream work is done.

Bed load sediment moves through transmission of shear stress from the flow of water on the channel bed. An increase in the hydraulic radius (measure of channel flow efficiency through a ratio of the channel's cross sectional area of the flow to its wetted perimeter) corresponds to an increase in shear stress. In order to initiate movement of bed material, however, a shear stress threshold must be exceeded. This is commonly referred to as critical shear stress, and is dependent on sediment and channel characteristics. For a given point on a channel where the bed composition and cross-section is known, the critical shear can be related to a stream flow. The flow that corresponds to the critical shear is known as the critical flow, or Q_c. For a given cross-section, flows that are below the value for Q_c do not initiate bed movement, while flows above this value do initiate bed movement.

SCVURPPP expressed Q_c as a percentage of the two-year flow in order to develop a common metric across watersheds of different size, and allow for easy application of HMP requirements. For the two watersheds studied in detail in the SCVURPPP study, a similar relationship was found where Q_c corresponded to 10 percent of the two-year flow. This became the basis for the lower range of geomorphically significant flows under the SCVURPPP HMP and is referred to as Q_{cp} to indicate that it is a percentage of flow. That program also adopted the 10-year flow as the upper end of the range of flows to control with the justification that increases in stream work above the 10-year flow were small for urbanized areas.

A similar study was conducted for the FSURMP on two watersheds in Fairfield, California following a geomorphic assessment. That study found Q_{cp} to be 20 percent of the pre-development two-year flow. The differences in the two values may be attributable to differences in watershed characteristics in Santa Clara County and Fairfield, the number of streams studied, and the precision of the modeling tools. Channels in Fairfield were found to have a more densely vegetated riparian corridor and may have a higher resistance to increases in shear stresses (FSURMP). Values for Q_{cp} appear to be similar among neighboring watersheds, but there appears to be a range of appropriate Q_{cp} values. The characteristics of individual biomes (climatically and geographically defined areas of ecologically similar climatic conditions, such as communities of plants, animals, and soil organisms, often referred to as ecosystems) should be taken into account when developing a Q_{cp}. For example, Western Washington State, which has more densely vegetated riparian zones than either Fairfield or Santa Clara County, has adopted a Q_{cp} of 50 percent of the 2-year flow.

A summary of flow control standards adopted in each of the approved HMPs in California and western Washington is given in **Table 3-1**.

Table 3-1: Summary of Flow Control Standards – Approved HMPs

Permitting Agency	Q_{cp}	Largest Managed Flow
Alameda County	10 percent of the 2-year flow (0.1Q2)	10-year flow (Q10)
Contra Costa County	10 percent of the 2-year flow (0.1Q2)	10-year flow (Q10)
Fairfield-Suisun Urban Runoff Management Program	20 percent of the 2-year flow (0.2Q2)	10-year flow (Q10)
San Diego County	10, 30, or 50 percent of the 2-year flow (0.1Q2, 0.3Q2, or 0.5Q2)	10-year flow (Q10)
San Mateo County	10 percent of the 2-year flow (0.1Q2)	10-year flow (Q10)
Santa Clara County	10 percent of the 2-year flow (0.1Q2)	10-year flow (Q10)
Western Washington State	50 percent of the 2-year flow (0.5Q2)	50-year flow (Q50)

As noted previously the South Orange County HMP has selected a low flow threshold ($0.1Q_2$) as a default value. The project proponent may put forth other low flow thresholds for individual projects, but other low flow thresholds will require site-specific justification using modeling or field tests to support the unique threshold value.

3.2.3 Stream Channel Stability

Numerous stream channel stability assessment methods have been proposed to help distinguish which channels are most at risk from hydrograph modification impacts and/or define where HMP requirements should apply. Assessment strategies range from purely empirical approaches to channel evolution models to energy-based models (see Simon et al., 2007 for a critical evaluation). Stream channel stability assessment methods are useful in assessing the impact of urbanization, or control programs over time. Their value lies in showing trends as changes in a watershed occur, rather than classifying the reach of a discrete channel section at a given point in time.

Stream Classification Systems

A recent study by Bledsoe et al. (2008) for SCCWRP describes nine types of classification and mapping systems with an emphasis on assessing stream channel susceptibility in Southern California. The summary below is taken from that study. Bledsoe also provides a summary of the implications of these classification and mapping systems to the development of hydromodification tools for Southern California. The article provides a detailed breakdown of guidelines for developing hydromodification tools given the advantages and disadvantages of each system previously assessed.

Planform Classifications and Predictors

Alluvial channels form a continuum of channel types whose lateral variability is primarily governed by three factors: flow magnitude, bank erodibility, and relative sediment supply. Though many natural channels conform to a gradual continuum between straight and intermediate, meandering, and braided patterns, abrupt transitions in lateral variability imply the existence of geomorphic thresholds where sudden change can occur. The conceptual framework for geomorphic thresholds has proven integral to the study of the effects of disturbance on river and stream patterns. Many empirical and theoretical thresholds have been proposed relating stream power, sediment supply and channel gradient to the transition between braiding and meandering channels. Accounting for the effects of bed material size has been shown to provide a vital modification to the traditional approach of defining a discharge-slope combination as the threshold between meandering and braided channel patterns. The many braided planforms in Southern California indicate the need to refine and calibrate established thresholds to river networks of interest. However, at this time there is not a well-accepted model to predict how hydromodification affects channel planform.

Energy-Based Classifications

The link between channel degradation and urbanization has been studied; however, impervious area is not the solitary factor influencing channel response. Studies have shown that the ratio between specific stream power and median bed material size D50b, where b is approximately 0.4 to 0.5 for both sand-and gravel-bed channels, can be used as a valuable predictor of channel form. Stream power, which is related to the square root of total discharge, is the most comprehensive descriptor of hydraulic conditions and sedimentation processes in stream channels. Several studies have been performed relating channel stability to a combination of parameters such as discharge, median bed-material size, and bed slope, as an analog for stream power.

General Stability Assessment Procedures

By assessing an array of qualitative and quantitative parameters of stream channels and floodplains, several investigators have developed qualitative assessment systems for stream and river networks. These assessment methods have been incorporated into models used to analyze channel evolution and stability. Many parameters used to establish methodologies such as the Rosgen approach are extendable to a qualitative assessment of channel response in Californian river networks. Field investigations in Southern California have shown that grade control can be the most important factor in assessing the severity of channel response to hydromodification. Qualitative methodologies have proven extendable to many regions, and they use many parameters that may provide valuable information for similar assessments in California.

Sand vs. Gravel Behavior / Threshold vs. Live-Bed Contrasts

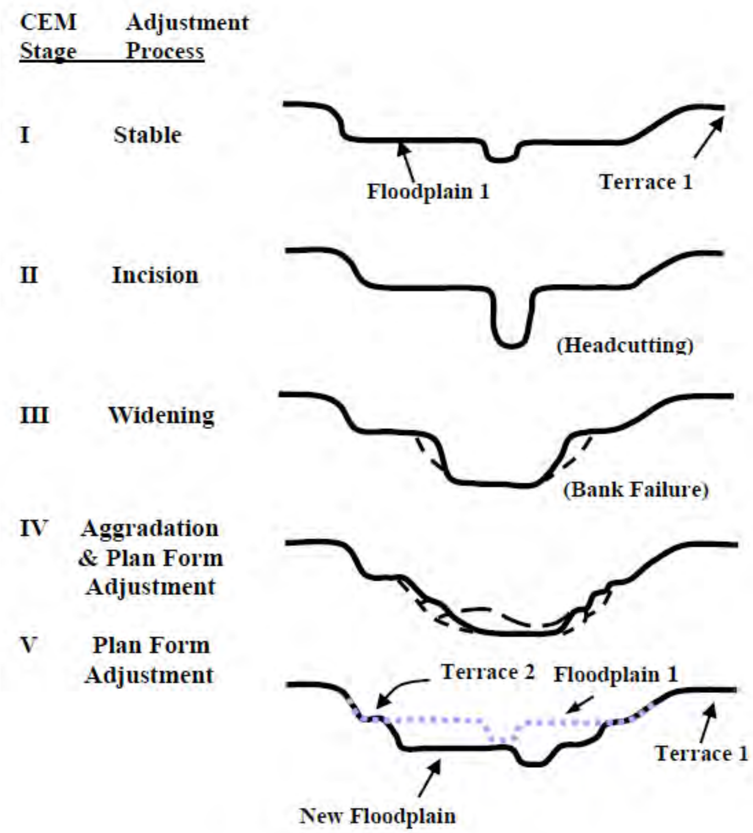
It is well recognized that the fluvial-geomorphic behavior varies greatly between sand and gravel/cobble systems. Live bed channels (of which sand channels are good examples) are systems where sediment moves at low flows, and where sediment is frequently in motion.

Threshold channels, such as gravel streams, by contrast, require considerable flow to initiate bedload movement. Live bed channels are more sensitive to increases in flow and decreases in sediment supply than threshold channels. Scientific consensus shows that sand bed streams lacking vertical control show greater sensitivity to changes in flow and sediment transport regimes than do their gravel/cobble counterparts. Factors such as slope, and sedimentation regimes are known to have greater impact on sand-bed streams. This can be an important issue for storm water systems receiving runoff from watersheds composed primarily of streams with sandy substrate. The transition between sand and gravel bed behavior can be rapid, enabling the use of geographic mapping methods to prioritize channel segments according to their susceptibility to the effects of hydromodification.

Channel Evolution Models of Incising Channels

The Channel Evolution Model (CEM) developed by Schumm et al. (1984) posits five stages of incised channel instability organized by increasing degrees of instability severity, followed by a final stage of quasi-equilibrium (**Figure 3-1**). Work has been done to quantify channel parameters, such as sediment load and specific stream power, through each phase of the CEM. A dimensionless stability diagram was developed by Watson et al. (2002) to represent thresholds in hydraulic and bank stability. This conceptual diagram can be useful for engineering planning and design purposes in stream restoration projects requiring an understanding of the potential for shifts in bank stability.

Figure 3-1: Five Stages of the Channel Evolution Model (CEM)



(Schumm et al. 1984)

Channel Evolution models Combining Vertical and Lateral Adjustment Trajectories

Originally, CEMs focused primarily on incised channels with geotechnically, rather than fluvially, driven bank failure. Several CEMs have been proposed that incorporate channel responses to erosion and sediment transport into the original framework for channel instability. In these new systems, an emphasis is placed on geomorphic adjustments and stability phases that consider both fluvial and geomorphic factors. The state of Vermont has developed a system of stability classification that suggests channel susceptibility is primarily a function of the existing Rosgen stream type and the current stream condition referenced to a range of variability. This system places more weight on entrenchment (vertical erosion of a channel that occurs faster than the channel can widen, resulting in a more confined channel) and slope than differentiation between bed types.

Equilibrium Models of Supply vs. Transport-capacity / Qualitative Response

The qualitative response model builds on an understanding of the dynamic relationship between the erosive forces of flow and slope relative to the resistive forces of grain size and sediment supply to describe channel responses to adjustments in these parameters. In this system, qualitative schematics provide predictions for channel response to positive or negative fluctuations in physical channel characteristics and bed material. Refinements to such frameworks have been made to account for channel susceptibility relative to existing capacity and riparian vegetation among other influential characteristics.

Bank Instability Classifications

Early investigations provided the groundwork for bank instability classifications by analyzing shear, beam, and tensile failure mechanisms. The dimensionless stability approach developed by Watson characterized bank stability as a function of hydraulic and geotechnical stability. Rosgen (1996) proposed the widely applied Bank Erosion Hazard Index (BEHI) as a qualitative approach based on the general stability assessment procedures outlined above. Other classification systems, like the CEM, determine bank instability according to channel characteristics that control hydrogeomorphic behavior.

Hierarchical Approaches to Mapping Using Aerial Photographs / GIS

It has become increasingly common practice to characterize stream networks as hierarchical systems. This practice has presented the value in collecting channel and floodplain attributes on a regional scale. Multiple studies have exploited geographical information systems (GIS) to assess hydrogeomorphic behavior at a basin scale. Important valley scale indices such as valley slope, confinement, entrenchment, riparian vegetation influences, and overbank deposits can provide information for river networks in California. Many agencies are developing protocols for geomorphic assessment using GIS and other database associated mapping methodologies. These tools may be useful as they are further developed in a monitoring program, but are not viable at a scale useful for reach-by-reach channel analysis.

The approach taken by this HMP to monitor its effectiveness is embedded in a derivative of the channel classification approach defined by Rosgen (1996). The author distinguishes three different levels of stream classification including (1) level I that generally describes stream relief, landform, and valley morphology ; (2) level II that describes the morphology of stream and associates the later to a stream type based on channel form and bed composition. Field measurements of entrenchment, width-to-depth ratio, sinuosity, slope, and representative sampling of channel material may be suitable ; (3) level III that assesses stream condition and departure. A stream that is geomorphically stable per Rosgen's definition is characterized by two elements: dimension, pattern, and profile of a stream are maintained over time; the transport capacity of a watershed's flows and detritus is maintained. As such, physical and biological functions of a geomorphologically stable stream remain at an optimum.

3.3 Continuous Simulation Modeling

As part of the HMP development, an integrated flow control sizing tool has been prepared. The tool offers the same interface as that of the San Diego Hydrology Model, which has been approved by the SDRWQCB. The SOCHM has been developed to help applicants comply with hydromodification requirements. This modeling approach is different from Orange County's calibrated rainfall-runoff procedures and criteria for flood control design and mitigation purposes. HMP requirements from the Regional Board are separate from Orange County's requirement for mitigation within the drainage system of development effects on runoff per the Orange County Hydrology Manual (OCHM). Specific evaluation criteria were developed for the design and analysis of hydromodification controls using continuous simulation hydrologic modeling. Evaluation criteria discussed herein focuses on the following items:

- Continuous Simulation Hydrologic Modeling
- Continuous Simulation Modeling Software
- Long-Term Hourly Precipitation Gauge Data
- Parameter Validation for Rainfall Losses
- Hydromodification Control Processes
- Peak Flow and Flow Duration Statistics

Pursuant to criteria set forth by the SDRWQCB and by the South Orange County Permittees in the hydromodification criteria, the use of continuous simulation hydrologic modeling is required to size storm water facilities to mitigate hydromodification effects. Continuous simulation modeling uses an extended time series of recorded precipitation data as input and generates hydrologic output, such as surface runoff, infiltration, and evapotranspiration, for each model time step.

Continuous hydrologic models are typically run using either 1-hour or 15-minute time steps. Based on a review of available rainfall records in Orange County, the SOCHM will use a 1-hour time step (15-minute time series rainfall data are very limited). Continuous models generate model output for each time step. In this case, hydrologic output is generated for each hour of the continuous model. A continuous simulation model with 35 years of hourly precipitation data will generate 35 years of hourly runoff estimates, which corresponds to runoff estimates for 306,600 time steps over the 35-year simulation period.

Use of the continuous modeling approach allows for the estimation of the frequency and duration by which flows exceed the lower flow threshold (adopted as 10 percent of the 2-year flow for this Plan). The limitations to increases of the frequency and duration of flows within that geomorphically significant flow range represent the key component to the South Orange County approach to hydromodification management.

3.3.1 Continuous Simulation Modeling Software

The following public domain software models may be used to assess hydromodification controls for storm water facilities to meet the hydromodification criteria:

- Hydrologic Simulation Program – FORTRAN (HSPF), distributed by U.S. EPA
- Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS), distributed by the U.S. Army Corps of Engineers Hydrologic Engineering Center
- Storm Water Management Model (SWMM); distributed by U.S. EPA

3.3.2 Parameter Validation for Rainfall Losses

In preparing computer models to assess storm water controls and meet the hydromodification criteria, rainfall loss parameters describing soil characteristics, land cover descriptions, and evapotranspiration data have been validated to prove consistency with the local environment and climatic conditions. The validation process should include documentation of the source of evapotranspiration data and commentary of the effects of varying evapotranspiration patterns between the subject site and parameter data source. To meet the hydromodification criteria, soil and land cover parameter validation are based on the following:

- Calibration to local stream flow data, where applicable. Examples of local calibration studies include, but are not limited to, modeling efforts prepared for the Orange County Retrofit Study. Two watersheds were modeled, including the Anaheim Bay-Huntington Harbor watershed and the Aliso Creek watershed.
- Published parameter values consistent with previous studies for Orange County and Southern California, such as HSPF-related regional calibration studies, research projects, regional soil surveys, etc.
- Recommended parameter value ranges from BASINS (Better Assessment Science Integrating point and Nonpoint Sources) Technical Notice 6, Estimating Hydrology, and Hydraulic Parameters for HSPF, U.S. EPA, July 2000.

Where parameters have been transposed or modified from calibration efforts outside of Southern California, the source was determined and justification provided stating why such data are applicable for Orange County. Details have been provided justifying how parameters from such studies were adjusted to be applicable to Orange County conditions. Storm water flow control devices designed to meet the hydromodification criteria have been analyzed pursuant to the following criteria:

- Infiltration processes have been modeled with sufficient complexity to properly quantify the flow control benefit to the receiving streams.
- Infiltration quantification includes provisions for water head and pore suction effects for multiple layers of varying materials (i.e., ponding areas, amended soil layer, gravel layer, etc.)
- Storage processes associated with each layer of the storm water device are quantified.

- Device outflow curves are considered controls associated with device underdrains.

3.3.3 Peak Flow and Flow Duration Statistics

To assess the effectiveness of storm water flow control devices in mitigating hydromodification effects to meet the hydromodification criteria, peak flow frequency statistics have are required. Peak flow frequency statistics estimate how often flow rates exceed a given threshold. In this case, the key peak flow frequency values are the lower and upper bounds of the geomorphically significant flow range. Peak flow frequency statistics can be developed using either a partial-duration or peak annual series. Partial-duration series frequency calculations consider multiple storm events in a given year while the peak annual series considers just the peak annual storm event.

Flow duration statistics are also summarized to determine how often a particular flow rate is exceeded. To determine if a storm water facility meets the hydromodification criteria, peak flow frequency and flow duration curves are generated for the pre-development condition, or naturally occurring condition, and the post-project condition. Both pre-development and post-project simulation runs are extended for the entire length of the rainfall record.

The need for partial-duration statistics is more pronounced for control standards based on more frequent return intervals (such as the 2-year runoff event), since the peak annual series does not perform as well in the estimation of such events. This phenomenon is especially pronounced in the South Orange County region’s semi-arid climate. After a review of supporting literature, the use of a partial-duration series is recommended for semi-arid climates similar to Orange County, where prolonged dry periods can skew peak flow frequency results determined by a peak annual series for more frequent runoff events.

For the statistical analysis of the rainfall record, partial duration series events have been separated into discrete rainfall events assuming the following criteria.

1. To determine a discrete rainfall event, a lower flow limit was set to a very small value, equal to 0.002 cubic feet per second (cfs) per acre of contributing drainage area.
2. A new discrete event is designated when the flow falls below 0.002 cfs per acre for a period of 24 hours.

3.4 Rainfall Data

The SOCHM integrates local rainfall data to design storm water flow control devices. To provide for clear climatic designation between coastal, foothill and mountain areas of the southern part of Orange County, historical records for a series of three rainfall data stations located throughout South Orange County were compiled, formatted and quality controlled for analysis.

Long-term hourly rainfall records have been prepared for these three rainfall stations. Sources of the rainfall data include Orange County Automated Local Evaluation in Real Time (ALERT) telemetry system rain gauges (extending back to 1991), the California Climatic Data Archive, National Oceanic and Atmospheric Administration (NOAA), the National Climatic Data

Center, and the Western Regional Climate Center. In all cases, the length of the overall rainfall station record is a minimum of 20 years.

Gauge selection was further governed by minimum continuous simulation modeling requirements, including the following:

- The selected precipitation gauge data set should be located near the project site to ensure that long-term rainfall records are similar to the anticipated rainfall patterns for the site. Thus, gauges were selected near areas planned for future development and redevelopment.
- Recording frequency for the gauge data set should be at least hourly.
- The gauge rainfall data set should extend for the entire length of the record. Where the gauge record length is less than 20 years, then adjacent gauge data sets were used to extend the rainfall record to at least 20 years.
- Use of the most applicable long-term rainfall gauge data, as opposed to the scaling of rainfall patterns from Laguna Beach, is required to account for the diverse rainfall patterns across South Orange County.

Data gathered from precipitation gauges are summarized in **Table 3-2** below. They all have recording frequencies of one hour and recording data ranges of at least 20 years.

Table 3-2: Summary of Precipitation Gauges

Station	Elevation (feet)	Watershed	Hourly data span
Laguna Beach (CA044647)	35	Laguna Coastal Streams	March 1928 – December 2006
Sulphur Creek Reservoir	200	Aliso Creek	July 1991 – September 2010
Trabuco Canyon (CA048992)	970	San Juan	January 1950 – March 2006

For a given project location, the following factors have been considered in the selection of the appropriate rainfall data set.

In most cases, the rainfall data set nearest the project site is the appropriate choice. A rainfall station map associated with this HMP is presented in **Figure 3-2** for public use.

In some cases, the rainfall data set nearest the project site was a less applicable data set. Such a scenario involved a data set, for instance, with an elevation significantly different from the project site. In addition to a simple elevation comparison, the project proponent may also consult with the Orange County's average annual precipitation isopluvial map, which is provided in the Orange County Technical Guidance Manual, Appendix XVI (2011). Review of this map could provide an initial estimate as to whether the project site is in a similar rainfall zone as compared to the rainfall stations. Generally, precipitation totals in South Orange County increase with increasing elevation.

Where possible, rainfall data sets located in the same topographic zone (coastal, foothill, mountain) as the project should be selected.

Figure 3-2: Rainfall Data – Available Stations and Starting Date

3.5 Rainfall Losses – Infiltration Parameters

Standards developed as part of this HMP to control runoff peak flows and durations are based on a continuous simulation of runoff using locally derived parameters for initial infiltration. A review was conducted of available continuous hydrologic simulation modeling reports in Southern California. These included water quality HSPF models developed for the County of Orange, regional continuous models developed by SCCWRP, and watershed-level continuous models developed for river and large creek systems in San Diego and Los Angeles Counties. Of particular interest and focus in this review was how local and regional continuous hydrologic models simulated the pervious land surface for various combinations of soils and land use types, because this component of hydrologic modeling is typically the most variable and difficult to describe.

The HSPF software package is an industry standard for continuous simulation hydrologic modeling. However, HEC-HMS and SWMM also provide adequate public domain continuous modeling alternatives. The HMP allows the option to use HEC-HMS for a project submittal but only provides infiltration data review for HSPF modeling approaches. Therefore, applicants choosing HEC-HMS should seek prior authorization by the governing municipality.
In preparing computer models to assess storm water controls and meet hydromodification criteria, rainfall loss parameters describing soil characteristics, land cover descriptions, and slope should be validated to prove consistency with the local environment and climatic conditions. The goal, with regard to the South Orange County HMP, is to develop a set of appropriate parameter ranges to account for variations.

In addition to the reports listed in **Table 3-3**, other TMDL reports in Southern California were reviewed. However, only those reports with a substantial description of modeling activities were summarized in the table.

Table 3-3: TMDL Technical Reports

No.	Title	Authors	Date	Summary/Comments
1	Orange County Stormwater Program – Identification of Retrofitting Opportunities – Watershed HSPF Model Development	County of Orange / RBF Consulting	September 12, 2009	Combination of hydrologic and water quality modeling to estimate both pollutant loadings and pollutant removal from retrofitting opportunities. Two watersheds were modeled: Anaheim Bay-Huntington Harbor and Aliso Creek HSPF calibration parameters are specific to each local watershed.
2	TMDL to Reduce Bacterial Indicator Densities at Santa Monica Bay Beaches During Wet Weather (Preliminary Draft)	Los Angeles RWQCB / Tetra Tech	June 21, 2002	Combination of hydrologic and water quality modeling to estimate bacterial loadings to Santa Monica Bay. The HSPF/LSPC model was calibrated and validated using stream flow data collected on Malibu Creek and Ballona Creek. (LSPC stands for Loading Simulation Program in C++, a recoded C++ version of HSPF.) No HSPF model parameters are included.

No.	Title	Authors	Date	Summary/Comments
3	Technical Report – TMDLs for Indicator Bacteria in Baby Beach and Shelter Island Shoreline Park	San Diego RWQCB / Tetra Tech	June 11, 2008	HSPF/LSPC model was calibrated to flow data collected in Aliso Creek and Rose Creek. Calibrated infiltration rates were reported for Natural Resources Conservation Survey (NRCS) Group A, B, C, and D soils. However, it is unclear if these rates correspond to specific HSPF model parameters. The issue of how to apply the calibrated infiltration rates should be addressed through correspondence with study authors.
4	Evaluating HSPF in an Arid, Urbanized Watershed (in Journal of the American Water Resources Association, 2005, p477-486)	Drew Ackerman, Kenneth Schiff, Stephen Weisburg (SCCWRP)	February 2005	HSPF was used to simulate hydrologic processes in arid region, e.g., precipitation on dry soils, effect of irrigation. The model was calibrated to gauge data collected in the lower reaches of Malibu Creek. The calibration set aggregated the soil and land cover variations in the watershed (i.e., spatially "lumped" parameters). Pervious land surface (PWATER) parameters were included.
5	TMDL for Indicator Bacteria Project I – Twenty Beaches and Creeks in the San Diego Region	San Diego RWQCB / Tetra Tech	December 12, 2007	HSPF/LSPC model parameters were selected from regional calibration. Calibration efforts used daily average stream flows as the baseline calibration condition. The Appendices describe the regional calibration process. The modeling files are provided by the San Diego RWQCB.
6	Lake Elsinore and Canyon Lake Nutrient Source Assessment (Final Report) for Santa Ana Watershed Project Authority	Tetra Tech, Inc.	January 2003	The HSPF/LSPC model was calibrated and validated using United States Geological Survey (USGS) gauging site data in the San Jacinto watershed. Model simulated pollutant loading to Lake Elsinore and Canyon Lake. Pervious land surface (PWATER) parameters were not published in the report.

The technical reports listed in **Table 3-3** demonstrate that a variety of detailed HSPF modeling studies have been conducted in the past 10 years in Southern California. The modeling efforts conducted in Orange County, particularly the HSPF model for Aliso Creek watershed, have been adapted for use in the South Orange County HMP (see No. 1 above). The parameters developed for this watershed model were specifically calibrated and validated by using stream flow and water quality data from the Aliso Creek watershed. In addition, the Ackerman study (**Table 3-3**, item No. 3) published a set of generalized parameters that aggregates or "spatially lumps" the contributions of different soil/land use combinations in the upper watershed.

The HSPF model described in the Ackerman paper (**Table 3-3**, item No. 4) simulates all soil and land use combinations using a single composite parameter set. The purpose of the model was to estimate pollutant loadings to area beaches and water bodies. Therefore, the HSPF model was calibrated only to gauge data in the lower Santa Monica Bay watershed. Additionally, the effect of upstream surface water impoundments would have made the development of an accurate, detailed calibration at the sub-catchment scale very difficult to achieve. Unfortunately, this "spatially lumped" parameter set is of limited usefulness for the purpose of the HMP project, given the need to develop parameter sets that describe a variety of common soil and land use combinations.

The following model parameters were incorporated into the Aliso Creek HSPF model. Specific values were associated to each type of land use such that several values are possible for each pervious parameter.

Table 3-4: Model Parameters

Pervious Parameters	Acronym	Value	Unit
Fraction of Remaining Evapotranspiration (E-T) from Active Groundwater Storage	AGEWTP	0.05	-
Basic Groundwater Recession Rate	AGWRC	0.8/0.99	1/day
Fraction of Remaining E-T from baseflow	BASETP	0.2	-
Interception Storage Capacity	CEPSC	0.2	inch
Fraction of Groundwater to Deep Aquifer	DEEPFR	0.05/0.15	-
Forest Fraction	FOREST	0 or 1	-
Infiltration Equation Exponent	INFEXP	2	-
Ratio between the Maximum and Mean Infiltration Capacities	INFILD	2	-
Infiltration Capacity	INFILT	0.1/2	inch/hour
Interflow Inflow Parameter	INTFW	0.2	-
Interflow Recession Parameter	IRC	0.5	1/day
Groundwater Recession Flow Coefficient	KVARY	5/8	1/inch
Overland Flow Length	LSUR	75 to 190	feet
Lower Zone E-T Parameter	LZETP	0.9	-
Lower Zone Nominal Storage	LZSN	0.8/2.4/3.2	in
Manning's n for Overland Flow	NSUR	0.15/0.25/0.35	Complex
Temperature Maximum for E-T	PETMAX	35	deg F
Temperature that E-T is Zero	PETMIN	30	deg F
Overland Flow Slope	SLSUR	0.2	foot/feet
Upper Zone Nominal Storage	UZSN	0.05/0.07	inch

Additional reference material is contained in the BASINS Technical Notice 6, Estimating Hydrology and Hydraulic Parameters for HSPF, prepared by U.S. EPA (July 2000). This document provides details regarding pervious and impervious land hydrology parameters along with flow routing parameters. Parameter and value range summary tables are included in the document.

3.6 Rainfall Losses - Evapotranspiration Parameters

Standards developed as part of this HMP to control runoff peak flows and durations are based on a continuous simulation of rainfall runoff using locally derived parameters for evaporation and evapotranspiration. Known data sources for potential evapotranspiration data in South Orange County are listed below.

Historical potential evapotranspiration at Laguna Beach station (CA044647) is considered to best represent the coastal evapotranspiration conditions of the San Juan hydrologic unit. Historical potential evapotranspiration at Vista station (CA049378) was found to best correspond to the foothills and mountainous conditions. It is located in San Diego County but remains in the San Juan hydrologic unit.

Other gauging stations that record potential evapotranspiration were not selected because the elevation and land use were not representative of the specific foothill and mountainous conditions present in South Orange County. The potential evapotranspiration will be coupled with historical records of temperature to determine the actual daily evapotranspiration. **Table 3-5** summarizes available sources for potential evapotranspiration in South Orange County.

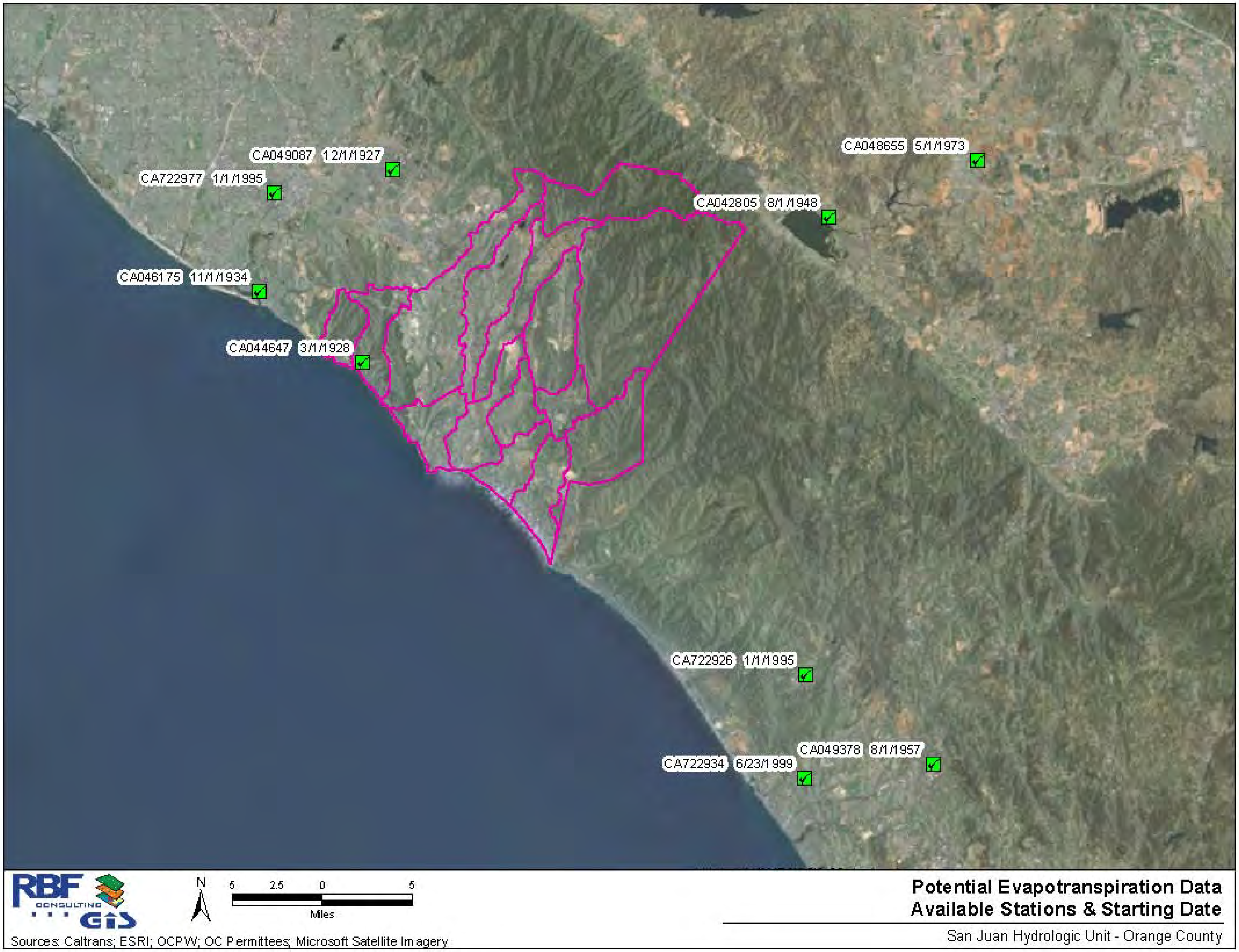
Table 3-5: Available Evapotranspiration Sources

Station Name ID	Data Type	Data Source	Recording Frequency	Hourly data span
Laguna Beach (CA044647)	Potential Evapotranspiration	BASIN	Daily	March 1928 – December 2006
Vista (CA049378)	Potential Evapotranspiration	BASIN	Daily	August 1957 – December 2006

Long-term evaporation / evapotranspiration data sets are being generated to correspond with long-term rainfall records. The final selection of rainfall loss parameters and evaporation data is part of the SOCHM development process.

In summary, the published literature reviewed as part of this study support the methods and approach taken in developing the South Orange County HMP.

Figure 3-3: Potential Evapotranspiration Data – Available Stations and Starting Date



4.0 Requirements and Standards for Projects

Priority Development Projects are required to implement hydrologic control measures and on-site management controls so that post-project runoff flow rates and durations do not exceed pre-development, i.e. naturally occurring conditions, flow rates and durations where they would result in an increased potential for erosion or significant impacts to beneficial uses (Permit Section F.1.h.). The purpose of this chapter is to identify the HMP criteria, detail the HMP applicability requirements, and provide a framework for alternative compliance.

4.1 HMP Criteria

The HMP criteria are designed to manage increases in runoff discharge rates and durations from all Priority Development Projects (PDPs) and they apply to all PDPs. The HMP criteria include the following:

- All PDPs must use continuous simulation to ensure that post-project runoff flow rates and durations for the PDP shall not exceed pre-development, naturally occurring, runoff flow rates and durations by more than 10% for peak flow rates, from 10% of the 2-year runoff event up to the 10-year runoff event.

This HMP includes a tool to provide continuous simulation of peak flow rates, from 10% of the 2-year runoff event up to the 10-year runoff event for PDPs. The tool is the South Orange County Hydrology Model, which is an HSPF model based on the San Diego Hydrology Model and allows PDPs to meet the HMP criteria through interactive graphic user interface. Details about how to use the model are provided in **Appendix C**.

4.2 HMP Applicability Requirements

To determine if a proposed project must implement hydromodification controls, refer to the HMP Decision Matrix in **Figure 4-3**.

The HMP Decision Matrix can be used for all projects. Project tiers are based on the size and type of development or re-development, are identified in **Figure 4-3**, and their associated requirements are defined in **Section 4.5**.

It should be noted that all PDPs are subject to the Permit's LID and water quality treatment requirements even if hydromodification flow controls are not required.

As noted in **Figure 4-3**, projects may be exempt from HMP criteria under the following conditions.

- If the project is not a PDP; or
- If the proposed project discharges storm water runoff directly into underground storm drains discharging directly to bays or the ocean; or
- If the proposed project discharges runoff directly to an exempt receiving water as defined in **Section 4.3.1**; or
- If the project classifies as an infill development projects per the definition provided in **Section 4.3.2**; or
- If the project is an in-stream flood control or restoration project (See **Section 4.3.3**), or,

- If the project discharges to a large river per the definition provided in **Section 4.3.4**

Figure 4-1 through **Figure 4-2** provide an overview of the inventoried south Orange County storm drains, and identify potentially exempt areas per the requirements of the permit and non-exempt areas. **Figure 4-1** through **Figure 4-2** are classified per watershed and geographical localization within the San Juan Hydrologic Unit.

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Figure 4-1: South Orange County Storm Drain Inventory 2010

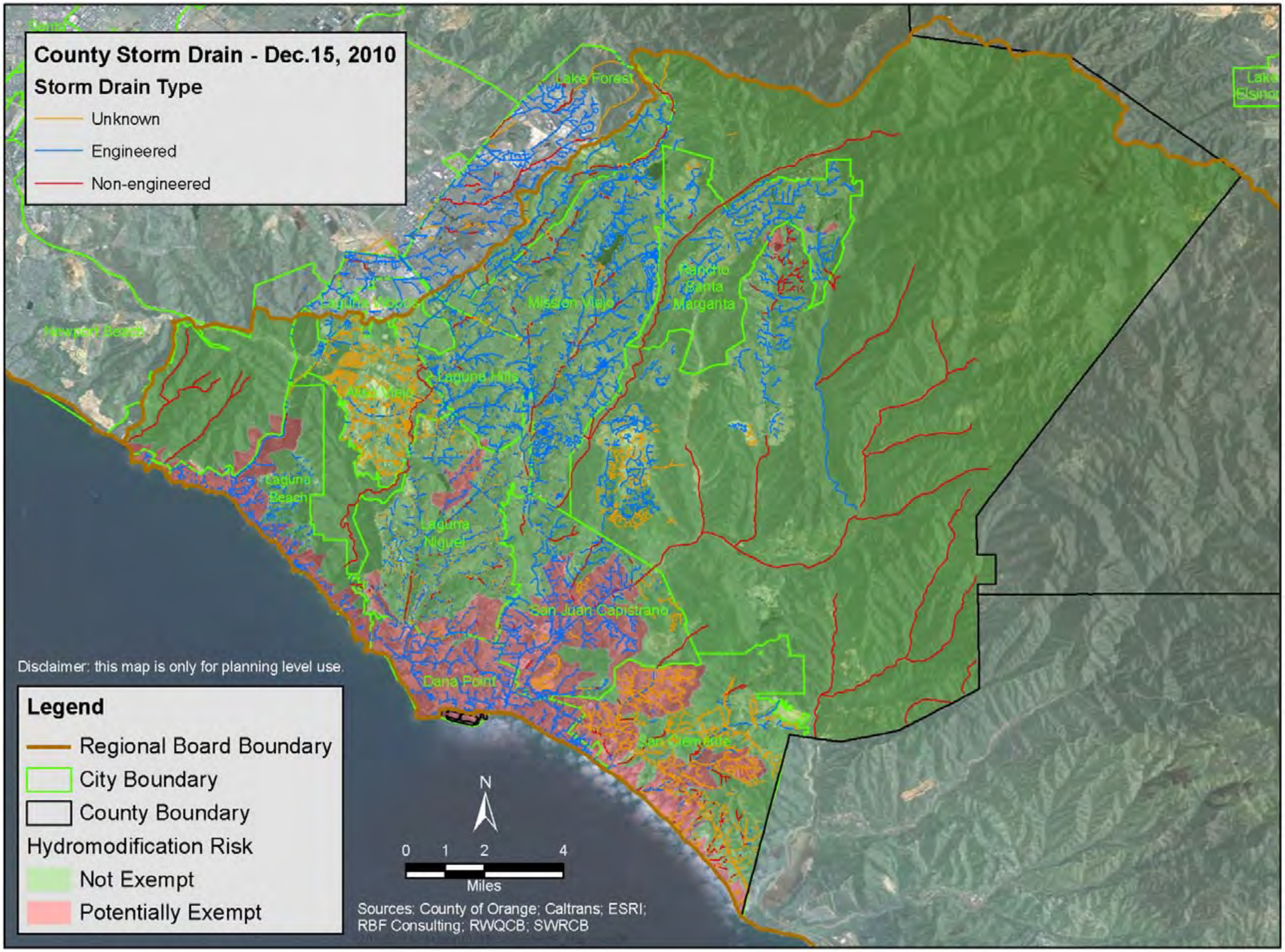


Figure 4-2: Southern Portion South Orange County Storm Drain Inventory 2010

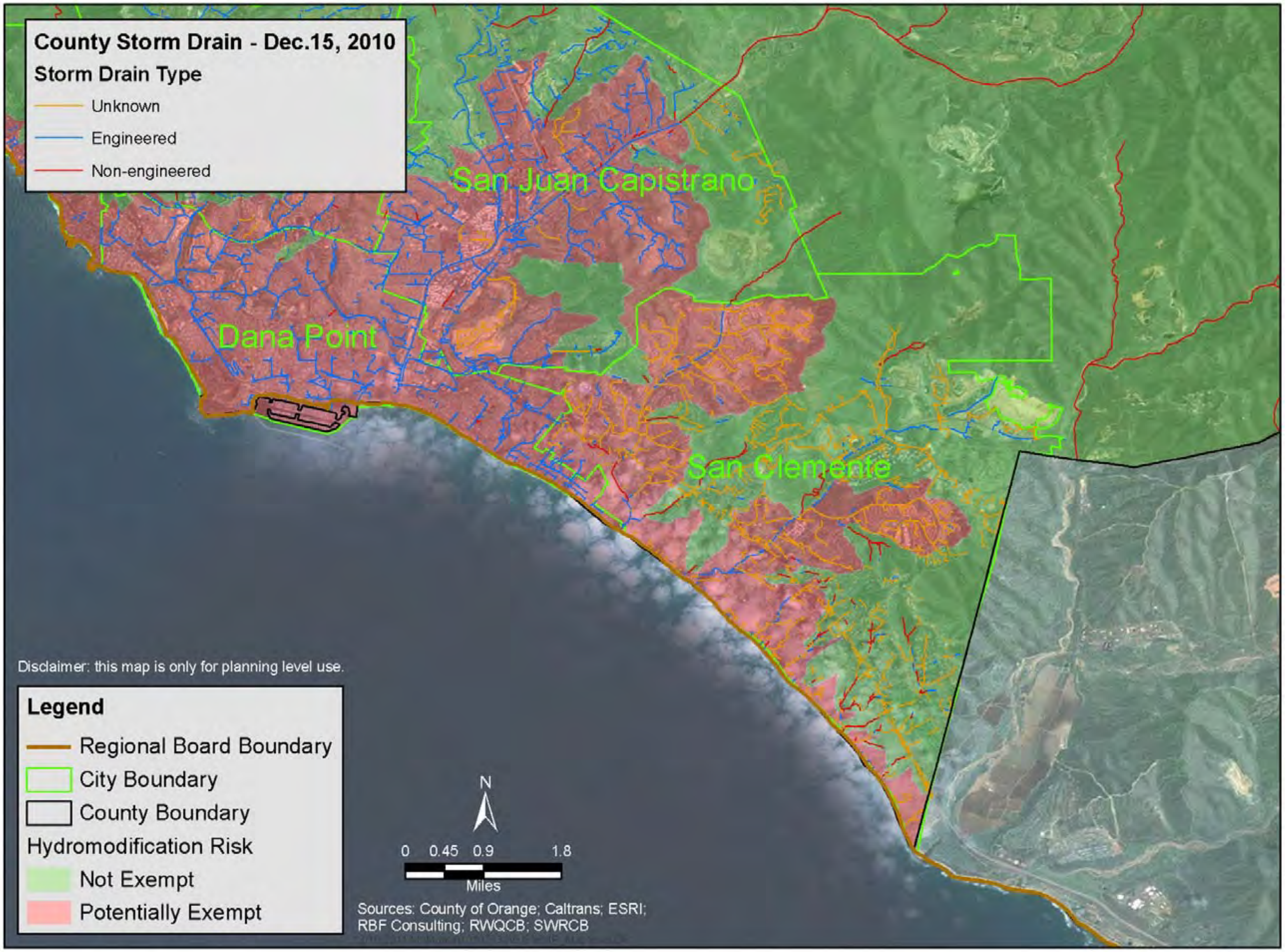
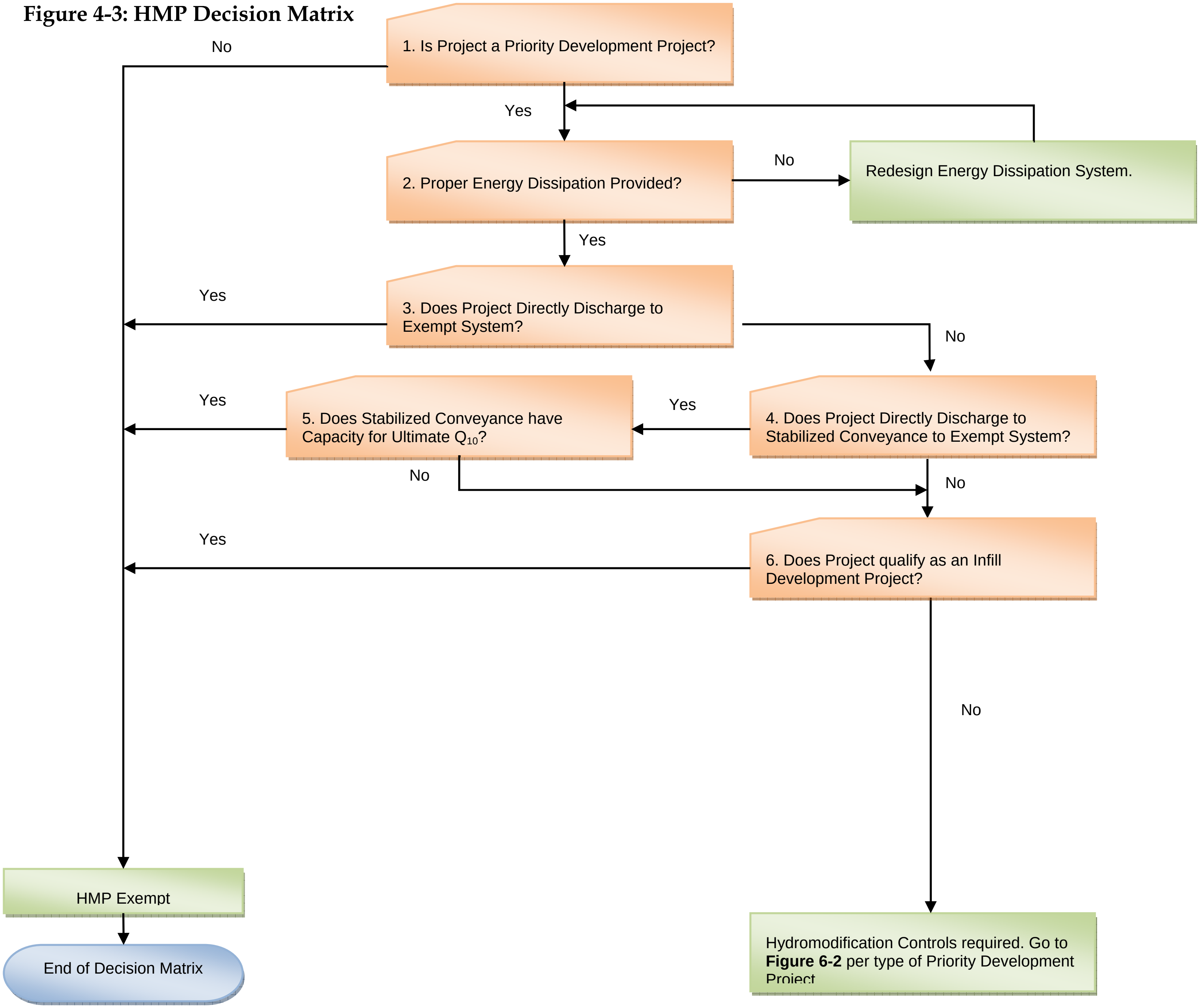


Figure 4-3: HMP Decision Matrix



- **Figure 4-3**, Node 1 – Hydromodification mitigation measures are only required if the proposed project is a PDP, as defined per Permit Item F.1.d.
- **Figure 4-3**, Node 2 – Properly designed energy dissipation systems are required for all project outfalls to unlined channels. Such systems should be designed in accordance with the Orange County Local Drainage Manual to ensure downstream channel protection from concentrated outfalls.
- **Figure 4-3**, Node 3 – Potential exemptions may be granted for projects discharging runoff directly to an exempt receiving water, such as the Pacific Ocean, an exempt river system (identified in **Table 4-1**), an exempt reservoir system (identified in **Table 4-2**), a large river stream (identified in **Section 4.3.4**), but also for in-stream flood control projects (identified in **Section 4.3.3**).
- **Figure 4-3**, Nodes 4 and 5 – For projects discharging runoff directly to an engineered conveyance system that extends to exempt receiving waters detailed in Node 3, potential exemptions from hydromodification criteria may be granted. Such engineered systems could include existing storm drain systems, existing hardened conveyance channels, or stable engineered unlined conveyance channels that are part of the MS4 but that are not receiving waters. To qualify for this exemption, the existing hardened or rehabilitated conveyance system must continue uninterrupted to the exempt system. The engineered conveyance system cannot discharge to an unlined, non-engineered channel segment prior to discharge to the exempt system. Additionally, the project proponent must demonstrate that the engineered conveyance system has the capacity to convey the 10-year ultimate condition flow through the conveyance system. The 10-year flow should be calculated based upon single-event hydrologic criteria as detailed in the Orange County Hydrology Manual.
- **Figure 4-3**, Node 6 – Potential exemption may be granted to a project classified as an infill development project. The criteria that the infill development project must fulfill are listed in **Section 4.3.2**.

4.3 HMP Exemptions

PDPs may be exempt from HMP criteria based on either channel conditions or if the project qualifies as an infill development. These exemptions are detailed in this section.

4.3.1 Engineered Channel Exempt Areas

The channel exempt areas include those areas that discharge to engineered channels sections that have the capacity to convey the 10-year ultimate condition discharge. This includes, as identified in Section F.1.h.3. of the permit,

- PDPs that discharge runoff directly into underground storm drains discharging directly to bays or the ocean; or
- PDPs that discharge runoff into conveyance channels whose bed and bank are concrete lined all the way from the point of discharge to Ocean waters, enclosed bays, estuaries, or water storage reservoirs and lakes.

Only engineered sections (defined as metal, plastic, or concrete closed conduits, and engineered earthen) or concrete channels (concrete or reinforced concrete, riprap and articulated concrete mat) are exempt from the hydromodification requirements. To confirm the exemption, the succession of existing engineered conveyance sections must be continuous from the upstream point to the Pacific Ocean, or to an exempt receiving water, such as a reservoir.

In addition, channel segments that are tidally influenced are exempt from hydromodification requirements. Tidal influence to stream segments may be established for those segments whose invert is below the Mean Higher High Water (MHHW). MHHW is defined by the National Oceanic and Atmospheric Administration (http://tidesandcurrents.noaa.gov/).

The South Orange County Permit area was screened for identification of exempt channels. The screening analysis was conducted using the 2010 Orange County Countywide Storm Drain Inventory. The storm drain inventory defines the type of material and size composing each section of a channel or storm drain. Major storm drains that are exempt from hydromodification requirements are presented in **Table 4-1** for reference only. The PDP may use the exemption map for planning purposes and must determine if the development or redevelopment project discharges runoff into a continuous succession of existing hardened or rehabilitated conveyance sections all the way to the Pacific Ocean or other exempt water body. The table contains the name of the storm drain, as well as the associated downstream and upstream limits. The upstream limit being reported corresponds to the nearest cross street. The resulting map from this effort is presented in **Figure 4-4**. The map shows drainage areas that are exempt from HM criteria. The effect of tidal influence on channel exemption is not reported into these maps.

Table 4-1: Channels Exempt from Hydromodification Requirements in Orange County

Channel	Downstream Limit	Upstream Limit
Laguna Canyon Channel	Pacific Ocean	Philips Street
Sleepy Hollow Storm Drain	Pacific Ocean	Park Avenue
Bluebird Storm Drain	Pacific Ocean	Glenneyre Street
Aliso Creek Channel	Pacific Ocean	Pacific Coast Highway
Salt Creek Channel	Pacific Ocean	300 ft north of Pacific Coast Highway
San Juan Creek Channel	Pacific Ocean	Paseo Michelle
Prima Deshecha Canada Channel	Pacific Ocean	Avenida Vaquero
North Creek	Pacific Ocean	Doheny Park Road
Cacadita Canyon Storm Channel	Prima Deshecha Canada Channel	Via Cascadita
Segunda Deshecha Canada Channel	Pacific Ocean	Calle Frontera
Marquita Storm Channel	Pacific Ocean	Encino Lane
Trafalgar Storm Drain	Pacific Ocean	South Ola Vista

Table 4-2 provides a summary of exempt reservoirs in South Orange County. Large reservoirs or lakes can be exempt systems from a hydromodification standpoint since reservoir and lake storm water inflow velocities are naturally mitigated by the significant tailwater condition in the reservoir. HMP exemptions would only be granted for projects discharging runoff directly to the exempt reservoirs or into conveyance systems designed convey the 10-year ultimate condition discharging into a lake or reservoir. To qualify for the potential exemption, the outlet elevation of the conveyance system must be within (or below) the normal operating water surface elevations of the reservoir and properly designed energy dissipation must be provided.

Table 4-2: Reservoirs in Orange County

Reservoir	Watershed
Sulphur Creek Reservoir	Sulphur Creek
El Toro Reservoir	Oso
Rancho Santa Margarita Lake	Middle Trabuco
Dove Canyon Lake	Upper San Juan

Figure 4-4 below displays the areas of exemption for the entire South Orange County permit area based on the criteria outlined above, where the areas in pink are potentially exempt as they discharge to engineered conveyances all the way to exempt receiving waters (ocean waters, enclosed bays, estuaries, water storage reservoirs, lakes). **Figure 4-5** and **Figure 4-6** show more detailed maps for the exempt areas in the northern coastal part of South Orange County and the southern coastal part of south Orange County, respectively.

Figure 4-4: Exemption Map

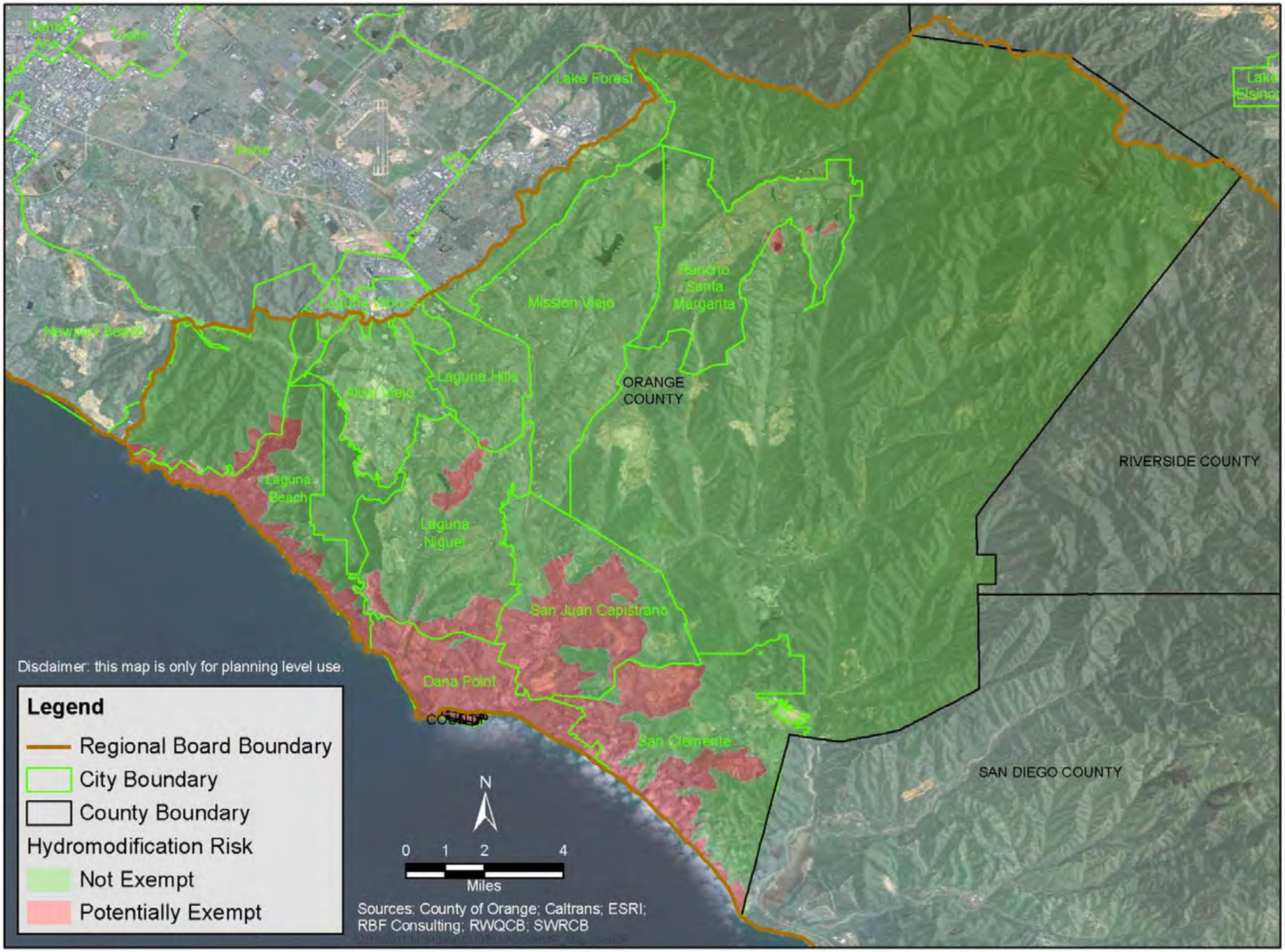


Figure 4-5: Exemption Map Coastal Areas Northern South Orange County

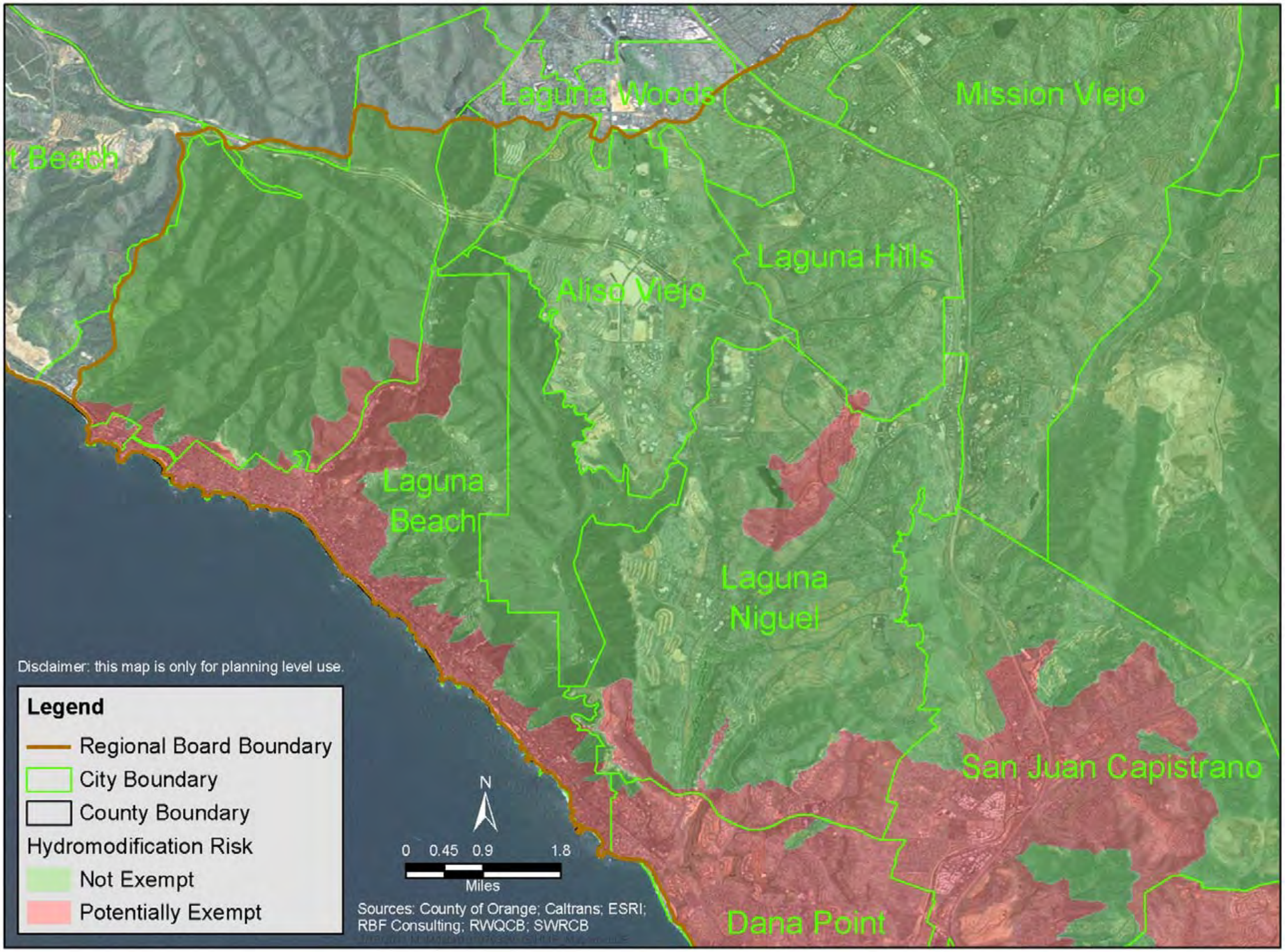
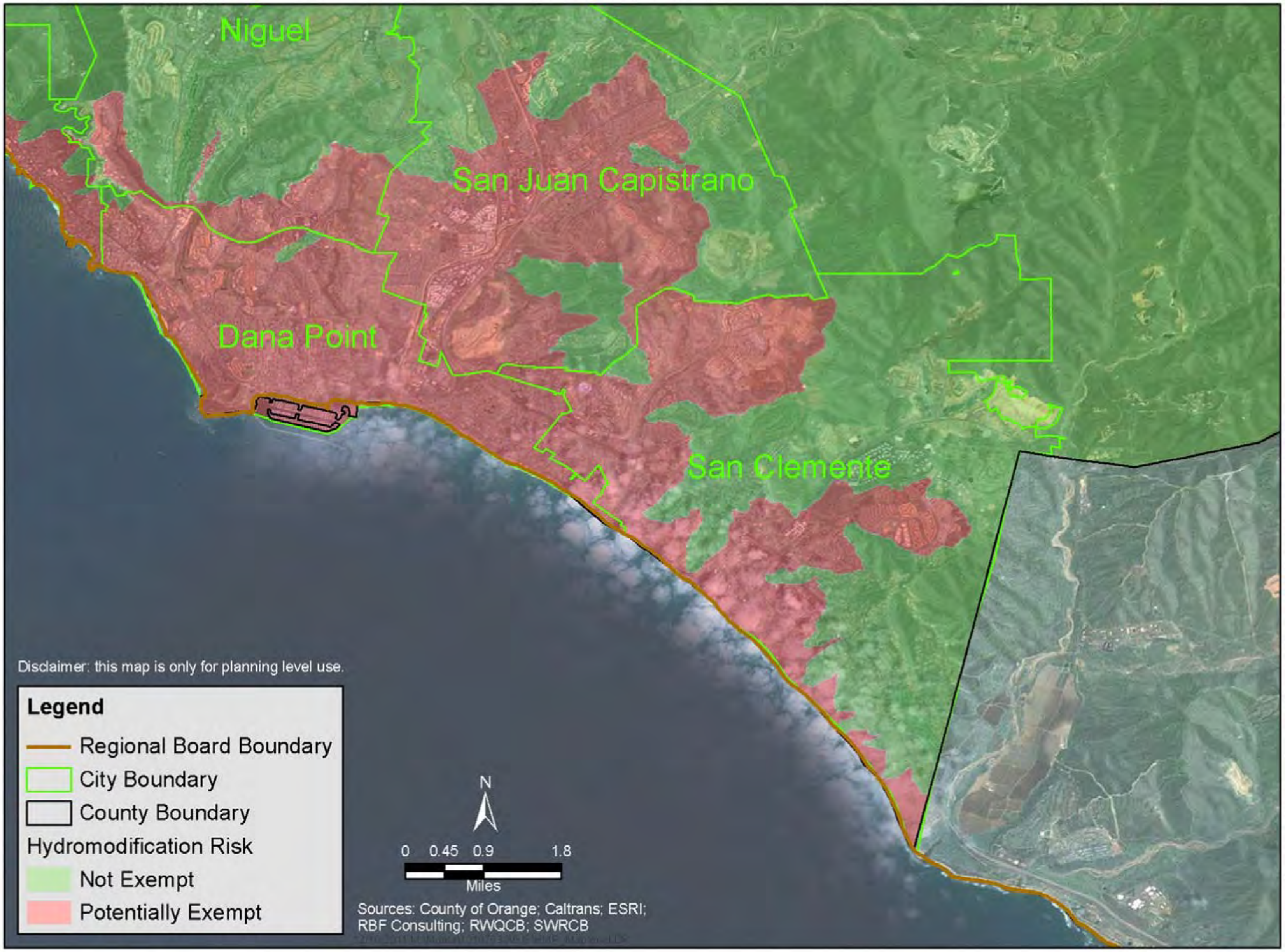


Figure 4-6: Exemption Map Coastal Areas Southern South Orange County



4.3.2 Exemption for Infill Development Projects

Infill development is the development of vacant, underdeveloped or underused sites within an urban area. Section 15332 of the State California Environmental Quality Act (CEQA) Guidelines provide a categorical exemption for infill development projects. Requiring the same hydromodification requirements for infill development as greenfield development will discourage redevelopment and result in lost opportunities to improve water quality through redevelopment projects.

Small urban developments have also been shown to have minor effect on hydromodification in urban watersheds. The effects of cumulative watershed impacts were evaluated through continuous simulation in the San Diego HMP. Findings of the sensitivity analysis include that small urban development or re-development projects have a relatively minor effect on the overall watershed's flow duration curve if the future cumulative additional impacts have the potential to increase the existing watershed impervious area by less than three percent. These findings occurred when the sensitivity analysis was performed on sub-watershed of imperviousness exceeding 40%. For sub-watersheds of imperviousness lesser than 40%, the continuous simulation models indicated a more pronounced response to the flow duration curve when small urban development or re-development projects were added. The effects of hydromodification on the geomorphology of a stream may be assessed across a domain of analysis, which is defined in **Section 3.1** (SCCWRP, 2010). These findings apply to the south Orange County region as the physiographic, geomorphic, and environmental conditions are similar to those encountered in San Diego County.

An exemption to the requirements of the HMP will be provided for redevelopment projects meeting all of the following criteria:

1. The project is consistent with the applicable general plan designation and all applicable general plan policies, as well as with applicable zoning designation and regulations.
2. The proposed development occurs on a project site of no more than eight[1] acres in size and is substantially surrounded by urban uses[2].
3. The project site has no value as habitat for endangered, rare or threatened species.
4. The project site is located within half a mile of an existing – or planned and funded – commuter rail or light rail; or within a quarter mile of one or more stops for two or more public or campus bus lines. The definition corresponds to the LEED Sustainable Sites Credit 4.1 – Alternative Transportation.
5. The urban project is located within a subwatershed whose imperviousness is higher than 40%. The imperviousness is determined from the entire subwatershed, as delineated from the outfall of the urban conveyance system.
6. Planned future developments within the subwatershed would not increase the composite imperviousness by more than three percent when compared to the existing

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[1] Eight-acre thresholds for infill projects criteria based on SB 375, which sets 8 acres as one of the criteria for defining a sustainable communities project.

[2] The term "urban use" includes the following land use categories, as defined in the 2005 Orange County General Plan: Urban Residential (1C), Community Commercial (2A), Regional Commercial (2B), and Public Facilities (4). The existence of surrounding urban uses and the associated density of development are to be determined per the 2008 SCAG land use digital aerial imagery

conditions. The subwatershed boundaries correspond to the entire subwatershed area draining to the outfall of the urban conveyance system. An assessment of the planned future developments may be derived from the 2005, or most current Orange County General Plan.

7. The urban project discharges runoff to an existing engineered conveyance system that extends beyond the domain of analysis defined for the urban project. The domain of analysis is defined per guidelines provided in **Section 3.1**.

4.3.3 Exemption for In-stream Flood Control and Restoration projects

In-stream flood control projects protect citizens and property from injury and damage by flooding. In-stream restoration projects restore beneficial uses of streams and channels, which ultimately provide benefit to benthic communities. Public health and safety, transportation corridors, economic activities, and in-stream aquatic health all benefit from in-stream flood control and restoration projects. For these reasons, in-stream flood control and restoration projects are exempt from the HMP requirements.

4.3.4 Exemption for Large River Reaches

Effects of cumulative watershed impacts are minimal in stream reaches of large depositional rivers. These large rivers typically have very wide floodplain areas when in the natural condition or are stabilized when in the engineered condition, and are of low gradient. The results of a flow duration curve analysis that was performed for the San Diego River are presented in the San Diego HMP.

This analysis demonstrated that the effect of cumulative watershed impacts are minimal in those reaches for which the contributing drainage area exceeds 100 square miles and with a 100-year design flow in excess of 20,000 cfs. Development and re-development projects that discharge either directly or via a conveyance system designed convey the 10-year ultimate condition into such large river streams are hence exempt from the South Orange County HMP requirements, provided that properly sized energy dissipation is implemented at the outfall location. All exempt river reaches, which are presented in **Table 4-3** have a drainage area larger than 100 square miles and a 100-year design flow higher than 20,000 cfs (SDRWQCB, 2002). **Table 4-3** also provides the corresponding upstream and downstream limits to define the exempted reach.

Table 4-3: Exempt River Reaches in South Orange County

River	Downstream Limit	Upstream Limit
San Juan Creek	Outfall to Pacific Ocean	Caper Park Road
San Mateo Creek	Outfall to Pacific Ocean	Nickel & Tenaja Canyons

4.4 HMP Alternative Compliance

For some PDPs, implementation of onsite hydromodification controls consistent with the HMP may not be feasible due to site constraints. These projects require alternatives to onsite hydromodification controls. The LID requirements of the permit require the implementation of LID techniques that effectively result in hydrologic processes that mimic the desired natural watershed conditions. There are two alternative compliance options for PDPs that cannot implement onsite hydromodification controls. One option is for a PDP proponent to identify and construct off-site mitigation to offset the inability to meet the HMP criteria onsite. The other option is for the PDP proponent to pay into an HMP mitigation bank, if an HMP mitigation bank is available to the PDP. The details of these options are provided below.

4.4.1 HMP Alternative Compliance Option 1: Off-site Mitigation

A progression through a defined process is required to document eligibility then implementation of alternative compliance for the HMP. Off-site mitigation is based on a progression of steps to meet compliance that is consistent with Section F.1.h.2 of the MS4 Permit. These steps include the following:

1. Technical feasibility study of onsite hydromodification controls; and
2. Off-site mitigation project within the same hydrologic unit as the PDP or in-stream restoration of the receiving water of the PDP.

Step A: Conduct a technical feasibility study for onsite hydromodification controls

A technical feasibility study is required to identify why onsite hydromodification controls cannot be incorporated into the project. The technical feasibility study must include the project constraints and provide detailed technical justification as to why the project constraints prevent implementation of onsite controls. The technical feasibility study will be submitted to the jurisdiction of the location of the PDP for review as part of the Preliminary WQMP. The jurisdiction must approve the technical feasibility before the PDP moves on to Step B.

Model WQMP Integration

Guidance on the hydromodification technical feasibility study will be incorporated into the Model WQMP and Technical Guidance. The hydromodification technical feasibility study will be integrated with the LID feasibility analysis as part of the Model WQMP; however, it should be noted that the criteria for hydromodification and LID requirements are different. The feasibility analysis for both hydromodification and LID will be integrated into one feasibility study for the project and submitted with the Preliminary WQMP.

Step B: Implement off-site mitigation within the same hydrologic unit as the PDP or in-stream restoration of the PDP receiving water

For those PDPs where the technical feasibility study for onsite controls has been approved by the jurisdiction, step B for the PDP is to either (1) implement an off-site mitigation project within the same hydrologic unit as the PDP, or (2) implement an in-stream restoration project for the receiving water of the PDP. The process for these options under Step B is detailed below:

B(1) Implement off-site mitigation within the same hydrologic unit as the PDP

In choosing this option, the PDP must investigate potential locations for implementation of an off-site mitigation project within the same hydrologic unit as the PDP. The off-site mitigation project must be sized to mitigate the equivalent runoff volume as implementing onsite hydromodification controls for the PDP. The PDP will evaluate and identify potential sites in the same hydrologic unit for implementation of an off-site hydromodification project that has the capacity to mitigate the PDP's hydromodification requirements. If an adequate site is identified by the PDP in the same hydrologic unit, the PDP will submit a report detailing:

- that the off-site mitigation project will be sized to mitigate the equivalent volume as implementing onsite hydromodification controls for the PDP; and
- conceptual plans for the off-site mitigation project as part of an amended WQMP for review and approval.

If no potential off-site mitigation project sites are identified in the same hydrologic unit as the PDP, the PDP must implement Option 2(b), an in-stream restoration project of the PDP receiving water.

B(2) Implement in-stream restoration of the PDP receiving water

In choosing this option, the PDP investigates the potential for implementation of an in-stream restoration project for the receiving water of the project. It must be determined that the receiving water for the project has hydromodification impacts. The in-stream restoration project must be located in the receiving water of the PDP. The PDP must submit a report detailing the condition of the receiving water due to hydromodification, as well as conceptual plans for the in-stream restoration project to the PDP's jurisdiction for review.

Once the project conceptual plans have been approved by the PDP's jurisdiction, the PDP must submit the appropriate permit applications to the appropriate regulatory agencies (e.g., Regional Board, California Department of Fish and Game, U.S. Army Corps of Engineers) for review and approval. If the PDP identifies no opportunities for in-stream restoration in the receiving water that the PDP discharges to, then the PDP must implement Option 2(a), an off-site mitigation project within the same hydrologic unit as the PDP.

4.4.2 HMP Alternative Compliance Option 2: HMP Mitigation Bank

(Note: Option 2 is available only if an HMP mitigation bank has been developed and is available to the PDP.)

The County and the Permittees have the option to develop an HMP mitigation bank or multiple HMP mitigation banks. A mitigation bank will develop regional HMP mitigation projects where PDPs can buy HMP mitigation credits if it is determined that implementing onsite hydromodification controls is infeasible. The development and operation of an HMP mitigation bank will include the identification of potential regional HMP mitigation projects; the planning, design, permitting, construction, and maintenance of regional HMP mitigation projects; the development of a fee structure for PDPs participating in the mitigation bank; and managing the HMP mitigation bank fund. Regional HMP mitigation projects can also serve as projects for an LID waiver program if site conditions allow for implementation of LID-type projects.

If PDPs are unable to meet the HMP criteria by incorporating onsite hydromodification controls, and a HMP mitigation bank is available, the PDP can apply to participate in the bank. The application must include a technical feasibility study to identify why onsite hydromodification controls cannot be incorporated into the project. The technical feasibility study must include the project constraints and detailed technical justification as to why the project constraints prevent implementation of onsite controls. The technical feasibility study will be submitted to the jurisdiction where the PDP is located for review as part of the Preliminary WQMP. The jurisdiction must approve the technical feasibility study for the PDP to participate in a HMP mitigation bank.

4.5 Tiered Requirements

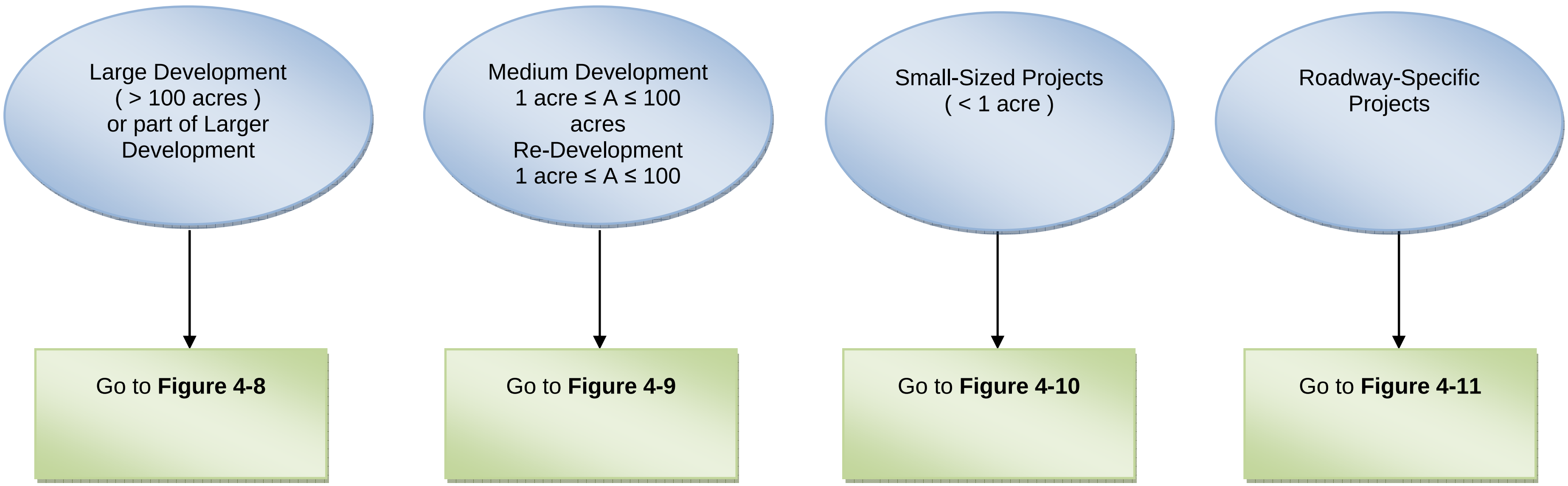
A proposed PDP that is not located in an exemption zone (see **Figures 4-4, 4-5, and 4-6**) must meet the HMP requirements defined in **Section 4.4**. **Figures 4-4, 4-5, and 4-6** are provided for planning purposes; however, the project proponent shall verify the eligibility to exemption criteria as defined in **Section 4.3**. The PDP must be classified by an applicable tier and meet all the requirements outlined for that tier. The project proponent may associate the size and type of the PDP to one of the following four tiers:

- Tier 1 – Large development projects exceeding 100 acres or development projects that are part of a common initial or phased development plan that exceeds 100 acres
- Tier 2 – Medium-sized development projects between one and 100 acres or re-development projects over one acre
- Tier 3 – Small-sized projects less than one acre yet defined as a PDP
- Tier 4 – Roadway-specific projects

Proposed development or re-development projects face different levels of spatial, environmental, financial, technical, and permitting constraints based on their size and type. As such, the permit language was translated into HMP requirements that are specific and adapted to each tier configuration. The definition of the four tiers was principally derived from the elements of the permit, as well as from a review of the other HMPs (Santa Clara, Alameda, Sacramento, and San Diego). The proposed tiers were defined based on the size and type of proposed projects, and include all PDPs as defined in Permit Item F.1.d.(11). Most individual single-family residential projects will be exempt from the HMP requirements.

Figure 4-7 illustrates the four tiers. The following subsections detail the HMP criteria specific to each tier.

Figure 4-7: Hydromodification Controls: PDP Tiers



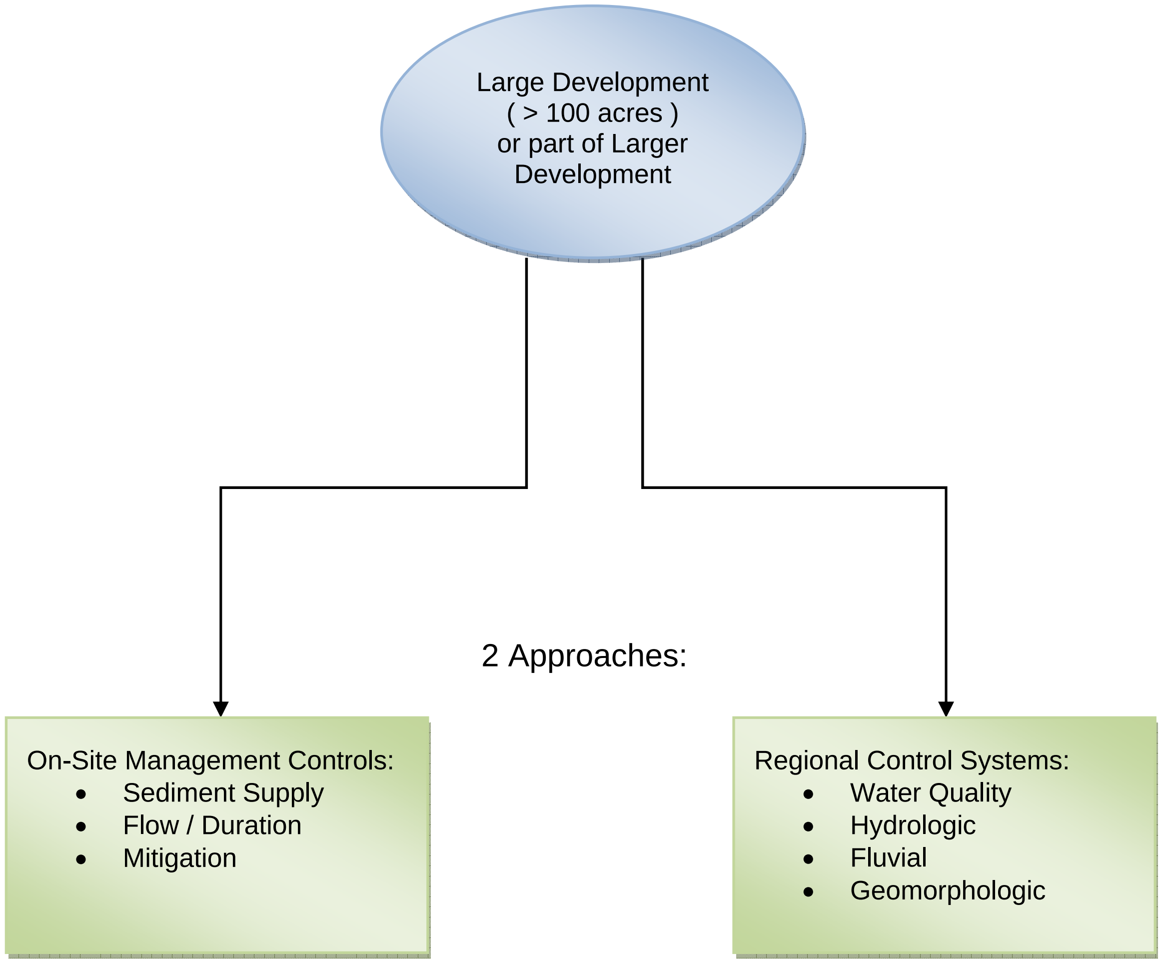
4.5.1 Tier 1 - Large developments (higher than one hundred acres)

Tier 1 includes large development projects greater than 100 acres or development projects in a common development plan that exceeds 100 acres. These developments typically offer a enough space for on-site implementation of flow and sediment management controls. Pursuant to permit item F.1.d.(11), implementation of regional control systems for hydromodification may also be considered. Overall, either of the following approaches may be pursued by the applicant:

- Meet the HMP Criteria identified in **Section 4.1** by mitigating flow and duration through on-site hydrologic control measures and addressing sediment loss through on-site management controls.
- Implement regional control systems in lieu of on-site management controls, consistent with the language in permit item F.1.d.(11). A technical feasibility study must be performed to define regional control systems that fulfill water quality, hydrologic, and fluvial geomorphologic requirements consistent with a study framework. Permit item F.1.d.(11) includes also a clause that allows applicants to implement conventional treatment BMPs, as well as participate in the LID waiver program when the regional LID implementation has been shown to be technically infeasible. This clause would not be translated for hydromodification requirements if such technical infeasibility were demonstrated. The technical feasibility study is Step A in **Section 4.4.1**. If a HMP mitigation bank is available, the PDP can pursue this option. The PDP can also pursue the in-stream restoration option (B2) identified in **Section 4.4.1**.

Figure 4-8 shows the two different approaches in a graphical form.

Figure 4-8: Hydromodification Controls: Large Development



4.5.2 Tier 2 – Medium sized projects (between one acre and one hundred acres)

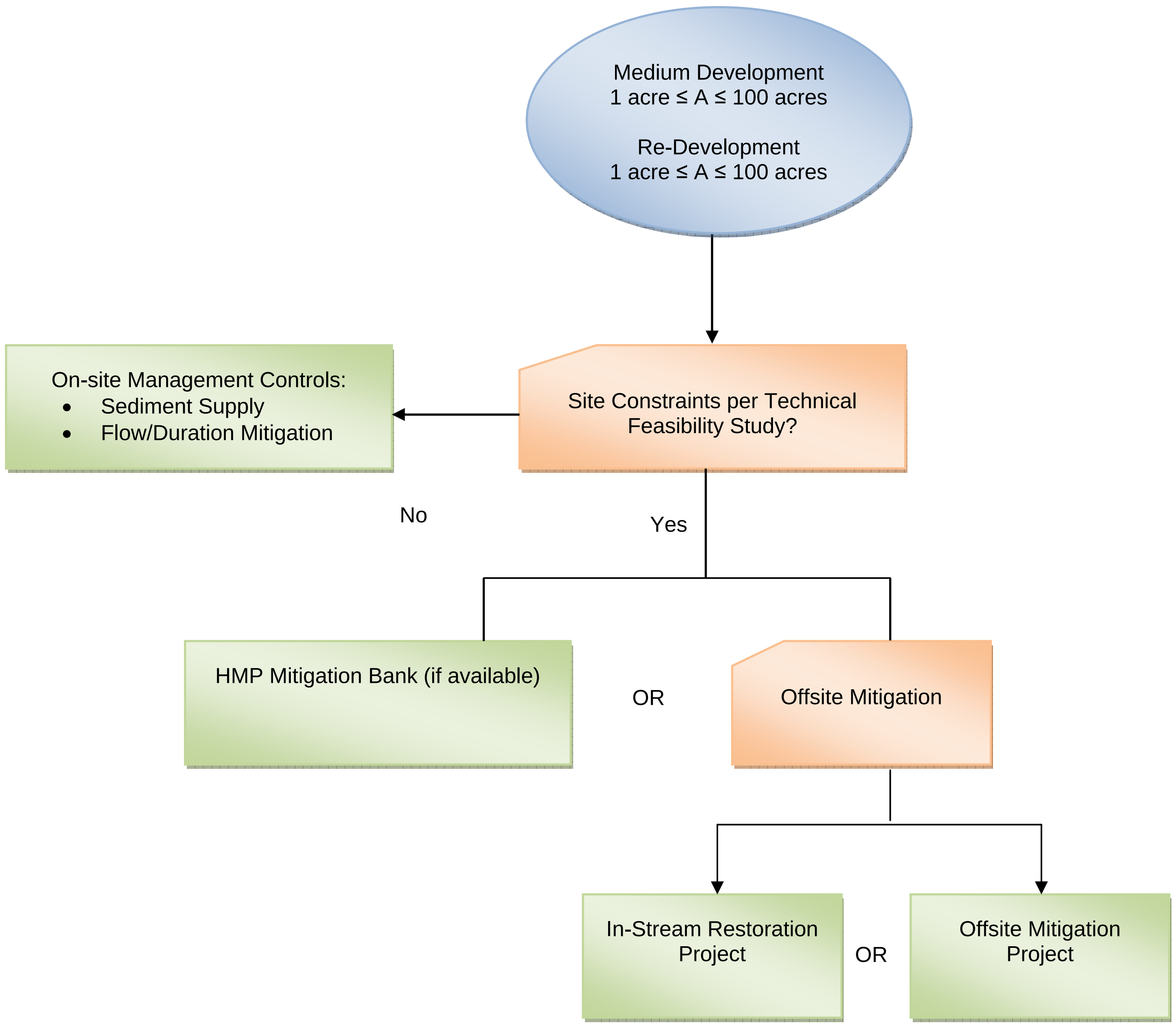
Tier 2 includes medium size development projects of area comprised between one acre and 100 acres, as well as re-development projects of one acre or more. The two boundaries define Tier 2. Tier 2 development or re-development projects will be subject to a large panel of spatial, environmental, financial, technical, and permitting constraints.

Hydrologic control measures and on-site management controls to ensure compliance with the HMP criteria are described in **Section 4.1**. Using this approach, mitigation of both flow and duration is achieved through on-site hydrologic control measures, and sediment loss is addressed through on-site management controls.

Alternatively, if on-site hydrologic control measures and management controls are not technically feasible due to site constraints, a technical study will be developed to demonstrate the infeasibility, per Step A in **Section 4.4.1**. Step B involves implementation of either an off-site mitigation project in the same hydrologic unit as the PDP or implementation of an in-stream restoration project in the receiving water that the PDP discharges to. Details of Step B are provided in **Section 4.4.1**. PDPs can pursue the HMP mitigation bank option, if available.

A flow chart indicating which HM criteria should be pursued and implemented for a Tier 2 project is shown in **Figure 4-9**.

Figure 4-9: Hydromodification Controls: Medium Development



4.5.3 Tier 3 – Smaller-sized projects (less than one acre)

Tier 3 encompasses small-sized projects less than one acre but defined as a PDP. The tier may include the following projects, as characterized by permit Item F.1.d.(1) and Permit item F.1.d.(2):

- New development projects that are smaller than one acre that create 10,000 square feet or more of impervious surfaces (collectively over the entire project site) including commercial, industrial, residential, mixed-use, and public projects. This category includes development projects on public or private land which fall under the planning and building authority of the Permittees.
- Projects on automotive repair shops that are smaller than one acre,. This category is defined as a facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 7532-7534, or 7536-7539.
- Restaurants. This category is defined as a facility that sells prepared foods and drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and drinks for immediate consumption (SIC code 5812), where the land area for development is greater than 5,000 square feet but lesser than one acre.
- All hillside development greater than 5,000 square feet but lesser than one acre. This category is defined as any development which creates 5,000 square feet of impervious surface which is located in an area with known erosive soil conditions, where the development will grade on any natural slope that is twenty-five percent or greater.
- All development lesser than one acre that are located within or directly adjacent to or discharging directly to an ESA (where discharges from the development or redevelopment will enter receiving waters within the ESA), which either creates 2,500 square feet of impervious surface on a proposed project site or increases the area of imperviousness of a proposed project site to 10 percent or more of its naturally occurring condition. “Directly adjacent” means situated within 200 feet of the ESA. “Discharging directly to” means outflow from a drainage conveyance system that is composed entirely of flows from the subject development or redevelopment site, and not commingled with flows from adjacent lands.
- Parking lots 5,000 square feet or more or with 15 or more parking spaces and potentially exposed to runoff. Only parking lots that are lesser than one acres are included into Tier 3. Parking lot is defined as a land area or facility for the temporary parking or storage of motor vehicles used personally, for business, or for commerce.
- Retail Gasoline Outlets (RGOs) This category includes RGOs that meet the following criteria: (a) 5,000 square feet or more or (b) a projected Average Daily Traffic (ADT) of 100 or more vehicles per day. RGO projects that are lesser than one acre are included into Tier 3.
- Those redevelopment projects lesser than one acre that create, add, or replace at least 5,000 square feet of impervious surfaces on an already developed site and the existing development and/or the redevelopment project falls under the project categories or locations listed in permit section F.1.d.(2). Where redevelopment results in an increase of less than fifty percent of the impervious surfaces of a previously existing development, and the existing development was not subject to Standard Stormwater Mitigation Plan (SSMP) requirements, the numeric sizing criteria discussed in permit section F.1.d.(6) applies only to the addition or replacement, and not to the entire development. Where redevelopment results in an increase of more than fifty percent of the impervious

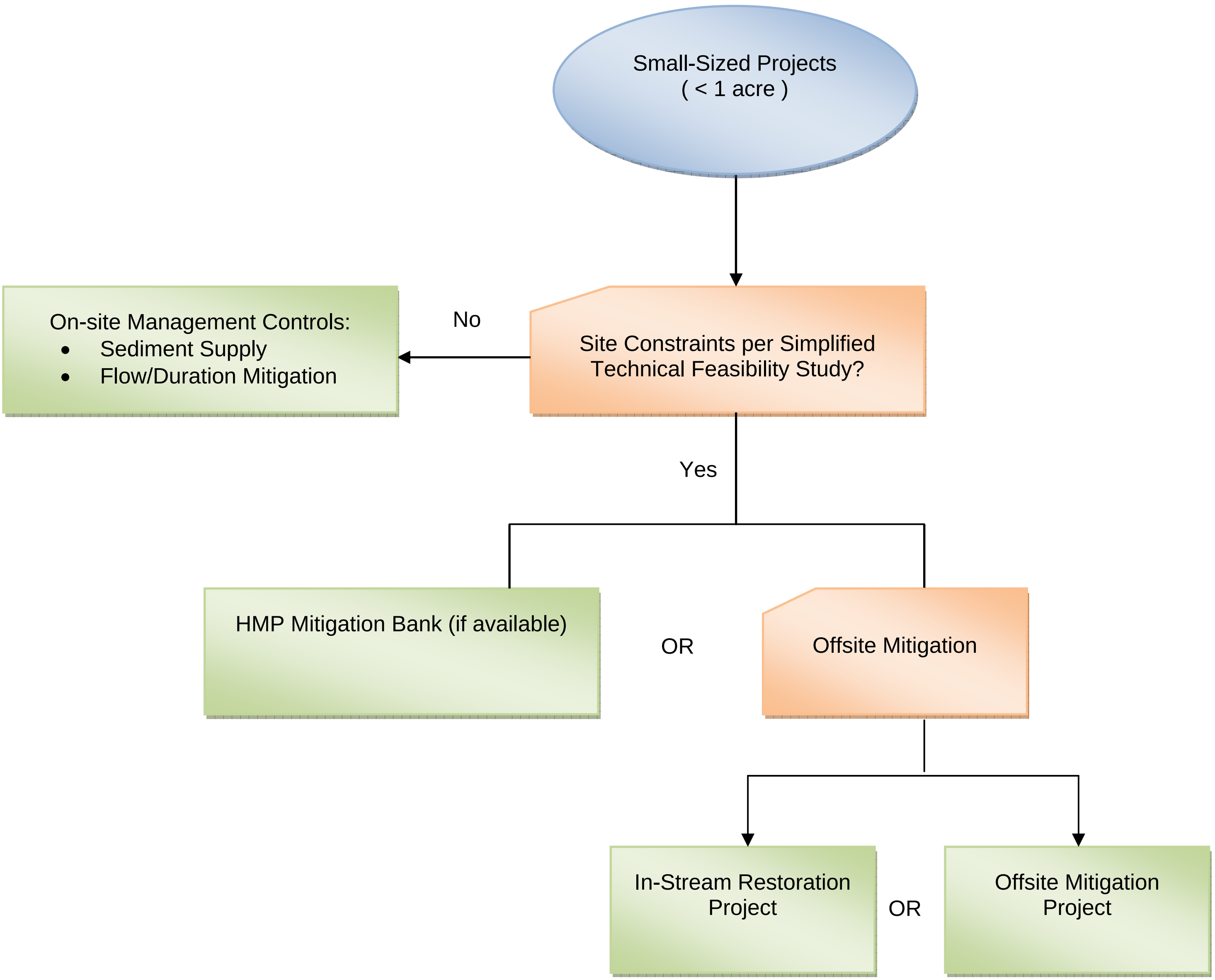
surfaces of a previously existing development, the numeric sizing criteria applies to the entire development.

The majority of Tier 3 projects are completed within a very limited amount of space, making it unlikely the applicant will be able to implement on-site management controls. Two approaches are available.

- Implementing hydrologic control measures and on-site management controls within the project boundaries to ensure compliance with the HMP Criteria identified in **Section 4.1**. Using this approach, mitigation of both flow and duration is achieved through on-site hydrologic control measures, and sediment loss is addressed through on-site management controls.
- If on-site hydrologic control measures and management controls are not technically feasible due to site constraints, a simplified technical feasibility study shall be developed to explain why the HMP criteria cannot be met onsite. The simplified technical feasibility study must include:
  - the soil conditions of the PDP site;
  - a demonstration of the lack of available space for onsite controls; and
  - an explanation of prohibitive costs to implement onsite controls.
  - a written opinion from a California Registered Geotechnical Engineer, who will identify the infeasibility due to geotechnical concerns.
- Once the simplified technical feasibility study is accepted by the jurisdiction of the PDP, the PDP can pursue payment into the HMP mitigation bank, if one exists and is available to the PDP. If not, the PDP must pursue either an off-site mitigation project or an in-stream restoration project detailed in Step B in **Section 4.4.1**.

A flow chart indicating which HMP criteria should be considered for a Tier 3 project is shown in **Figure 4-10**.

Figure 4-10: Hydromodification Controls: Small-Size Projects



4.5.4 Tier 4 – Municipal Roadway Projects

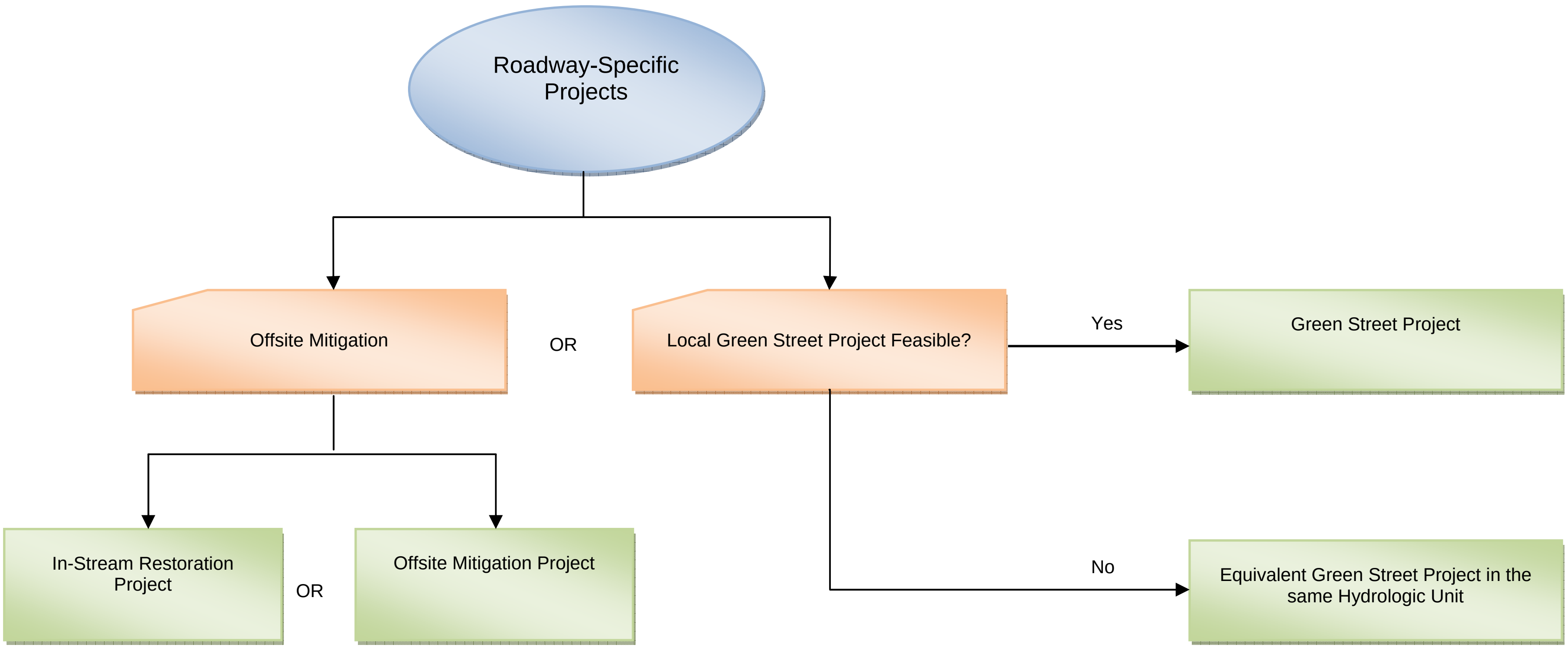
Municipal roadway projects constitute a standalone tier based on their unique characteristics. Roadway projects are linear development or re-development projects to be completed within a limited right-of-way. Tier 4 includes the following roadway projects, as defined per Permit Items F.1.d.(1) and F.1.d.(2):

- Streets, roads, highways, and freeways. This category includes any paved surface that is 5,000 square feet or greater used for the transportation of automobiles, trucks, motorcycles, and other vehicles.
- Roadway redevelopment projects that create, add, or replace at least 5,000 square feet of impervious surfaces. Where a roadway redevelopment project results in an increase of less than 50% of the impervious surface within the limits of the project, and the existing development was not subject to SSMP requirements, the numeric sizing criteria discussed in permit section F.1.d.(6) applies only to the addition or replacement, and not to the entire development. Where the roadway redevelopment project results in an increase of more than 50% of the impervious surface within the limits of the project, the numeric sizing criteria applies to the entire project.

Routine roadway maintenance projects that maintain the original line and grade, hydraulic capacity, original purpose of the facility, or emergency roadway maintenance activities that are required to protect public health and safety are exempt from HMP requirements. The exemption is consistent with the requirements of the 2011 Model WQMP.
Roadway projects have the option to implement a green street approach to meet compliance with the HMP. The opportunity to develop a green street project will depend upon several factors, including but not limited to the ownership of the land adjacent to the right-of-way, the location of existing utilities, the course of the existing storm drain, and potential access opportunities. The PDP will take the following course of action for meeting the HMP Criteria for municipal roadway projects:

- The PDP will evaluate, to the maximum extent practicable (MEP), implementation of a "green streets" approach consistent with the 2008 U.S. EPA Green Streets Manual. If it is determined that due to site constraints implementation of a "green streets" approach for the municipal roadway project is infeasible, the PDP will complete a checklist identifying the constraints of why a "green streets" approach cannot be implemented. If a "green streets" approach is infeasible for the municipal roadway project, the PDP shall implement a "green street" project elsewhere in the same hydrologic unit. This alternative "green street" project shall mitigate an equivalent or greater tributary area than that of the proposed municipal roadway project.
- Alternatively, the PDP may pursue either an off-site mitigation project or an in-stream restoration project detailed in Step B in **Section 4.4.1**.
- The flow chart in **Figure 4-11** shows the four scenarios that shall apply to each proposed roadway project.

Figure 4-11: Hydromodification Controls: Roadway-Specific Projects



4.6 Hydrologic Management Measures

PDPs are encouraged to use the full suite of hydrologic management measures available to meet the HMP criteria identified in **Section 4.1**. The intent of the HMP is not to specify the types of hydrologic control measures that can be used but rather identify the criteria that must be met allowing flexibility for PDPs to use the full suite of management measures to meet the HMP criteria. Section 5 of the Technical Guidance Document provides information on hydromodification control design. Section 5.5 includes Hydromodification Control BMPs, which specifies the type of BMPs that can be used to meet hydromodification standards. The South Orange County Hydrology Model includes BMPs that can be used to meet the HMP criteria and has been developed as the primary tool to select and size the appropriate hydrologic site design and BMP controls to meet the HMP criteria. The model also incorporates buffer zones as a management measure for those PDPs adjacent to stream channels.

4.6.1 Selection and Design of Hydrologic Management Measures

Selection and design of hydrologic management measures is an iterative process that can be facilitated using the South Orange County Hydrology Model (SOCHM). The SOCHM has a comprehensive menu of hydrologic site design measures and hydrologic management measures that can be selected for implementation for PDPs. The design parameters for these hydrologic measures have been incorporated into the model and can be modified to an extent based on site constraints.

4.6.2 Inspection and Maintenance of Hydrologic Management Measures

Maintenance for hydrologic control measures is critical to ensure there optimal operation. PDPs are conditioned to provide verification of inspections and maintenance operations as defined in Section 7.II-4.0 of the approved 2011 Model WQMP. The list of such inspections and maintenance operations shall be included in the WQMP submitted by the applicant. Maintenance activities shall ensure that the systems are properly controlling flow rates and durations to ensure the HMP criteria is being met and inspections shall document the maintenance activities performed and that the hydrologic control measure is functioning properly

5.0 Hydromodification Sediment and Bioassessment Standards

5.1 Sediment Supply Management

Sediment supply plays a role in the stability of alluvial stream channels. A change in coarse (bed material) sediment supply will cause instability in the channel manifested through general scour or aggradation. Lateral bank migration may also result from changes in sediment supply as the channel slope increases or decreases.

The delivery of bed material during construction may increase as land surface is cleared and the potential for erosion is increased. Once the land surface is urbanized, runoff may be discharged through closed conduits and lined channels. The potential for bed material transport may be reduced as compared to the pre-development condition. The purpose of this portion of the HMP is to maintain the pre-development delivery of bed material to receiving streams following urbanization. Bed material is defined as the sediment that comprises the bed and banks of the receiving stream. Bed material load is the material transported by the stream during runoff events. It is comprised partly of the bed load (material that moves along the bed by sliding or saltating) and partly of the suspended load, including particle size fractions in the channel bed sediments. Bed material load is a primary variable controlling stream channel morphology. Wash load is the portion of the total sediment load carried continuously in suspension by the flow, and generally consists of the finest particles. Changes in wash load are not likely to significantly affect the channel stability, and reductions in wash load are generally assumed to improve habitat function.

The resiliency of receiving channels to forestall changes in the watershed due to urbanization varies with the magnitude of the change and characteristics of the channel (bed and bank material, vegetation, channel cross section and slope). It is difficult to quantitatively predict the response in a receiving channel to changes in the fundamental variables described by Lane (1955) of discharge, bed material grain size, channel slope and sediment supply. Accordingly, the most effective approach to ensuring channel stability may be to avoid changes in the fundamental variables (Lane’s relationship) during urbanization through the implementation of stream channel management guidelines. In the case of bed material sediment supply, this will be accomplished by avoiding development in areas that are a significant contributor of bed material load to the receiving channel.

The general approach to ensure maintenance of the pre-project sediment supply is a three-step process:

1. Determine whether the site is a significant source of bed material to the receiving stream.
2. Avoid significant bed material supply areas in the site design.
3. Replace significant bed material supply areas that are eliminated through urbanization.

An alternative compliance option allows the project applicant to model the site conditions and the receiving stream and provide additional mitigation in site runoff to compensate for the reduction (or addition) of bed material. This option may only be used if the general approach outlined above is deemed infeasible by the permitting authority, or if the project site design requires significant alteration of on-site streams.

5.1.1 Methodology

The project applicant must determine the location of the downstream alluvial receiving water that may be impacted by the project. Only the first downstream conveyance that is unlined (invert, side slopes or both) will be considered and will serve as the "assessment" or "receiving" stream for the project. The following methodology will be used to ensure that the project does not adversely impact bed material load to the assessment stream.

Step 1

A triad approach will be completed to determine whether the site is a significant source of bed material to the receiving stream and includes the following components:

1. Site soil assessment, including an analysis and comparison of the bed material in the receiving stream and the onsite streams;
2. Determination of the capability of the onsite streams to deliver the site bed material (if present) to the receiving stream; and
3. Present and potential future condition of the receiving stream.

A geotechnical and sieve analysis is the first piece of information to be used in a triad approach to determine of the site is a significant source of bed material load to the assessment stream. An investigation shall be completed of the assessment stream to complete a sieve analysis of the bed material. Two samples shall be taken of the assessment stream using the "reach" approach (TS13A, 2007). Samples in each of the two locations should be taken using the surface and subsurface bulk sample technique (TS13A, 2007) a total of for four samples.

A similar sampling assessment should be conducted on the project site. First-order and greater streams that will be impacted by the project (drainage area changed, stabilized, lined or replaced with underground conduits) will be analyzed in each subwatershed. One stream per subwatershed that will be impacted on the site must be assessed. A subwatershed is defined as tributary to a single discharge point at the project property boundary.

The sieve analysis should report the coarsest 90 percent (by weight) of the material for comparison between the site and the assessment stream. The Geotechnical Engineer shall render an opinion if the material found on the site is of similar gradation to the material found in the receiving stream. The opinion will be based on the following information:

- Sieve analysis results
- Soil erodibility (K) factor
- Topographic relief of the project area
- Lithology of the soils on the project site

The Geotechnical Engineer shall rate the site as having either a high, medium or low probability of supplying bed material load to the receiving stream. This site soil assessment serves as the first piece of information for the triad approach.

The second piece of information is to qualitatively assess the sediment delivery potential of the site streams to deliver the bed material load to the receiving stream, or the bed material sediment delivery potential or ratio. There is no documented procedure to estimate the sediment delivery ratio; it is affected by a number of factors, including the sediment source, proximity to the receiving stream, on-site channel density, project watershed area, slope, length, land use and land cover, and rainfall intensity. The Engineer will qualitatively assess the bed material sediment delivery potential and rate the potential as high, medium or low potential. The final piece of information is the present and potential future condition of the receiving stream. The Engineer shall assess the receiving stream for the following:

- Bank stability. Receiving streams with unstable banks may be more sensitive to changes in bed material load.
- Degree of incision. Receiving streams with moderate to high incision may be more sensitive to changes in bed material load.
- Bed material gradation. Receiving streams with more coarse bed material (such as gravel) are better able to buffer change in bed material load as compared to beds with finer gradation of bed material (sand).
- Transport vs. supply limited streams. Receiving streams that are transport limited may be better able to buffer changes in bed material load as compared to streams that are supply limited.

The Engineer will qualitatively assess the receiving stream using the metrics noted and rate the potential for adverse response based on a change in bed material load as high, medium or low. The Engineer shall use a triad assessment approach, weighting each of the components based on professional judgment to determine if the project site provides a significant source of bed material load to the receiving stream, and the impact the project would have on the receiving stream. The final assessment and recommendation shall be documented in the HMP portion of the WQTR.

The recommendation may be any of the following:

- Site a significant source of sediment bed material – all on-site streams must be preserved.
- Site a source of sediment bed material – some of the on-site streams must be preserved (with identified streams noted).
- Site is not a significant source of sediment bed material.

The final recommendation will be guided by the triad assessment. Projects with predominantly "high" values for each of the three assessment areas would indicate preservation of on-site streams. Sites with predominantly "medium" values may warrant preservation of some of the on-site streams, and sites with generally "low" values would not require site design considerations for bed material.

The Engineer shall also assess if the receiving stream has been altered either for alignment, cross section, or longitudinal grade, or has degraded to the extent that an in-stream restoration project would be required to restore the functions and values of the stream bed. In such cases, the Engineer should discuss options for participating in an in-stream project in lieu of on-site design features to preserve bed material load.

Provision for waiver of sediment assessment. If any of the following are present, the site shall not be required to consider sediment component as a part of the HMP mitigation.

1. The site was previously developed and is being redeveloped.

2. There was no stormwater discharge from the site to a receiving water for the range of flows associated with the HMP.
3. The site discharges directly to a bay, estuary, reservoir, lake or the ocean, or through hardened and maintained channels to any of these receiving waters.

Step 2

If the analysis in Step 1 indicates that some or all of the site stream courses must be preserved as a contributor of bed material load to the receiving stream, the site plan shall be developed to avoid impacting the identified streams. The Engineer will designate streams onsite that should be avoided to preserve the discharge of bed material load from the site. The Engineer may consider the factors discussed above when determining whether a specific on-site stream course is a significant contributor of bed material load and should be preserved.

Step 3

If it is infeasible to avoid on-site streams that contribute significant bed material load in the design of the site plan, the drainage(s) may be moved and replicated elsewhere on the site, provided the Engineer will certify that the relocated drainage course has a similar potential to generate bed material load. The Geotechnical Engineer will also certify that the revised drainage location is in substantially similar material as the natural stream location.

5.1.2 Alternative Compliance Methodology

Applicants may propose an alternative compliance methodology for bed material load mitigation from a project based on numerical modeling. The Engineer may propose adjusting the flow duration curve to maintain pre-project conditions in the receiving channel with the expected change in bed material load discharge from the site. This option may not be practical when the changes in bed material supply from the project are relatively small, due to limitations in the accuracy of modeling. The Engineer shall determine, using best professional judgment, if the alternative modeling approach is applicable.
The alternative modeling approach shall include the following:

1. Continuous hydrologic simulation for the project baseline condition and proposed condition over the range of flow values up to the pre-project 10-year event.
2. Sediment transport model of the receiving stream for the project baseline condition and proposed condition.
3. Analysis of the change in sediment bed material from the project baseline condition to the proposed condition
4. Explanation of method used to control the discharge from the project to account for changes in the delivered sediment bed material.
5. Summary report

Site specific modeling is discussed further in **Appendix D**.

5.2 Bioassessment

5.2.1 Historical hydromodification impacts and IBI scoring

Permit Section F.1.h.(1)(f) requires the identification of areas within the San Juan hydrologic unit where historical hydromodification has resulted in negative impacts to benthic macroinvertebrate communities. This section of the HMP was developed to address permit Section F.1.h.(1)(f). The upper part of the San Juan hydrologic unit (HU 901) is located in Orange County. A Surface Water Ambient Monitoring Program (SWAMP) was prepared in July 2007 for this portion of the hydrologic unit by the Southern California Coastal Water Research Project (SCCWRP, 2007). Findings of the 2007 SWAMP report indirectly identify such areas that are associated with the negative impact to benthic macroinvertebrate and benthic periphyton. These areas are characterized by low (poor) or very low (very poor) Index of Biotic Integrity (IBI) scores. This reporting effort was completed under the supervision of the SDRWQCB. SWAMP monitoring efforts are conducted every five years.

The bioassessment analysis included monitoring data from the following historical monitoring programs:

- California Department of Fish and Game (1998-2000)
- Orange County NPDES (2002-2006)
- Camp Pendleton (2004-2005)

The Southern California IBI is computed as a composite of seven metrics summed and scaled from 0 to 100, as follows:

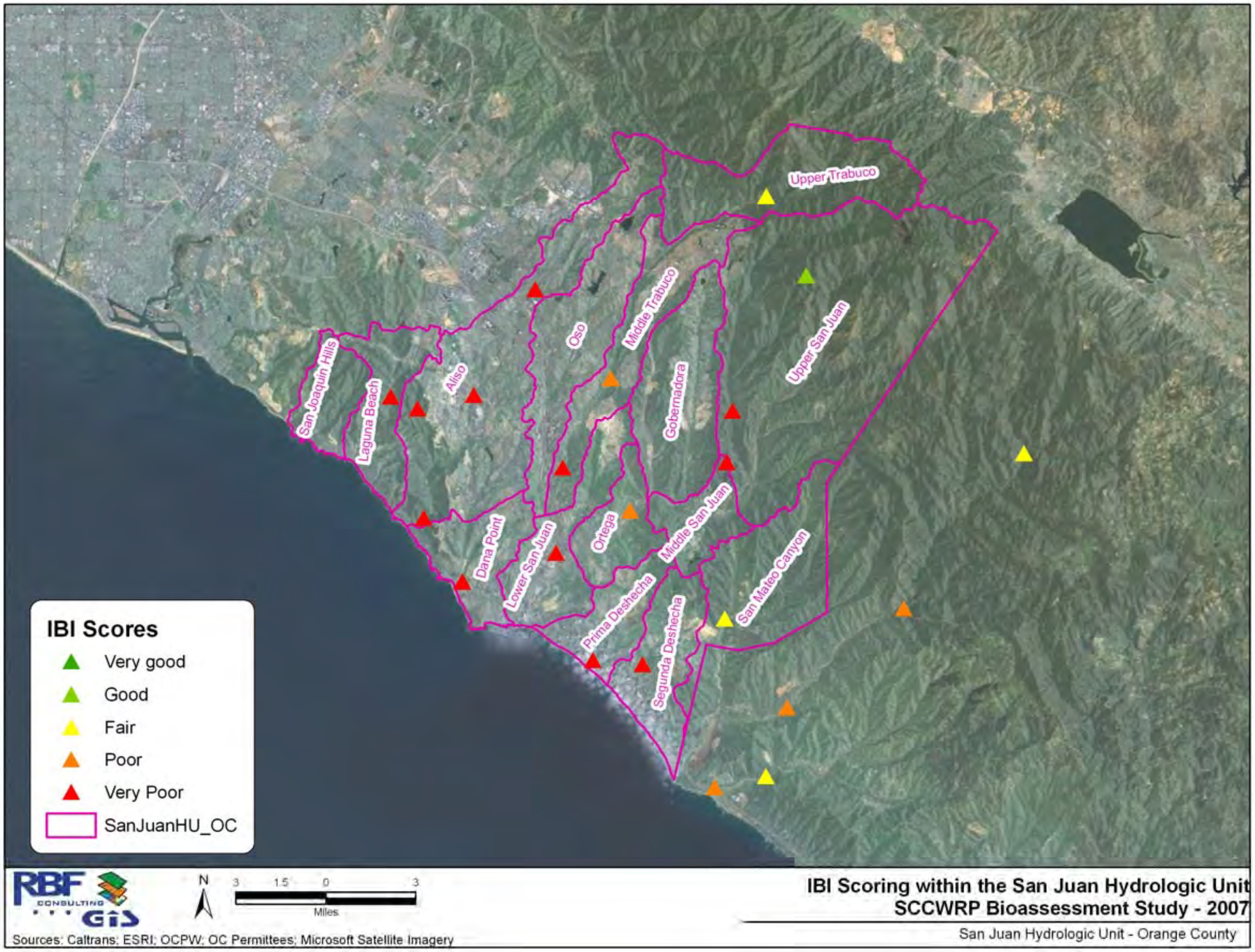
- 0–19 (very poor condition)
- 20–39 (poor condition)
- 40–59 (fair condition)
- 60–79 (good condition)
- 80–100 (very good condition)

Seventeen monitoring stations are located within the Orange County boundaries. **Figure 5-1** shows the location of these stations, as well as their associated IBI scoring category. Associated IBI scores were derived from the statistical analysis of monitoring data that was collected over several seasons (winter, spring, summer, and fall) and different hydrologic conditions.

The SWAMP study considers three monitoring locations as unimpacted by anthropogenic development in the hydrologic unit. They are characterized as reference monitoring locations. The three reference stations and their associated IBI scores are

- Bell Creek (64)
- Cold Spring Creek (34)
- Arroyo Trabuco Creek (68)

Figure 5-1: IBI Scoring within the San Juan Hydrologic Unit



Overall, benthic macroinvertebrate communities may have been impacted by hydromodification in several coastal and foothill subwatersheds that exhibit very poor IBI scores. These include the following subwatersheds: Laguna Beach, Aliso Creek, Dana Point, Lower San Juan, Prima Deshecha, Segunda Deshecha, Middle San Juan subwatersheds, as well as the lower portion of the Middle Trabuco subwatershed. Similarly, benthic macroinvertebrate communities may have been impacted to a lesser level in the Middle Trabuco and Ortega subwatersheds. One of the reference monitoring stations, Cold Creek, exhibits poor IBI scores. Conversely, benthic macroinvertebrate communities of the following subwatersheds may have been not impacted by hydromodification: San Mateo Canyon, Upper Trabuco, and Upper San Juan. Developments in these subwatersheds are limited.

No monitoring stations are available in the Gobernadora, Oso, and San Joaquin Hills subwatersheds. Impacts of hydromodification on IBI scores were not extrapolated to these subwatersheds because of the geographic variability of environmental conditions.

5.2.2 Assessment of watercourses

Hydromodification impacts from development projects and/or maintenance activities may have led to the impairment of state and federal waters and wetlands. U.S. EPA reports three major types of hydromodification activities: channelization and channel modification, dams, and streambank and shoreline erosion (U.S. EPA, 2007). Studies suggest a link between the value of physical habitat/structure and IBI values. Waterbodies that are impacted by hydromodification may have lower IBI scores due to direct and indirect impacts of upstream development.

Accelerated impacts occur to natural or earthen drainages from projects that increase in runoff flow rates and duration. Such impacts to aquatic species may include changes in flow, increased sedimentation, higher water temperatures, lower dissolved oxygen, degradation of biotic structure and decreased water quality (U.S. EPA 2007). Once these environmental stressors are present, subsequent direct and indirect impacts occur, especially to aquatic life. For example, increased sediment loading can decrease fish spawning and reduce macro-invertebrate communities. Hydromodification generally increases the transport of sediment and associated constituents (nitrates, sulfates, metals, turbidity), which impacts water quality to the point where aquatic life thresholds may be exceeded (SCCWRP 2007). Studies suggest a link between the value of physical habitat/structure and IBI values. Waterbodies that are impacted by hydromodification would be expected to have lower IBI scores from direct and indirect impacts of upstream development. It should be noted, however, that low IBI scores may be caused by natural variability.

The second aspect to consider is the reduction of wash load, which is generally viewed as favorable to benthic health. "Natural" discharge of course material (bed material) is beneficial, but colloidal material, clay, and silt are unfavorable. Stabilization of the watershed, particularly of areas generating turbidity in runoff, is the goal. The reduction of wash load during construction activities may be accomplished with the implementation of the requirements of the Construction General Permit.

The impacts of potential hydrograph changes will be assessed through the SWAMP monitoring program, as presented in **Section 6**. In addition, records of channel morphology will be taken at selected monitoring locations.

6.0 HMP and Bioassessment Monitoring & Effectiveness

The following section defines the monitoring approach and the performance protocol that will be implemented to verify the effectiveness of the South Orange County HMP. The section presents technical concepts and defines approaches to monitor the effectiveness of the HMP as required by provisions F.1.h. (1)(g) and F.1.h. (1)(l) of Regional Board Order No. R9-2009-0002. Section F.1.h.(1)(g) requires the definition of a protocol to evaluate the potential hydrograph change impacts to downstream watercourses from PDPs. The protocol must include the use of IBI scores. Section F.1.h.(1)(l) also requires a description of pre- and post- project monitoring and other program evaluation, including IBI score, to assess the effectiveness of the HMP. The defined performance protocol addresses the requirements of provisions F.1.h.(1)(k), including a description of inspections and maintenance of hydrologic controls and sediment supply management measures, as well as a protocol to address potential hydromodification impacts.

6.1 Technical Concepts

6.1.1 HMP Monitoring Measures

Stream Benthic Community

A stream benthic community is a metric for assessing the condition of a stream. Biological communities represent the health of a portion of the benthic stream community. This is explained by the fact that biological organisms, especially benthic macroinvertebrate and periphyton communities, integrate exposure over time and respond to cumulative stressors (SCCWRP, 2011). The IBI integrates several populations of organisms, and as such the combination of organisms offers a differential sensitivity to stressors, allowing for early detection of potential degradation (SCCWRP, 2011). Bioassessment may only be conducted from May to July and only if water is present; however, samples that are collected late spring may provide the most representative results, as vegetation cover and flow conditions are usually optimal. This is particularly true for non-perennial streams of the San Juan Hydrologic Unit. Seasonal variability in benthic communities is typical for non-perennial streams; however, the current IBI has almost exclusively been calibrated for perennial streams (SCCWRP, 2011). SCCWRP is in the process of developing a Benthic Macroinvertebrate Index (BMI) that would account for the typical seasonal variability of non-perennial streams.

Channel incision and widening

The most obvious way to assess changes due to scour or deposition is to physically measure the pre-project and post-project cross sections, and determine if the channel is incising and/or widening over time. This is accomplished by conducting geomorphic assessments and channel surveys downstream of a planned development before and after construction. In addition to physical measurements, comparison of current and historical photos, aerial photography, and site inspection for signs of channel degradation can provide important supporting evidence.

6.1.2 Temporal and Spatial Variability of Monitoring Locations

Temporal variability

The single most important factor affecting the temporal variability inherent to measuring stream degradation is variable inter-annual rainfall frequency and intensity. Droughts in California can last years, with little to no rainfall occurring in Southern California. During El Niño years, anomalously high storm frequencies and intensities can result in sudden geomorphic changes. Rainfall intensity also varies intra-annually. Accordingly, the value of the monitoring program will be derived only over the long-term. Significant trends will likely require many years to identify. IBI scores may be a correlating variable to geomorphic changes in streams.. However, the method used to compute the index is specifically for perennial streams, and does not account for the typical seasonal variability associated with non-perennial streams, as it exists in the San Juan Hydrologic Unit.

Spatial variability

Sampling a representative set of streams is important to capture the range of watershed conditions and biological organisms present in the permit coverage area. Other important factors that affect stream responses to hydromodification include channel grade, watershed area, vegetated cover, and stream sinuosity. In addition to channel and watershed features, location within the watershed is an important consideration. Monitoring stations should be located in the watershed headwaters just downstream of a development project of sufficient size, so that hydromodification effects from the proposed development can be isolated for comparison purposes to the maximum extent practicable. Upper watershed sites provide more definitive measures of HMP effectiveness because they can more directly correlate effects to specific development projects.

Middle watershed and lower watershed sites would be influenced by confounding variables (such as mass wasting and impacts from natural tributary confluences and other existing development projects), including phased developments over many years, in the watershed. Therefore, middle and lower watershed monitoring sites would require much more time to assess overall program effectiveness, if achievable.
The concept of providing hydromodification effectiveness measurements in the watershed headwaters is supported by SCCWRP. Research by SCCWRP has shown that hydromodification effects of a development project become muted with increasing distance from the development site (defined by SCCWRP as the Domain of Effect). To the extent practicable, monitoring locations detailed in this plan will be distributed throughout the San Juan Hydrologic Unit to provide for geographic and climatic variability across south Orange County.

6.2 Approaches Selected to Assess HMP Effectiveness

The HMP Effectiveness Plan extends for a period of five years. However, interim data may be provided to the Regional Board on an annual basis. A period of five years is necessary to implement the monitoring stations, analyze the data, and account for spatial and temporal variability of the conditions in South Orange County.

An examination of benthic macroinvertebrate organisms will be conducted to assess both biological and geomorphologic health of the streams. Additionally, channel assessment cross sections at selected locations, coincident with the IBI sampling locations, will be selected. South Orange County Permittees seek cost-effective methods to implement the HMP Effectiveness Plan. Stream bioassessment for the purpose of HMP effectiveness should be coupled with the Urban Stream Bioassessment and be reported annually in the Orange County Unified Program Effectiveness Assessment (PEA) (OCDP, 2010). Several bioassessment monitoring sites already exist for both the SWAMP, which is developed on a five-year cycle, and the annual PEA. At each of these existing sites, historical bioassessment data is readily available for the establishment of pre-project conditions. Several reference monitoring sites are also readily available including, but not limited to, three urban bioassessment sites. The ultimate selection of bioassessment sites should consider integrating one or several of these existing sites if consistent with the objectives of the HMP Effectiveness Plan.

Considering the constraints and technical approach detailed above, the following approaches are recommended for HMP monitoring.

Evaluate the HMP effectiveness by monitoring benthic macroinvertebrate communities. Biological organisms provide essential information to the overall health of a stream. The evolution of benthic macroinvertebrate communities may be the precursor to an impacted or improved stream. Benthic communities should be monitored once a year, preferably in late spring, at defined monitoring stations. Bioassessment should be done by computing the IBI score and comparing it to historical levels in the same stream. Ultimately, the Benthic Macroinvertebrate Index (BMI) could be used once it has been developed by SCCWRP, however at this time there is no estimated date as far as completion.

Complete a stream channel survey at each of the selected channel sections on an annual basis. The stream channel survey consists of collecting topographic and bathymetric measurements along each cross-section to characterize morphology and longitudinal slope of the stream segment. Four parameters will be surveyed: the floodprone width, the bankfull width, the bankfull depth, and the longitudinal slope. Each surveyed stream segment will be subsequently classified per the simplified Rosgen system of channel classification (Rosgen, 1996). **Figure 6-1** shows the different types of channels per Rosgen channel classification (Rosgen, 1996).

Figure 6-1: Simplified Rosgen Channel Classification

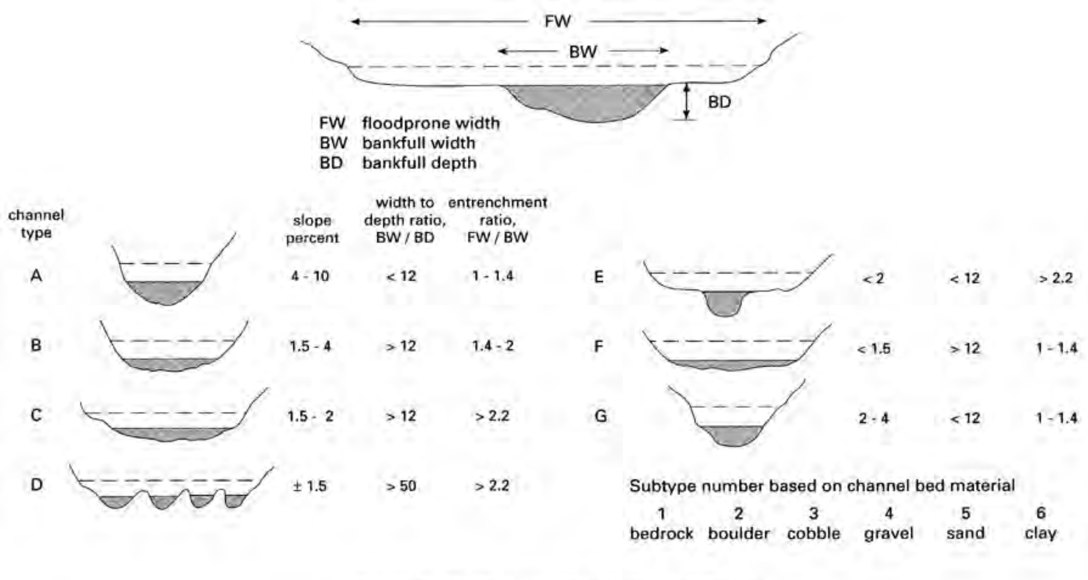
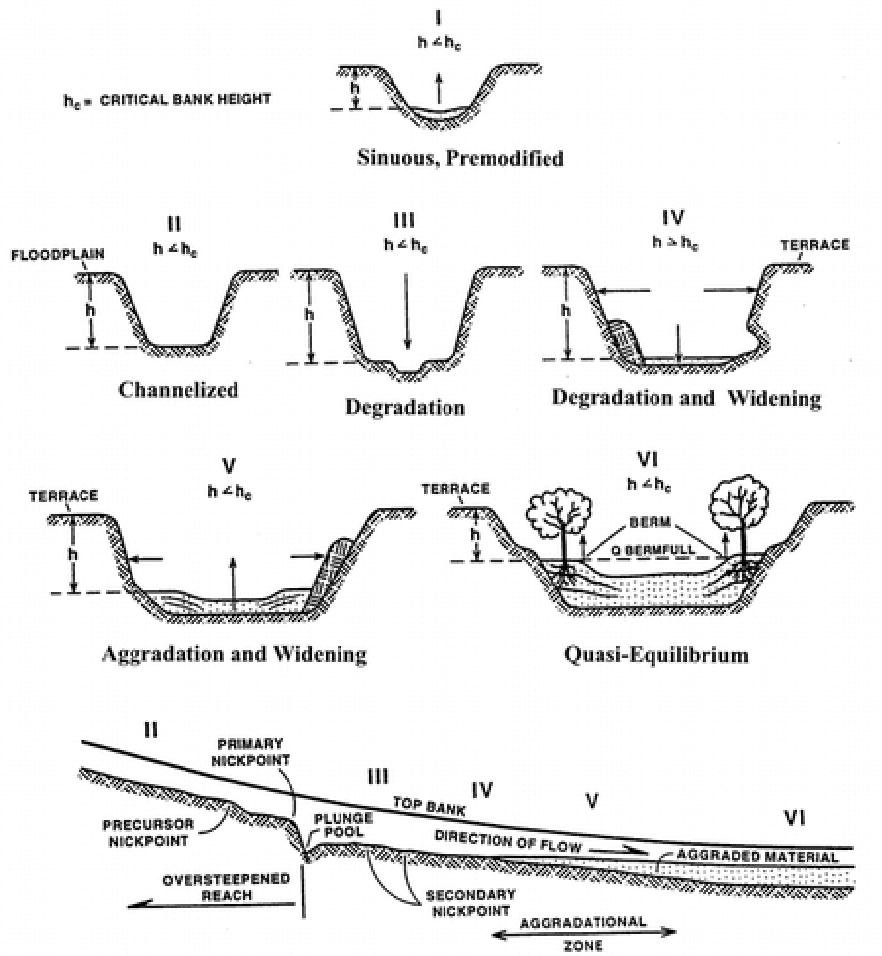


Figure 1.12 The Rosgen system of channel classification.

(Rosgen, 1996)

The temporal evolution in geomorphology, if any, of the surveyed stream segment will be compared to the six-stage Channel Evolution Model defined by Simon, as well as the previous year cross section data, to correlate any potential impacts of urbanization to this change of stream channel geomorphology (Simon et al., 1992). The geomorphologic evolution of a stream segment, if any, will also be compared to the annual bioassessment to determine if the observed aggradation or degradation is associated with changes in the benthic macroinvertebrate communities. **Figure 6-2** illustrates the six-stage sequence of incised channel evolution (Simon et al., 1992). A stream segment will be considered stable over time if features of the stream segment (such as dimension, pattern, and profile) are maintained, and the stream system neither aggrades nor degrades. The channel classification procedure is described in more detail in **Appendix B**.

Figure 6-2: Six-Stage Channel Evolution Model



(Simon et al, 1992)

Monitoring in the upper watershed

Upper watershed monitoring (channel surveys) is recommended to eliminate confounding lower watershed variables that would skew the analysis and minimize the potential for reaching meaningful conclusions.

Monitor three representative locations and one reference station

Providing three geographically representative stations would be sufficient to account for spatial and temporal variability of the conditions present in South Orange County. The reference monitoring station would be located in a watershed for which no upstream development (existing or future) is anticipated, preferably where historical bioassessment has been carried out. Data from the reference stations can be used to supplement pre-project condition data obtained at the representative monitoring sites, since the amount of pre-project condition data that can be obtained at such sites is dependent on the land development process. Providing three representative stations balances the need to characterize spatial variability against the cost of monitoring.

6.3 HMP Effectiveness Evaluation

The effectiveness of the HMP is to be evaluated into two main axes:

- BMP inspections and maintenance
- Performance protocol

6.3.1 BMP Inspections and Maintenance

One key component of the implementation of the HMP is to ensure hydrologic controls and sediment supply management measures perform effectively. PDPs are conditioned to verify inspections and maintenance operations as defined in Section 7.II-4.0 of the approved 2011 Model WQMP. The list of such inspections and maintenance operations shall be included in the WQMP submitted by the applicant. Maintenance activities shall ensure that the systems are properly controlling flow rates and durations to meet the requirements defined in the permit Item F.1.h.(1)(k).

6.3.2 Performance Protocol

As defined in **Section 6.2**, channel section surveys and IBI scores are to be monitored on a regular basis at representative locations in the San Juan Hydrologic Unit. If a significant degradation of a stream segment has been detected, a hydrologic analysis shall be performed. A significant degradation of the stream segment will be subjectively interpreted by the analyst as a sudden decline in the IBI, or a rapid change of the morphology of the channel (cross-section). A drastic change in IBI scores may indicate that flow conditions have consequently changed. A significant improvement of the IBI scores may validate the approach taken in this HMP.

The hydrologic analysis, if required, shall determine if the significant degradation of the stream segment is associated to geomorphically significant flows (10% of the 2-year storm event to the 10-year storm event). A significant difference between the expected and the observed flow duration curves for the identified flow range would automatically trigger a performance protocol. The objective of the performance protocol is to correct any performance deficiencies in the existing hydrologic controls and sediment supply management measures. If the stream degradation was caused by flows outside the critical range (a relatively rare storm event), the extensive hydrologic analysis may terminate and no further investigation is needed.

The performance protocol consists of investigating the tributary area of the impacted stream segment to identify the potential source(s). Hydrologic controls and sediment supply management measures of one or several PDPs will be examined to determine if they are under-performing due to a lack of maintenance or poor design. In this case, the lack of performance may appear to be directly responsible for the drastic change in stream conditions (IBI score, morphology). Rehabilitation of the stream segment may be required. It is expected that initial conclusions regarding the effectiveness of the HMP will be drawn after a minimum of five years of observations.

6.4 Summary and Conclusions

The HMP Effectiveness Plan, scheduled for initial implementation over a five-year period, will include the following specific activities:

Baseline Monitoring Plan Requirements:

- Development of QAPP (to be provided to Regional Board staff for review and comment)
- Bioassessment monitoring station analysis and installation
- Annual data analysis (2013–2017)
- Mid-term evaluation of the HMP Effectiveness after review of initial findings (interim report to be submitted in 2015)
- Report preparation (final report to be prepared in 2017)

Monitoring stations:

- Four monitoring locations – three representative stations monitoring exclusively areas in development located in the upper part of the San Juan Hydrologic Unit, and one reference station.
- Bioassessment conducted once a year

Bioassessment

- Annual sampling, preferably during spring season – similar to annual PEA and SWAMP (2012–2017)

Channel Assessments:

- Initial geomorphic assessment at each monitoring location (2012-2013)
- Baseline cross section surveys at each monitoring location (2012-2013)
- Annual geomorphic assessments and cross-section survey at each monitoring location to assess channel condition and response (2013–2017)

7.0 HMP and Model WQMP Integration

Within 90 days after a finding of adequacy from the San Diego Regional Water Quality Control Board Executive Officer the Final South Orange County HMP requirements will be incorporated into the Model Water Quality Management Plan (Model WQMP) and the Technical Guidance Document (TGD). The HMP requirements including the HMP criteria, alternative compliance options and steps, tiered requirements, and the sediment supply management methodology and steps will be incorporated into the Section 7II-2.4.2.2 Determine Hydromodification Performance Criteria under the South County Requirements. The HMP alternative compliance and the alternative compliance for sediment supply management will also be integrated into the Section 7.II-3.0 Alternative Compliance Approaches.

Guidance regarding the hydromodification technical feasibility study will be integrated with the LID feasibility analysis as part of the TGD. This guidance will identify that the criteria for hydromodification and LID requirements are different, however the feasibility analysis for both hydromodification and LID are to be integrated into one feasibility study for the project and submitted with the Preliminary WQMP. Section 5.4, "System Design to Address HCOCs" in South Orange County of the TGD will be updated to include the requirements of the HMP. The Permittees will use the revised Model WQMP and TGD with the HMP requirements to incorporate requirements into the local approval processes via their local WQMPs and municipal ordinances. This will also be completed within 90 days after receiving a finding of adequacy from the San Diego Regional Water Quality Control Board Executive Officer.

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APPENDIX A
HSPF Pervious Land Parameters

Pervious Land Hydrology (PWATER) Parameters

The HSPF hydrology parameters of PWATER are divided into four sections, titled PARM1-4. PARM1 is a series of checks to outline any monthly variability versus constant parameter values within the simulated algorithm; whereas, PARM2 and 3 are a series of climate, geology, topography, and vegetation parameters that require numerical values to be input.

PARM2 involves the basic geometry of the overland flow, the impact of groundwater recession, potential snow impact due to forest cover and the expected infiltration and soil moisture storage. The main parameters of groundwater recession are KVARY and AGWRC. The infiltration and soil moisture storage parameters are INFILT and LZSN.

PARM3 involves the impact of climate temperature during active snow conditions, a wide range of evaporation parameters due to the variability of the onsite soil and existing vegetation and subsurface losses due to groundwater recharge or the existing geology. The main evaporation parameters are INFEXP, INFILD, BASETP, and AGWETP. The parameter for subsurface loss is DEEPFR, which accounts for one of only three major losses from the PWATER water balance (i.e., in addition to evaporation, and lateral and stream outflows).

PARM4 involves the flow and hydrograph characteristics, the expectation of rain interception due to the inherent moisture storage capacity from existing vegetation, land use and/or near surface soil conditions and evaporation due to the root zone of the soil profile. The main interception parameters are CEPSC and UZSN. The parameter for evaporation as a primary function of vegetation is LZETP.

PARM2

KVARY. Groundwater recession flow parameter used to describe non-linear groundwater recession rate (/inches) (initialize with reported values, then calibrate as needed).
KVARY is usually one of the last PWATER parameters to be adjusted; it is used when the observed groundwater recession demonstrates a seasonal variability with a faster recession (i.e., higher slope and lower AGWRC values) during wet periods, and the opposite during dry periods. Value ranges are shown in Table A-4. Values that are representative of the conditions in south Orange County have been selected for the SOCHM. Plotting daily flows with a logarithmic scale helps to elucidate the slope of the flow recession.

AGWRC. Groundwater recession rate, or ratio of current groundwater discharge to that from 24 hours earlier (when KVARY is zero) (/day) (estimate, then calibrate).

The overall watershed recession rate is a complex function of watershed conditions, including climate, topography, soils, and land use. Hydrograph separation techniques can be used to estimate the recession rate from observed daily flow data (such as plotting on a logarithmic scale).

INFILT. Index to mean soil infiltration rate (in/hr); (estimate, then calibrate).
In HSPF, INFILT is the parameter that effectively controls the overall division of the available moisture from precipitation (after interception) into surface runoff. Since INFILT is not a maximum rate nor an infiltration capacity term, its values are normally much less than published infiltration rates, percolation rates (from soil percolation tests), or permeability rates from the literature.

INFILT is primarily a function of soil characteristics, and value ranges have been related to SCS hydrologic soil groups (Donigian and Davis, 1978, p.61, variable INFIL) as follows (Table A-1):

Table A-1: SCS Hydrologic Soil Group Characteristics

SCS Hydrologic Soil Group	INFILT Estimate		Runoff Potential
	(in/hr)	(mm/hr)	
A	0.4 – 1.0	10.0 – 25.0	Low
B	0.1 – 0.4	2.5 – 10.0	Moderate
C	0.05 – 0.1	1.25 – 2.5	Moderate to High
D	0.01 – 0.05	0.25 – 1.25	High

An alternate estimation method that has not been validated is derived from the premise that the combination of infiltration and interflow in HSPF represents the infiltration commonly modeled in the literature (e.g., Viessman et al., 1989, Chapter 4). With this assumption, the value of 2.0*INFILT*INTFW should approximate the average measured soil infiltration rate at saturation, or mean permeability.

LZSN. Lower zone nominal soil moisture storage (inches).

LZSN is related to both precipitation patterns and soil characteristics in the region. Viessman, et al, 1989, provide initial estimates for LZSN in the Stanford Watershed Model (SWM-IV, predecessor model to HSPF) as one-quarter of the mean annual rainfall plus four inches for arid and semiarid regions, or one-eighth annual mean rainfall plus 4 inches for coastal, humid, or subhumid climates.

PARM3

INFEXP. Exponent that determines how much a deviation from nominal lower zone storage affects the infiltration rate (HSPF Manual, p. 60).

Variations of the Stanford approach have used a POWER variable for this parameter; various values of POWER are included in Donigian and Davis (1978, p. 58). However, the vast majority of HSPF applications have used the default value of 2.0 for this exponent.

INFILD. Ratio of maximum and mean soil infiltration capacities.

In the Stanford approach, this parameter has always been set to 2.0, so that the maximum infiltration rate is twice the mean (i.e., input) value; when HSPF was developed, the INFILD parameter was included to allow investigation of this assumption. However, there has been very little research to support using a value other than 2.0.

DEEPFR. The fraction of infiltrating water which is lost to deep aquifers (i.e., inactive groundwater), with the remaining fraction (i.e., 1-DEEPFR) assigned to active groundwater storage that contributes baseflow to the stream.

It is also used to represent any other losses that may not be measured at the flow gauge used for calibration, such as flow around or under the gauge site. Watershed areas at high elevations, or in the upland portion of the watershed, are likely to lose more water to deep groundwater (i.e., groundwater that does not discharge within the area of the watershed), than areas at lower elevations or closer to the gauge.

BASETP. ET by riparian vegetation as active groundwater enters streambed; specified as a fraction of potential ET, which is fulfilled only as outflow exists.

If significant riparian vegetation is present in the watershed then non-zero values of BASETP are typically applied. If riparian vegetation is significant, a generic BASETP value of 0.2 is typically representative of the evapotranspiration conditions in the San Juan Hydrologic Unit. This value was established in conjunction with a satisfactory annual water balance.
AGWETP. Fraction of model segment (i.e., pervious land segment) that is subject to direct evaporation from groundwater storage, e.g., wetlands or marsh areas, where the groundwater surface is at or near the land surface, or in areas with phreatophytic vegetation drawing directly from groundwater. This is represented in the model as the fraction of remaining potential ET (i.e., after base ET, interception ET, and upper zone ET are satisfied), that can be met from active groundwater storage.

A value of 0.05 has been selected for inclusion into the SOCHM. This value was adjusted and calibrated in the Aliso Creek watershed HSPF model based on adjustment of the low-flow simulation, and ultimately the annual water balance.

PARM4

CEPSC. Amount of rainfall, in inches, which is retained by vegetation, that never reaches the land surface, and is eventually evaporated (estimate, then calibrate). Typical guidance for CEPSC for selected land surfaces is provided in Donigian and Davis (1978, p. 54, variable EPXM) (**Table A-2**).

Table A-2: CEPSC for Selected Land Surfaces

Land Cover	Maximum Interception (in)
Grassland	0.10
Cropland	0.10 – 0.25
Forest Cover, light	0.15
Forest Cover, heavy	0.20

LZETP. Index to lower zone evapotranspiration (unitless).

LZETP is a coefficient to define the ET opportunity; it affects evapotranspiration from the lower zone, which represents the primary soil moisture storage and root zone of the soil profile. LZETP behaves much like a “crop coefficient” with values mostly in the range of 0.2 to 0.7; as such, it is primarily a function of vegetation. Typical and possible value ranges are shown in **Figure 4-3**, and the following ranges for different vegetation are expected for the "maximum" value during the year (**Table A-3**):

Table A-3: LZETP Value Ranges

Land Cover Type	Input Coefficient
Forest	0.6 – 0.8
Grassland 0.4	0.4 - 0.6
Row Crops 0.5	0.5 – 0.7
Barren 0.1	0.1 – 0.4
Wetlands 0.6	0.6 – 0.9

Table A-4: Typical permanent channel cross-section with benchmark locations and points of measurement – Rosgen (1996)

HSPF HYDROLOGY PARAMETERS AND VALUE RANGES

			RANGE OF VALUES					
NAME	DEFINITION	UNITS	TYPICAL		POSSIBLE		FUNCTION OF ...	COMMENT
			MIN	MAX	MIN	MAX		
PWAT - PARM2								
FOREST	Fraction forest cover	none	0.0	0.50	0.0	0.95	Forest cover	Only impact when SNOW is active
LZSN	Lower Zone Nominal Soil Moisture Storage	inches	3.0	8.0	2.0	15.0	Soils, climate	**Calibration**
INFILT	Index to Infiltration Capacity	in/hr	0.01	0.25	0.001	0.50	Soils, land use	**Calibration**, divides surface and subsurface flow
LSUR	Length of overland flow	feet	200	500	100	700	Topography	Estimate from high resolution topo maps or GIS
SLSUR	Slope of overland flow plane	ft/ft	0.01	0.15	0.001	0.30	Topography	Estimate from high resolution topo maps or GIS
KVARY	Variable groundwater recession	1/inches	0.0	3.0	0.0	5.0	Baseflow recession variation	Used when recession rate varies with GW levels
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	Baseflow recession	**Calibration**
PWAT - PARM3								
PETMAX	Temp below which ET is reduced	deg. F	35.0	45.0	32.0	48.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active
PETMIN	Temp below which ET is set to zero	deg. F	30.0	35.0	30.0	40.0	Climate, vegetation	Reduces ET near freezing, when SNOW is active
INFEXP	Exponent in infiltration equation	none	2.0	2.0	1.0	3.0	Soils variability	Usually default to 2.0
INFILD	Ratio of max/mean infiltration capacities	none	2.0	2.0	1.0	3.0	Soils variability	Usually default to 2.0
DEEPFR	Fraction of GW inflow to deep recharge	none	0.0	0.20	0.0	0.50	Geology, GW recharge	Accounts for subsurface losses
BASETP	Fraction of remaining ET from baseflow	none	0.0	0.05	0.0	0.20	Riparian vegetation	Direct ET from riparian vegetation
AGWETP	Fraction of remaining ET from active GW	none	0.0	0.05	0.0	0.20	Marsh/wetlands extent	Direct ET from shallow GW
PWAT - PARM4								
CEPSC	Interception storage capacity	inches	0.03	0.20	0.01	0.40	Vegetation type/density, land use	Monthly values usually used
UZSN	Upper zone nominal soil moisture storage	inches	0.10	1.0	0.05	2.0	Surface soil conditions, land use	Accounts for near surface retention
NSUR	Manning's n (roughness) for overland flow	none	0.15	0.35	0.05	0.50	Surface conditions, residue, etc.	Monthly values often used for croplands
INTFW	Interflow inflow parameter	none	1.0	3.0	1.0	10.0	Soils, topography, land use	**Calibration,** based on hydrograph separation
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	Soils, topography, land use	Often start with a value of 0.7, and then adjust
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	Vegetation type/density, root depth	**Calibration**

Source: U.S. EPA BASINS Technical Note 6

Model assumptions for stream reach infiltration rates were derived through calibration based on data collected within the reaches of Aliso Creek (11 stations) and Rose Creek (6 stations). In the model, infiltration rates vary by soil type. Stream infiltration was calibrated by adjusting a single infiltration value, which was varied for each soil type by factors established from literature ranges (U.S. EPA 2000) of infiltration rates specific to each soil type. The final resulting infiltration rates were 1.368 in/hr (Soil Group A), 0.698 in/hr (Soil Group B), 0.209 in/hr (Soil Group C) and 0.084 in/hr (Soil Group D). The infiltration rates for Soil Groups B, C, and D are within the infiltration range given in literature (Wanielisata et al. 1997). The result for Soil Group A is below the range given in Wanielisata et al. (1997); however, this result only represented one watershed in this TMDL study.

APPENDIX B
Stream Classification Procedure

The procedure derives from the "Stream Stability Validation" approach that is described by Rosgen (1996). Stream stability over time may be assessed by monitoring the stream channel for five factors: (1) aggradation (2) degradation (3) shifting of particle sizes of stream bed materials (4) changing the rate of lateral extension through accelerated bank erosion (5) morphological changes following the CEM (Simon et al., 1992). If any hydrological changes or disturbance occurs in the watershed, the five elements defined above are critical to analyze the channel response to the implementation of HMP mitigation measures.

One reference stream station will be used for comparison purposes and should coincide with the station selected for the bioassessment. The reference station should be located in a stream that shows the same lithology, sediment regime, and morphometric parameters as the study stream stations. Annual comparisons of channel stability will be carried out at the same time of the year, at the end of the spring season, thus maximizing the chances to monitor similar weather patterns.

Channel stability will be evaluated, on an annual basis, at selected cross-sections in the San Juan hydrologic unit. Evaluation of the vertical or bed stability will serve as the reference method to understand the geomorphological changes of a channel stream over time. Vertical or bed stability will be evaluated at each of the identified cross-sections: this field method will identify a potential aggradation or degradation, if any, of the stream. Rate, magnitude, and direction of vertical change, if any, will be quantified.

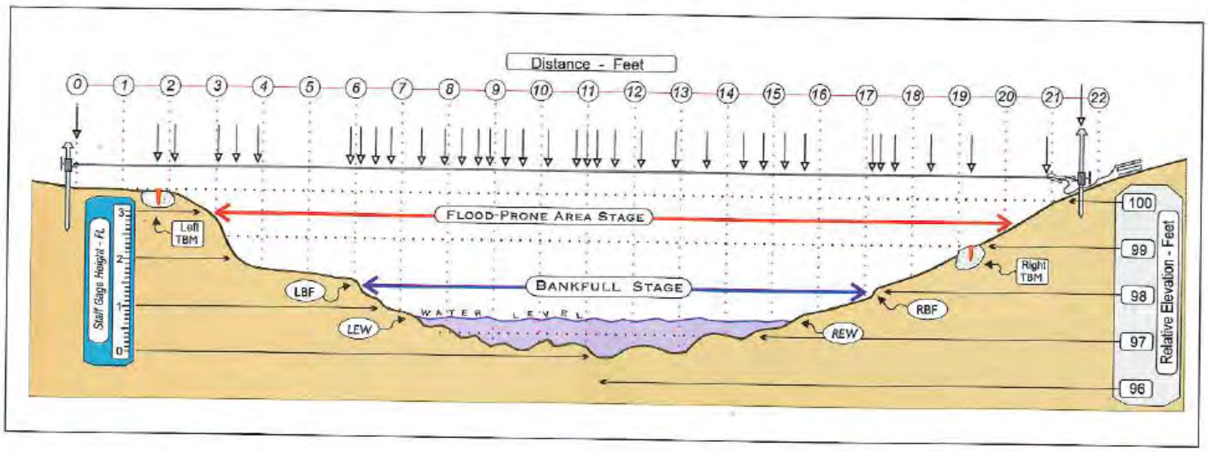
Vertical or bed stability:

Rosgen (1996) has documented a couple methods including one, known as the "Monumented cross-sections method". At each selected site, the method consists of setting permanently monumented cross-sections that are located on a riffle and pool segment (or step/pool segment), i.e., two monumented cross-sections per site. Annual measurements at the two monumented cross-sections per site will be compared to the reference elevations taken during the initial survey.

Initially, one permanent bench mark should be installed on each bank of the stream: a left temporary bench mark and a right temporary bench mark. These should be made permanent by digging a hole in which a 10-inch stove bolt will be set up by a pad of concrete. The intent is to avoid vandalism damage. These two bench marks will be located at the cross-section on a stable site above and away from the bankfull channel. Additionally, an elevation cross-section is often needed if the left or right side of the cross-section is located on an unstable slope. An elevation bench mark is established and often does not represent a true representation, but rather a relative elevation set at 100 feet.

During each cross-section survey, a leveled tape line is set above the stream channel. Measurements originate from the intercept of the rod with the leveled tape line (**Figure A-1**).

Figure A-1: Typical permanent channel cross-section with benchmark locations and points of measurement – Rosgen (1996)



Simple measurements are made with the measuring tape and elevation rod method as described by Rosgen (1996):

- Locate the permanent bench mark on both sides of the stream (or, if on one side, a bearing for the transect is needed)
- Stretch the tape very tight with spring clamp and tape level
- Locate tape at same elevation as reference bolt on bench mark
- Read distance and elevation reading of rod intercept with tape
- Measure major features, such as:
  - Left bench mark (LBM)
  - Left terrace/floodplain (LT, LFP)
  - Left bankfull (LBF)
  - Left bank (LB)
  - Left edge of water (LEW)
  - Various bed features, bars, etc.
  - Thalweg (TW)
  - Inner berm features (IB)
  - Right edge of water (REW)
  - Right bank (RB)
  - Right bankfull (RBF)
  - Right terrace/floodplain (RT, RFP)
  - Right benchmark (RBM)

Measurements must include the floodplain, terraces, and stream adjacent slopes. Other surveying procedures such as auto or laser levels and total station surveys may be adapted from the described "measuring tape and elevation rod" method. If technically feasible, any exceptional event associated with level higher than the bankfull level needs to be marked and indicated on the cross-section. The cross-section needs to be plotted for each measurement and compared to previous cross-sections to evaluate bed stability.

Finally, the longitudinal slope will be assessed based on measurements taken at two consecutive cross-sections. Rosgen (1996) also recommends developing a vicinity map and detailed site map indicating the locations of monumented cross-sections, as well as upstream and downstream photographs for site documentation. Channel dimensions for stream classification need to be correlated in order to document morphological comparisons for extrapolation.

Each stream segment being surveyed will be classified on an annual basis per the simplified Rosgen system of channel classification (Rosgen, 1996). Classification will be possible upon identification of the following parameters: floodprone width, bankfull width, bankfull depth, and longitudinal slope. **Figure A-2** shows the different types of channels per Rosgen channel classification (Rosgen, 1996).

Figure A-2: Simplified Rosgen Channel Classification (Rosgen, 1996)

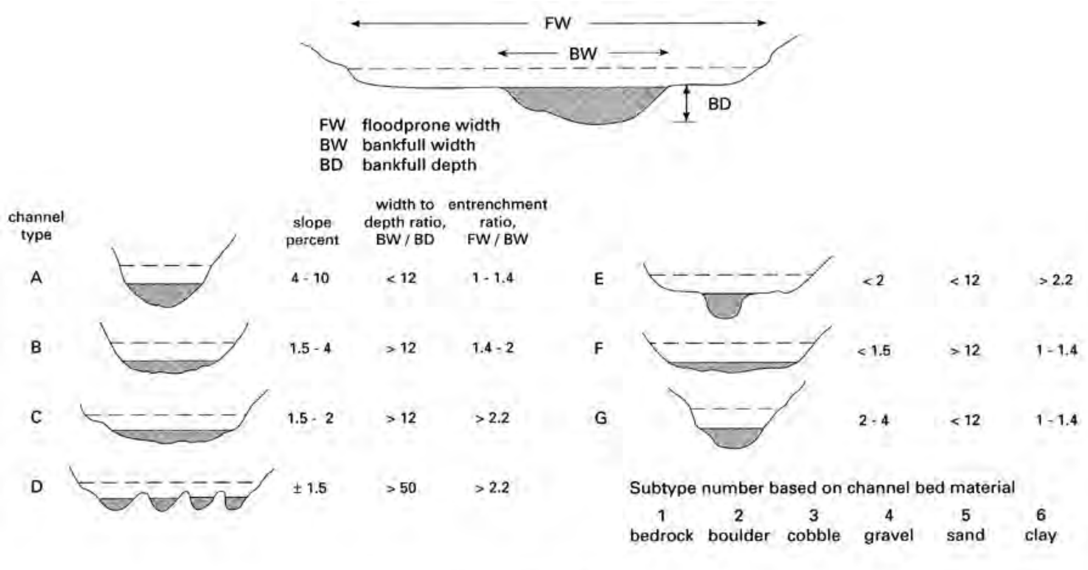


Figure 1.12 The Rosgen system of channel classification.

APPENDIX C
South Orange County Hydrology Model Instructions

To be developed upon completion of the model.

APPENDIX D
Conducting a Site-Specific Hydromodification Analysis

A project proponent may choose to develop a site specific hydromodification mitigation analysis in lieu of using the continuous simulation tool provided by the south Orange County Hydromodification Management Plan (HMP). The site specific analysis must be developed to demonstrate that the project will not adversely impact the receiving stream through either changes in the receiving stream hydrograph, or changes in bed material load supply to the stream.

The following items are not intended to be an approach to complete the analysis, rather, they are provided for information as suggestions for the engineering analysis. Each project will have unique conditions and will require a customized approach for analysis. A site specific analysis may or may not be ultimately approved by the reviewing agency. It is the responsibility of the engineer to assess the potential for an analysis to successfully demonstrate that the project is consistent with the guidelines of this HMP.

1. It is recommended that the applicant develop a study approach and outline, and review it with the local agency prior to beginning the full study.
2. The study must demonstrate that the project is consistent with the requirements of the south Orange County NPDES Permit and this HMP.
3. Site specific information to characterize bed sediment gradation, flow and rainfall data, and watershed hydrologic parameters will be required. Continuous simulation is required.
4. An objective of the study may be to determine if the loss of bed material load from the project site to the receiving stream can be partially or fully mitigated by additional mitigation of the runoff discharge from the project site.
5. Sediment transport modeling has inherent uncertainty. The agency may not approve a site specific analysis if it is apparent that the change in conditions that will be modeled are about the same magnitude as the model uncertainty.

The method of analysis, including the specific modeling program, the sediment transport function, the reach of the receiving water to be modeled, the method of determining bed material discharge in the receiving stream, the method of determining bed material discharge from the project site, the period of record for continuous simulation and other parameters are left to the discretion of the engineer. The study report should document and justify the approach, selected models and methods, data requirements, analysis method and results for review.

APPENDIX E
Practitioner Quick Start Sheet

The quick start summary lists the chronological steps that a practitioner should follow for their development project or re-development project to meet the requirements of this South Orange County Hydromodification Plan. The chronological steps are, as follows:

1. The first step consists of verifying if the project is exempt from hydromodification requirements. Exemption occurs:
   - If the project is not classified as Priority Development Project per permit item F.1.d., or,
   - If the proposed project discharges runoff directly to an exempt receiving water such as the Pacific Ocean, an exempt river reach, an exempt reservoir, or a tidally-influenced area. Or, if the proposed project discharges to an engineered conveyance system with the capacity to convey the 10-year ultimate condition that extends to the Pacific Ocean, a tidally-influenced area, an exempt river reach or reservoir (See **Section 4.3.1**), or,
   - If the project classifies as an infill development projects per the definition provided **in Section 4.3.2**, or,
   - If the project is an in-stream flood control or restoration project (See **Section 4.3.3**), or,
   - If the project discharges to a large river per the definition provided in **Section 4.3.4**

2. If the project is non-exempt, the practitioner should identify the tier requirements that apply to the proposed project. For specific tier requirements, the practitioner may refer to **Section 4.5**. These include hydrologic management controls and sediment supply management:
   a. Hydrologic management controls

The following table summarizes the different options that a practitioner may pursue to achieve hydrologic management controls. Prioritization of hydrologic controls, as well as the applicability of each type of hydrologic control are defined in this table. Onsite hydrologic controls are to be designed based on the South Orange County Hydrology Model. Alternatively, the practitioner may develop its own numerical criteria but should support his findings with continuous simulation models. Technical infeasibility of a type of hydrologic control should be documented. Specifics are provided in **Section 4.5**.

Type of hydrologic control	Onsite	Regional	Offsite (mitigation or instream restoration)	Mitigation bank (if available)	Green Street Project or equivalent
Large (>100 ac)	Yes	Yes	n/a	n/a	n/a
Medium (1 ac ≤A≤100 ac)	Yes - #1	n/a	Yes - #2a	Yes - #2b	n/a
Small (<1 ac)	Yes - #1	n/a	Yes - #2a	Yes - #2b	n/a

Type of hydrologic control	Onsite	Regional	Offsite (mitigation or instream restoration)	Mitigation bank (if available)	Green Street Project or equivalent
Public roadway	n/a	n/a	Yes	n/a	Yes

b. Sediment supply management

The practitioner may follow a three-step process to ensure maintenance of the pre-project sediment supply to the stream:

1. Determine whether the site is a significant source of bed material to the receiving stream.
2. Avoid significant bed material supply areas in the site design.
3. Replace significant bed material supply areas that are eliminated through urbanization.

If the three-step process is deemed infeasible, an alternative compliance option allows the project applicant to model the site conditions and the receiving stream and provide additional mitigation in site runoff to compensate for the reduction (or addition) of bed material. Specifics are detailed in **Section 5.1**.

3. The practitioner shall integrate hydrologic management controls and sediment supply management into the project site design, and define the design specifics in the preliminary WQMP that should be submitted to the jurisdiction. The jurisdiction may approve the proposed design upon identification of compliance with the requirements of this HMP.

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CONTRA COSTA
CLEAN WATER
PROGRAM

Municipal
Regional Permit
Edition

STORMWATER C.3 GUIDEBOOK

Stormwater Quality Requirements for Development Applications

Fifth Edition
October 20, 2010
Visit www.cccleanwater.org for updates.

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Stormwater C.3 Guidebook

Contra Costa Clean Water Program
Tom Dalziel, Interim Program Manager
925-313-2392
tdalz@pw.cccounty.us

This Guidebook is referenced in stormwater ordinances adopted by

Antioch
Phil Hoffmeister
925-779-7035
phoffmeister@ci.antioch.ca.us

Brentwood
Jagtar Dhaliwal
925-516-5128
jdhaliwal@ci.brentwood.ca.us

Clayton
Laura Hoffmeister
925-673-7308
lhoffmeister@ci.clayton.ca.us

Concord
Libbey Bell
925-671-3394
libbey.bell@ci.concord.ca.us

Danville
Chris McCann
925-314-3342
cmccann@ci.danville.ca.us

El Cerrito
Garth Schultz
510-215-4351
gschultz@ci.el-cerrito.ca.us

Hercules
Erwin Blancaflor
510-799-8242
eblancaflor@ci.hercules.ca.us

Lafayette
Donna Feehan
925-934-3908
defeehan@ci.lafayette.ca.us

Martinez
Alex Stroup
925-372-3519
astroup@cityofmartinez.org

Moraga
Jill Mercurio
925-888-7025
jmercurio@moraga.ca.us

Oakley
Frank Kennedy
925-932-7857
fjk@fjkennedy.com

Orinda
Cathleen Terentieff
925-253-4251
cterentieff@ci.orinda.ca.us

Pinole
Dean Allison
510-724-9010
nvoisey@ci.pinole.ca.us

Pittsburg
Jolan Longway
925-252-4803
jburke@ci.pittsburg.ca.us

Pleasant Hill
Rod Wui
925-671-5261
rwui@ci.pleasant-hill.ca.us

Richmond
Lynne Scarpa
510-307-8135
Lynne_Scarpa@ci.richmond.ca.us

San Pablo
Karineh Samkian
510-215-3037
karinehs@ci.san-pablo.ca.us

San Ramon
Steven Spedowfski
925-973-2653
spedowfski@sanramon.ca.gov

Walnut Creek
Rinta Perkins
925-256-3511
perkins@walnut-creek.org

Contra Costa County
Rich Lierly
925-313-2348
rlier@pw.cccounty.us

Contra Costa County Flood Control and Water Conservation District
Paul Detjens
925-313-2394
pdetj@pw.cccounty.us

Prepared with assistance from
Dan Cloak Environmental Consulting

Hydrograph Modification Management Plan consultants: **Philip Williams & Associates and Brown & Caldwell**

5TH EDITION — OCTOBER 20, 2010

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Stormwater Glossary

Best Management Practice (BMP)	Any procedure or device designed to minimize the quantity of pollutants that enter the storm drain system or to control stormwater flow. See Chapter Two.
C.3	Provision in the Municipal Regional Permit. Requires the Permittees to use their planning authorities to include appropriate source control, site design, and stormwater treatment measures in new development and redevelopment projects to address pollutant discharges and prevent increases in runoff flows. Updates C.3 Provisions added to a preceding permit issued by the San Francisco Bay Water Board in February 2003.
C.3 Web Page	http://www.cccleanwater.org/c3.html
California Stormwater Quality Association (CASQA)	Publisher of the California Stormwater Best Management Practices Handbooks, available at www.cabmphandbooks.com.
California BMP Method	A method for determining the required volume of stormwater treatment facilities. Described in Section 5.5.1 of the California Stormwater Best Management Practice Manual (New Development) (CASQA, 2003).
Condition of Approval (COA)	Requirements a municipality may adopt for a project in connection with a discretionary action (e.g., adoption of an EIR or negative declaration or issuance of a use permit). COAs may specify features required to be incorporated into the final plans for the project and may also specify uses, activities, and operational measures that must be observed over the life of the project.
Contra Costa Clean Water Program (CCCWP)	CCCWP is a collaboration established by an agreement among 19 Contra Costa cities and towns, Contra Costa County, and the Contra Costa County Flood and Water Conservation District. CCCWP implements common tasks and assists the member agencies to implement their local stormwater pollution prevention programs.
Design Storm	A hypothetical rainstorm defined by rainfall intensities and durations.
Detention	The practice of holding stormwater runoff in ponds, vaults, within berms, or in depressed areas and letting it discharge slowly to the storm drain system. See definitions of infiltration and retention.
Directly Connected Impervious Area	Any impervious surface which drains into a catch basin, area drain, or other conveyance structure without first allowing flow across pervious areas (e.g. lawns).
Direct Infiltration	Infiltration via methods or devices, such as dry wells or infiltration trenches, designed to bypass unsaturated surface soils and transmit runoff directly to groundwater.

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Drawdown time The time required for a stormwater detention or infiltration facility to drain and return to the dry-weather condition. For detention facilities, drawdown time is a function of basin volume and outlet orifice size. For infiltration facilities, drawdown time is a function of basin volume and infiltration rate.

Flow Control Control of runoff rates and durations as required by Provision C.3.g. of the Municipal Regional Permit.

Head In hydraulics, energy represented as a difference in elevation. In slow-flowing open systems, the difference in water surface elevation, e.g., between an inlet and outlet.

Hydrograph Runoff flow rate plotted as a function of time.

Hydrograph Modification Management Plan (HMP) A Plan implemented so that post-project runoff from projects creating or replacing an acre or more of impervious area shall not exceed estimated pre-project rates and/or durations, where increased runoff would result in increased potential for erosion or other adverse impacts to beneficial uses. The HMP is available on the CCCWP's C.3 web page. Also see definition for flow control.

Hydrologic Soil Group Classification of soils by the Natural Resources Conservation Service (NRCS) into A, B, C, and D groups according to infiltration capacity.

Impervious surface Any material that prevents or substantially reduces infiltration of water into the soil. See discussion of imperviousness in Chapter Two.

Indirect Infiltration Infiltration via facilities, such as bioretention areas, expressly designed to treat runoff and then allow infiltration to surface soils.

Infiltration Seepage of runoff through soil to mix with groundwater. See definition of retention.

Infiltration Device Any structure that is designed to infiltrate stormwater into the subsurface and, as designed, bypasses the natural groundwater protection afforded by surface or near-surface soil. See definition for direct infiltration.

Infiltration Rate Rate at which water can be added to a soil without creating runoff.

Integrated Management Practice (IMP) A facility (BMP) that provides small-scale treatment, retention, and/or detention and is integrated into site layout, landscaping and drainage design. See Low Impact Development.

Integrated Pest Management (IPM) An approach to pest management that relies on information about the life cycles of pests and their interaction with the environment. Pest control methods are applied with the most economical means and with the least possible hazard to people, property, and the environment.

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Lead Agency	The public agency that has the principal responsibility for carrying out or approving a project. (California Environmental Quality Act Guidelines §15367).
Low Impact Development (LID)	A stormwater management strategy aimed at maintaining or restoring the natural hydrologic functions of a site. LID design detains, treats, and infiltrates runoff by minimizing impervious area, using pervious pavements and green roofs, dispersing runoff to landscaped areas, and routing runoff to rain gardens, cisterns, swales, and other small-scale facilities distributed throughout a site.
Maximum Extent Practicable (MEP)	Standard, established by the 1987 amendments to the Clean Water Act, for the reduction of pollutant discharges from municipal storm drains. Also see Chapter Two.
Municipal Regional Permit	A stormwater NPDES permit and Waste Discharge Requirements issued by the San Francisco Bay Regional Water Quality Control Board to 76 cities, towns, and Flood Control Districts on October 14, 2009. Similar requirements are in an permit issued by the Central Valley Water Board to eastern Contra Costa municipalities on September 23, 2010.
Municipal Separate Storm Sewer System (MS4)	A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, diteches, manmade channels, or storm drains) as defined in 40 CFR 122.26(b)(8).
National Pollutant Discharge Elimination System (NPDES)	As part of the 1972 Clean Water Act, Congress established the NPDES permitting system to regulate the discharge of pollutants from municipal sanitary sewers and industries. The NPDES was expanded in 1987 to incorporate permits for stormwater discharges as well.
Numeric Criteria	Sizing requirements for stormwater treatment facilities established in Provision C.3.d. of the Municipal Regional Permit.
Operation and Maintenance (O&M)	Refers to requirements in the Municipal Regional Permit to inspect treatment BMPs and implement preventative and corrective maintenance in perpetuity. See Chapter Six.
Percolation Rate	The rate at which water flows through a soil.
Permeable or Pervious or Porous Pavements	Pavements for roadways, sidewalks, or plazas that are designed to infiltrate runoff, including pervious concrete, pervious asphalt, porous pavers, and granular materials. See the Design Sheet for Pervious Pavements.
Percentile Rainfall Intensity	A method of determining design rainfall intensity. Storms occurring over a long period are ranked by rainfall intensity. The storm corresponding to a given percentile yields the design rainfall intensity.
Permeability	The rate at which water flows through a saturated soil under steady state conditions.

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Pre-Project	Conditions that exist on a development site immediately before the project to which municipal approvals apply.
Proprietary Stormwater Treatment Facilities	Products designed and marketed by private businesses for treatment of stormwater. Many of these products do not meet requirements of the Municipal Regional Permit.
Rational Method	A method of calculating runoff flows based on rainfall intensity, tributary area, and a factor representing the proportion of rainfall that runs off.
Regional Water Quality Control Board (Regional Water Board or RWQCB)	California RWQCBs are responsible for implementing pollution control provisions of the Clean Water Act and California Water Code within their jurisdiction. There are nine California RWQCBs. Western and central Contra Costa County are under the jurisdiction of the RWQCB for the San Francisco Bay Region; eastern Contra Costa County is under the jurisdiction of the RWQCB for the Central Valley Region.
Self-retaining area	An area designed to retain runoff. Self-retaining areas may include graded depressions with landscaping or pervious pavements.
Self-treating area	Natural, landscaped, or turf areas that drain overland off-site or to the storm drain system.
Source Control	A facility or procedure to prevent pollutants from entering runoff.
Stormwater Control Plan	A plan specifying and documenting permanent features and facilities to control pollutants and stormwater flows for the life of the project.
Stormwater Control Operation & Maintenance Plan	A plan detailing operation and maintenance requirements for stormwater treatment and flow-control facilities incorporated into a project.
Storm Water Pollution Prevention Plan (SWPPP)	A plan providing for temporary measures to control sediment and other pollutants during construction.
Treatment	Removal of pollutants from runoff, typically by filtration or settling.
WEF Method	A method for determining the minimum design volume of stormwater treatment facilities, recommended by the Water Environment Federation and American Society of Civil Engineers. Described in *Urban Runoff Quality Management* (WEF/ASCE, 1998).
Water Board	See Regional Water Quality Control Board.
Water Quality Volume (WQV)	For stormwater treatment facilities that depend on detention to work, the volume of water that must be detained for a minimum specified drawdown time to achieve pollutant removal.

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Start

How to Use this Guidebook

Read the Overview to get a general understanding of the requirements. Then follow the step-by-step instructions to prepare your Stormwater Control Plan.

THIS *Guidebook* will help you ensure that your project complies with the C.3 requirements in the California Regional Water Quality Control Boards' Municipal Regional Permit. The requirements are complex and technical. Most applicants will require the assistance of a qualified civil engineer, architect, or landscape architect. Because every project is different, you should begin by scheduling a pre-application meeting with municipal planning staff.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

To use the *Guidebook,* start by reviewing Chapter One to find out whether and how Provision C.3 applies to your project. Chapter One also provides an overview of the entire process of planning, design, construction, operation, and maintenance leading to compliance.

If there are terms and issues you find puzzling, look for answers in the glossary or in Chapter Two. Chapter Two provides background on key stormwater concepts and water quality regulations, including design criteria.

Then proceed to Chapter Three and follow the step-by-step guidance to prepare a Stormwater Control Plan for your site. The Stormwater Control Plan is submitted with your application for entitlements and development approvals.

Chapter Four, the Low Impact Development Design Guide, includes instructions for preparing and presenting your design and calculations. The calculations must be included in your Stormwater Control Plan to show compliance with permit requirements.

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As you proceed with design and construction of your project, consult Chapter Five for guidance on preparing construction documents and overseeing construction of Low Impact Development features and facilities.

In Chapter Six you'll find a detailed description of the process for ensuring operation and maintenance of your stormwater facilities over the life of the project. The chapter includes step-by-step instructions for preparing a Stormwater Facilities Operation and Maintenance Plan.

Local Requirements

Cities, towns, or the County may have requirements that differ from, or are in addition to, this county-wide Guidebook. See Appendix A for local requirements.

Throughout each Chapter, you'll find references and resources to help you understand the regulations, complete your Stormwater Control Plan, and design stormwater control measures for your project.

The most recent version of the *Guidebook,* including updates and errata, is on the Contra Costa Clean Water Program website. The on-line *Guidebook* is in Adobe Acrobat format. If you are reading the *Guidebook* on a computer with an internet connection, you can use hyperlinks to navigate the document and to access various references. The hyperlinks are throughout the text, as well as in "References and Resources" sections (marked by the 🕮 icon) and in the Bibliography. Some of these links (URLs) may be outdated. In that case, try entering portions of the title or other keywords into a web search.

Construction-Phase Controls

Your Stormwater Control Plan is a separate document from the Storm Water Pollution Prevention Plan (SWPPP). A SWPPP provides for temporary measures to control sediment and other pollutants during construction at sites that disturb one acre or more. See the CCCWP website for information on requirements for construction-phase controls.

► PLAN AHEAD TO AVOID THE THREE MOST COMMON MISTAKES

The most common (and costly) errors made by applicants for development approvals with respect to C.3 compliance are:

1. Not planning for C.3 compliance early enough. You should think about your strategy for C.3 compliance before completing a conceptual site design or sketching a layout of subdivision lots (Chapter 3).

2. Assuming proprietary stormwater treatment facilities will be adequate for compliance. A complete Low Impact Development design, including reuse, infiltration, evapotranspiration, or bioretention facilities, is now required for nearly all projects (Chapter 2).

3. Not planning for periodic inspections and maintenance of treatment and flow-control facilities. Consider who will own and who will maintain the facilities in perpetuity and how they will obtain access, and identify which arrangements are acceptable to your municipality (Chapter 6).

Chapter

1

Policies and Procedures

Determine if your development project must comply with the Municipal Regional Permit C.3 requirements, and review the steps to compliance.

Thresholds, Effective Dates, and Requirements

Table 1-1 (on following page) summarizes requirements for development projects. Thresholds are based on impervious area created or replaced in connection with a project. Interior remodels and routine maintenance or repair such as roof or exterior surface replacement and pavement resurfacing are excluded.

The 2010-2012 effective dates refer to the date on which a planning application has received final discretionary approval. At the discretion of local municipal staff, projects with applications that are deemed complete and diligently pursued prior to these dates may not have to meet all requirements (requirements in previous *Guidebook* editions may apply).

► THE "50% RULE" FOR PROJECTS ON PREVIOUSLY DEVELOPED SITES

Projects on previously developed sites may also need to retrofit drainage to provide treatment of runoff from all impervious areas of the entire site. For sites creating or replacing a total amount of impervious area greater than the applicable threshold (Table 1-1):

- If the new project results in an alteration of more than 50% of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment measures, then the entire project must be included in the treatment measure design.

- If the new project results in an alteration of less than 50% of the impervious surface of a previously existing development, and the existing development was not subject to stormwater treatment

ICON KEY

- Helpful Tip
- Submittal Requirement
- Terms to Look Up
- References & Resources

measures, then only the new and replaced impervious surface must be included in the treatment system design.

In contrast to the 50% rule for treatment requirements, flow-control requirements use the developed condition of a previously developed site as a baseline when determining if runoff rates or durations will increase as a result of the project.

TABLE 1-1. THRESHOLDS, EFFECTIVE DATES, and Requirements summarized.*

Impervious Area Threshold	Effective Date	Requirement
All projects requiring municipal approvals or permits	May 1, 2010	As encouraged or directed by local staff, preserve or restore open space, riparian areas, and wetlands as project amenities, minimize land disturbance and impervious surfaces (especially parking lots) cluster structures and pavements, include micro-detention in landscaped and other areas, and direct runoff to vegetated areas. Use Bay-friendly landscaping features and techniques. Include Source Controls specified in Appendix D.
Projects between 2,500 and 10,000 square feet requiring approvals or permits	December 1, 2012	Install one or more of the following: Direct roof runoff into cisterns or rain barrels for reuse; direct roof runoff onto vegetated areas; direct runoff from sidewalks, walkways, and/or patios on to vegetated areas; direct runoff from driveways and/or uncovered parking lots on to vegetated areas; construct sidewalks, walkways, and/or patios with permeable surfaces; construct bike lanes, driveways, and uncovered parking lots with permeable surfaces.
Auto service facilities, gas stations, restaurants, and uncovered parking lots over 5,000 square feet	December 1, 2011	Prepare and submit a Stormwater Control Plan as described in Chapter 3, including features and facilities to ensure runoff is treated before leaving the site. Evaluate feasibility of storage for later use. Use the LID Design Guide in Chapter 4, including sizing factors and criteria for "treatment only."
All projects between 10,000 square feet and one acre†	August 15, 2006	
Projects an acre and larger†	October 14, 2006	Select one of four flow-control compliance options in Appendix C. Where required, design project features and facilities for hydrograph modification management (flow-control) as well as stormwater treatment. Prepare and submit a Stormwater Control Plan as described in Chapter 3 and use the LID Design Guide in Chapter 4, including the sizing factors and criteria for "treatment and flow control."

*Summary only. Requirements for any particular project are determined by your municipality.
†Detached single-family homes that are not part of a larger plan of development are specifically excluded. For road widening projects, count only the impervious area associated with new traffic lanes.

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Compliance Process at a Glance

For the applicant for development project approval, compliance follows these general steps:

1. Discuss C.3 requirements during a pre-application meeting with municipal staff.
2. Review the instructions in this *Guidebook* before you prepare your tentative map, preliminary site plan, drainage plan, and landscaping plan.
3. Prepare a Stormwater Control Plan and submit it with your application for development approvals (entitlements).
4. Following development approval, create your detailed project design, incorporating the features described in your Stormwater Control Plan.
5. In a table on your construction plans, list each stormwater control feature and facility and the plan sheet where it appears.
6. Prepare a draft Stormwater Facility Operation and Maintenance Plan and submit it with your application for building permits. Execute legal documents assigning responsibility for operation and maintenance of stormwater facilities. Some municipalities require legal agreements and financial commitments for operation and maintenance be recorded prior to recordation of a final parcel map.

Local Requirements

Cities, towns, or the County may have requirements that differ from, or are in addition to, this county-wide Guidebook. See Appendix A for local requirements.

7. Maintain stormwater facilities during construction and following construction in accordance with required warranties.
8. Following construction, submit a final Stormwater Facility Operation and Maintenance Plan and formally transfer responsibility for maintenance to the owner or permanent occupant.
9. The occupant or owner must periodically verify stormwater facilities are properly maintained.

Preparation of a complete and detailed Stormwater Control Plan is the key to cost-effective C.3 compliance and expeditious review of your project. Instructions for preparing a Stormwater Control Plan are in Chapter 3.

Implementing C.3 on Phased Projects

When determining whether Provision C.3 requirements apply, a "project" should be defined consistent with CEQA definitions of "project." That is, the "project" is the whole of an action which has the potential for adding or replacing or resulting in the addition or replacement of roofs, pavement, or other impervious surfaces and thereby resulting in increased flows and stormwater pollutants. "Whole of an action" means the project may not be segmented or piecemealed into small parts if the effect is to reduce the quantity of impervious area for any part to below the C.3 threshold.

Grandfathering. Municipalities may, at their discretion, exempt projects for which applications received final discretionary approval prior to the dates in Table 1-1. However, this "grandfathering" applies only to the specific discretionary approval that was the subject of the original application. Subsequent applications for further approvals constitute a "project" for the purposes of C.3. If those subsequent approvals or entitlements cover specific locations, modes, or designs for addition or replacement of roofs, pavement, or other impervious surfaces, and if the impervious area created or replaced is in excess of the applicable thresholds, then the C.3 requirements will apply to those areas of the project covered by the subsequent approval or entitlement.

CEQA
See the CCCWP's New Development web page for guidance on how to document stormwater impacts and mitigations in Initial Studies and Environmental Impact Reports.

Consider for example an application for a subdivision tentative map which receives final discretionary approval prior to the C.3 start dates. The project may be exempt from Provision C.3; however, if the project proponent later applies for discretionary approval of specific locations, modes, or designs of paving and structures, then C.3 requirements would apply to those improvements.

Applying the "50% rule." Municipal staff will determine case-by-case when and how the "50% rule" applies; in doing so staff may use the original entitlement (discretionary approval) as a guide when calculating the impervious area of the "previously existing development".

Stormwater Control Plan requirements for phased projects. Municipal staff may require, as part of an application for approval of a phased development project, a conceptual or master Stormwater Control Plan which describes and illustrates, in broad outline, how the drainage for the project will comply with the Provision C.3 requirements. The level of detail in the conceptual or master Stormwater Control Plan should be consistent with the scope and level of detail of the development approval being considered. The conceptual or master Stormwater Control Plan should

Local Requirements
Cities, towns, or the County may have requirements that differ from, or are in addition to, this countywide Guidebook. See Appendix A and check with local planning and community development staff.

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specify that a more detailed Stormwater Control Plan for each later phase or portion of the project will be submitted with subsequent applications for discretionary approvals.

Applying C.3 to New Subdivisions

If a tentative map approval would potentially entitle future owners of individual parcels to construct new or replaced impervious area which, in aggregate, could exceed the thresholds in Table 1-1, then the applicant must take steps to ensure C.3 requirements can and will be implemented as the subdivision is built out.

If the tentative map application does not include plans for site improvements, the applicant should nevertheless identify the type, size, location, and final ownership of stormwater treatment and flow-control facilities adequate to serve new roadways and any common areas, and to also manage runoff from an expected reasonable estimate of the square footage of future roofs, driveways, and other impervious surfaces on each individual lot. The municipality may condition approval of the map on implementation of stormwater treatment measures in compliance with Provision C.3 when construction occurs on the individual lots. This condition may be enforced by a grant deed of development rights or by a development agreement.

If a municipality deems it necessary, the future impervious area of one or more lots may be limited by a deed restriction. This might be necessary when a project is exempted from one or all C.3 provisions because the total impervious area is below a threshold, or to ensure runoff from impervious areas added after the project is approved does not overload a stormwater treatment and flow-control facility.

Subdivision maps should dedicate an "open space easement, as defined by Government Code Section 51075," to suitably restrict the future building of structures at each stormwater facility location.

In general, it is recommended **stormwater treatment facilities not be located on individual single-family residential lots**, particularly when those facilities manage runoff from other lots, from streets, or from common areas. However, local requirements vary. A better alternative may be to locate stormwater facilities on one or more separate, jointly owned parcels.

See the *Policy for C.3 Compliance for Subdivisions* on the Contra Costa Clean Water Program's C.3 web page.

After consulting with local planning staff, applicants for subdivision approvals will propose one of the following four options, depending on project characteristics and local policies:

1. Show the sum of future impervious areas to be created or replaced on all parcels could not exceed the applicable C.3 thresholds shown in Table 1-1.

2. Show that, for each and every lot, the intended use can be achieved with a design which disperses runoff from roofs, driveways, streets, and other impervious areas to self-retaining pervious areas, using the criteria in Chapter 4 of this *Guidebook*.

3. Prepare improvement plans showing drainage to treatment and/or flow-control facilities designed in accordance with this *Guidebook,* and commit to constructing the facilities prior to transferring the lots.

4. Prepare improvement plans showing drainage to treatment and/or flow-control facilities designed in accordance with this *Guidebook*, and provide appropriate legal instruments to ensure the proposed facilities will be constructed and maintained by subsequent owners.

For the option selected, municipal staff will determine the appropriate conditions of approval, easements, deed restrictions, or other legal instruments necessary to assure future compliance. In general, when new streets and common areas are constructed, facilities to treat runoff from those new impervious areas must be constructed concurrently, and agreements for the operation and maintenance of those facilities must be executed timely.

Compliance with Flow-Control Requirements

As shown in Table 1-1, in addition to incorporating treatment controls, projects creating or replacing an acre or more of impervious area must also provide flow control so post-project runoff does not exceed estimated pre-project rates and durations. Projects subject to flow-control requirements have four options for demonstrating compliance. The options are summarized in Table 1-2. Detailed requirements are in Appendix C.

Depending on location and existing site conditions, a project proponent may wish to consider the feasibility of these options in the following order:

- For projects on previously developed sites, it may be possible to show the project will not increase the existing quantity of impervious area and will not facilitate the efficiency of drainage collection and conveyance (Option 1).

- Depending on project location, the project proponent may be able show all downstream channels between the project site and the Bay/Delta are enclosed pipes, are engineered hardened channels, are subject to tidal action, or are aggrading (Option 4a).

- Proponents may use the LID Design Guide in Chapter 4 to meet both treatment and flow-control requirements (Option 2).

- Proponents of larger developments, particularly those with complex or extensive drainage, might consider creating a continuous hydrologic simulation model, using the criteria in Appendix C, to demonstrate that, after incorporation of flow-control measures, post-project runoff will not exceed pre-project rates or durations (Option 3).

TABLE 1-2. Options for compliance with flow-control requirements*

What must be demonstrated	*How applicants can comply*	*Stormwater Control Plan submittal requirements*
Option 1: No increase in impervious area	Compare the project design to the pre-project condition and show the project will not increase impervious area and also will not increase efficiency of drainage collection and conveyance.	Inventory and accounting of existing and proposed impervious areas, measures used to reduce imperviousness, and a qualitiative comparison of pre- and post-project drainage efficiency.
Option 2: Integrated Management Practices	Use the design procedure and design criteria in this *Guidebook*, and the Program's sizing tool, to select and size IMPs for flow control (also meets treatment requirements).	Stormwater Control Plan and sizing tool output (Chapter 3).
Option 3: Post-project runoff does not exceed pre-project rates and durations	Use a continuous-simulation model and 30 years or more of hourly rainfall data to simulate pre-project and post-project runoff, including the effect of proposed control facilities.	Model parameters and modeling techniques are specified in Appendix C.
Option 4a: All downstream reaches are at "low risk" of erosion	Show all downstream channels between the project site and the Bay/Delta are enclosed pipes, are engineered hardened channels, are subject to tidal action, or are aggrading.	Report or letter report by an engineer or qualified environmental professional documenting drainage between the project site and the Bay or Delta.
Options 4b and 4c: Erosion risks are mitigated by in-stream restoration projects	Propose and implement appropriate in-stream restoration projects to fully mitigate potential risk.	Requires additional regulatory approvals. See Appendix C.

*Summary only. Applicability to and requirements for any particular project are determined by your municipality.

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- Under Options 4b and 4c, proponents may propose and implement an appropriate in-stream restoration project to fully mitigate the potential risk of increased downstream erosion created by their proposed development.

Runoff treatment is required regardless of the flow-control compliance option chosen.

Alternative Compliance Options

In lieu of incorporating facilities to treat runoff from impervious areas at the development project site, an applicant may propose a secondary project that will treat runoff from an equivalent amount of impervious area at another location within the same watershed.

To be considered, the secondary project must include construction, operation, and maintenance of facilities meeting the criteria in Chapter 4. Those facilities must treat runoff from an amount of impervious surface equivalent to, or greater than, the impervious surface that would be subject to requirements at the project location.

An applicant may propose to combine on-site and off-site facilities to add up to the equivalent amount of impervious area as would be required for only on-site treatment. An applicant may also propose to share in a larger project and be credited for a proportional amount of the impervious area for which runoff is treated by that project.

Consideration or acceptance of such proposals is at the discretion of the local municipality.

Experience has shown implementation of LID facilities, as described in Chapter 4, is feasible on nearly all development sites with sufficient advance planning.

References and Resources:

- Appendix C—Flow Control
- CCCWP Policy for C.3 Compliance for Subdivisions
- CCCWP Web Page for Construction Activities
- CCCWP Hydrograph Modification Management Plan
- MRP Provision C.3.g. and Attachment C (Hydrograph Modification Management)
- MRP Provision C.3.e. (Alternative or In-Lieu Compliance)

Chapter 2

Concepts and Criteria

Technical background and explanations of policies and design requirements

The Regional Water Board first issued a municipal stormwater NPDES permit to Contra Costa County, its cities and towns, and the Contra Costa Flood Control and Water Conservation District in 1993. The permit mandates a comprehensive program to prevent stormwater pollution. That program now includes measures to prevent pollution from municipal facilities and operations, identification and elimination of illicit discharges to storm drains, business inspections, public outreach, construction site inspections, monitoring and studies of stream health, and control of runoff pollutants from new developments and redevelopments.

The Regional Water Board added Provision C.3 in 2003, and the permittees began implementing the provision in 2005. The Regional Water Board added hydrograph modification management (flow control) requirements in 2006.

In October 2009, the Regional Water Board included Contra Costa municipalities in its first Municipal Regional Permit (MRP). The MRP applies to 77 municipal Bay Area permittees and supersedes the countywide stormwater NPDES permits.

The MRP mandates a Low Impact Development (LID) approach similar to that developed by the CCCWP from 2003 through 2009. This chapter explains the technical background of the LID approach and how it was derived.

Water-Quality Regulations

MRP Provision C.3 requires municipalities to condition development approvals with incorporation of specified stormwater controls. The municipalities' annual report to the Regional Water Board includes a list of development projects approved during the year and the specific stormwater controls required for each project. In the annual report, the municipalities also document their program to verify stormwater treatment and flow-control facilities are being adequately

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maintained. The municipalities—not the Regional Board or its staff—are charged with ensuring development projects comply with the C.3 requirements. (Regional Water Board staff sometimes reviews stormwater controls in connection with applications for Clean Water Act Section 401 water-quality certification, which is required for projects that involve work in streams, including dredging and filling.)

In a nutshell, MRP Provision C.3 requires that applicable new developments and redevelopments:

- Design the site to minimize imperviousness, detain runoff, and infiltrate, reuse or evapotranspirate runoff where feasible
- Cover or control sources of stormwater pollutants
- Treat runoff prior to discharge from the site
- Ensure runoff does not exceed pre-project peaks and durations
- Maintain treatment and flow-control facilities

► MAXIMUM EXTENT PRACTICABLE

Clean Water Act Section 402(p)(3)(iii) sets the standard for control of stormwater pollutants as "maximum extent practicable," but doesn't define that term. As implemented, "maximum extent practicable" is ever-changing and varies with conditions.

Many stormwater controls, including LID, have proven to be practicable in most development projects. To achieve fair and effective implementation, criteria and guidance for those controls must be detailed and specific—while also offering the right amount of flexibility or exceptions for special cases. The MRP includes various standards, including hydrologic criteria, which have been found to provide "maximum extent practicable" control. CCCWP's C.3 guidance is continuously improved and refined based on the experience of municipal planners and engineers, with input from land developers and development professionals.

► BEST MANAGEMENT PRACTICES

Clean Water Act Section 402(p) and USEPA regulations (40 CFR 122.26) specify a municipal program of "management practices" to control stormwater pollutants. **Best Management Practice (BMP)** refers to any kind of procedure or device designed to minimize the quantity of pollutants that enter the **Municipal Separate Storm Sewer System** (MS4).

To minimize confusion, this guidebook refers to "facilities," "features," "controls," and Integrated Management Practices (IMPs) to be incorporated into development projects. All of these are BMPs.

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Hydrology for NPDES Compliance

► IMPERVIOUSNESS

Schueler (1995) proposed imperviousness as a "unifying theme" for the efforts of planners, engineers, landscape architects, scientists, and local officials concerned with urban watershed protection. Schueler argued (1) that imperviousness is a useful indicator linking urban land development to the degradation of aquatic ecosystems, and (2) imperviousness can be quantified, managed, and controlled during land development.

Imperviousness has long been understood as the key variable in urban hydrology. Peak runoff flow and total runoff volume from small urban catchments is usually calculated as a function of the ratio of impervious area to total area (rational method). The ratio correlates to the composite runoff factor, usually designated "C". Increased flows resulting from urban development tend to increase the frequency of small-scale flooding downstream.

Imperviousness links urban land development to degradation of aquatic ecosystems in two ways.

First, the combination of paved surfaces and piped runoff efficiently collects urban pollutants and transports them, in suspended or dissolved form, to surface waters. These pollutants may originate as airborne dust, be washed from the atmosphere during rains, or may be generated by automobiles and outdoor work activities.

Second, increased peak flows and runoff durations can cause erosion of stream banks and beds, transport of fine sediments, and disruption of aquatic habitat. Measures taken to control stream erosion, such as hardening banks with riprap or concrete, may permanently eliminate habitat. By reducing infiltration to groundwater, imperviousness may also reduce dry-weather stream flows.

Imperviousness has two major components: rooftops and transportation (including streets, highways, and parking areas). The transportation component is usually larger and is more likely to be directly connected to the storm drain system.

The effects of imperviousness can be mitigated by disconnecting impervious areas from the drainage system and by making drainage less efficient—that is, by encouraging detention and retention of runoff near the point where it is generated. Detention and retention reduce peak flows and volumes and allow pollutants to settle out or adhere to soils before they can be transported downstream.

► SIZING REQUIREMENTS FOR STORMWATER TREATMENT FACILITIES

MRP permit criteria for sizing stormwater treatment facilities and flow-control facilities are based on simulation of runoff from a long-term (30-year or more) rainfall record. This is different from the "event-based" or "design storm" hydrology typically used to size drainage and flood-control facilities.

The CCCWP's LID design guidance (Chapter 4) was crafted to ensure LID facilities comply with the NPDES permit's hydraulic sizing requirements for stormwater treatment facilities and flow-control facilities, as well as meeting the LID mandate in MRP Provision C.3.c. The technical background follows.

Most runoff is produced by frequent storms of small or moderate intensity and duration. Treatment facilities are designed to treat smaller storms and the first flush of larger storms—approximately 80% of average annual runoff.

MRP Provision C.3.d. identifies two sets of criteria for sizing stormwater treatment facilities—volume-based and flow-based.

For volume-based treatment facilities, MRP Provision C.3.d. references two alternative methods, the WEF method and the California BMP method. As described in Chapter 4, local rainfall data and the California BMP method are used for sizing detention basins in Contra Costa County. Both the WEF and California BMP methods are based on continuous simulation of runoff from a hypothetical one-acre area entering a basin designed to draw down in 48 hours. The simulation is iterated to find the unit basin size that detains about 80% of the total runoff during the simulation period. The unit basin storage size is expressed as a depth which varies from about 0.45" to 0.85" in Contra Costa County.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

For flow-based facilities, the NPDES permit specifies the rational method be used to determine flow. The rational method uses the equation

$Q = CiA$, where

Q = flow

C = weighted runoff factor between 0 and 1

i = rainfall intensity

A = area

The permit identifies three alternatives for calculating rainfall intensity:

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1. the intensity-duration-frequency method, with a hydrograph corresponding to a 50-year storm,

2. the 85th percentile rainfall intensity times two, and

3. 0.2 inches per hour.

An analysis conducted for the CCCWP determined all three methods yielded similar results. The 0.2 inches per hour rainfall intensity is used for sizing flow-based treatment facilities in Contra Costa County. This intensity corresponds to storms producing approximately 0.6 inches precipitation.

The CCCWP used the 0.2 inches per hour criterion to develop a consistent countywide sizing factor for bioretention facilities when used for stormwater treatment only (i.e., not for flow control). The factor is based on a design maximum surface loading rate of 5 inches per hour (now mandated by MRP Provision C.3.c.i.(2)(b)(iv)). The sizing factor is the ratio of the design intensity of rainfall on tributary impervious surfaces (0.2 inches/hour) to the design percolation rate in the facility (5 inches/hour), or 0.04 (dimensionless).

► FLOW-CONTROL (HYDROGRAPH MODIFICATION MANAGEMENT)

MRP Provision C.3.g. specifies for applicable projects:

> "Increases in runoff flow and volume shall be managed so that post-project runoff shall not exceed estimated post-project runoff peaks and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force."

Contra Costa applicants for development approvals may select among four options for compliance. See Table 1-2. The first three options allow an applicant to demonstrate—by showing there will be no net increase in impervious area, by using Integrated Management Practice designs and sizing factors developed by the CCCWP, or by constructing a site-specific hydrologic model—that runoff will not exceed pre-project rates and durations.* Applicants may use the fourth option to demonstrate that, even though runoff will increase, it will not cause erosion or other significant effects on beneficial uses. This may be done by showing downstream channels are not susceptible to erosion (Option 4a) or that a

* For sites that are already partially developed, see the Technical Memorandum, "Guidance on Flow Control For Development Projects on Sites that are Already Partially Developed," on the CCCWP's C.3 web pages.

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restoration project will mitigate any impacts from increased flows (Options 4b and 4c).

Details on compliance requirements are in Appendix C. Technical background is in the Hydrograph Modification Management Plan, which is available on the CCCWP's website.

Selection of Stormwater Treatment Facilities

The MRP mandates an LID approach similar to the approach developed by Contra Costa municipalities and incorporated in earlier editions of this *Stormwater C.3 Guidebook*.

► HARVESTING, USE, INFILTRATION, AND EVAPOTRANSPIRATION

MRP Provision C.3.c.i.(2)(b) requires applicable projects to treat 100% of the amount of runoff identified in Provision C.3.d. using LID facilities, which are defined as follows:

- LID treatment measures are harvesting and re-use, infiltration, evapotranspiration, or biotreatment.
- A properly engineered and maintained biotreatment system may be considered only if it is infeasible to implement harvesting and re-use, infiltration, or evapotranspiration at a project site.
- Infeasibility to implement harvesting and re-use, infiltration, or evapotranspiration at a project site may result from conditions including the following:
  - Locations where seasonal high groundwater would be within 10 feet of the LID treatment measure.
  - Locations within 100 feet of a groundwater well used for drinking water.
  - Development sites where pollutant mobilization in the soil or groundwater is a documented concern.
  - Locations with potential geotechnical hazards.
  - Smart growth and infill or development sites where the density and nature of the project would create significant difficulty for compliance with the onsite volume retention requirement.

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- Locations with tight clay soils that significantly limit the infiltration of stormwater.

Here is how these requirements are implemented in Contra Costa municipalities:

The LID Design Guide directs the applicant to first consider incorporating into the proposed project design LID features that minimize runoff. These features include:

- Minimized disturbance of natural drainage
- Minimized amount of roofs and paving
- Permeable pavements and green roofs
- Dispersing runoff to landscape

Remaining runoff from impervious surfaces must be directed to LID facilities designed to the hydraulic sizing criteria in Provision C.3.d.

The LID Design Guide then directs the applicant to assess the feasibility of meeting the permit's treatment and flow-control requirements—for each specific sub-drainage area within the site—by storing runoff for later use.

There are two options identified.

The first option is to store runoff for two days or less, which requires a consistent, reliable demand for a non-potable use other than irrigation. For this option, the applicant is directed to calculate the required storage and 48-hour drawdown rate for 80% capture. This calculation uses the methodology specified in CASQA Handbook and local rainfall data as specified in MRP Provision C.3.d.i.(1)(b). It is presumed storage of this quantity of runoff is feasible, and the applicant is directed to evaluate whether a reliable, accessible, implementable non-potable demand exists for this supply during the rainy season.

The second option is to accumulate runoff throughout the rainy season for use during the irrigation season. The required storage volume is calculated using the mean annual precipitation falling on the impervious surface times a factor of 0.6, which accounts for estimated losses to evaporation (less than 10%), the 80% capture of runoff, and runoff produced and used during the irrigation season (May – October). The applicant is directed to evaluate whether (1) there is sufficient landscape within or near the project to ensure demand for this quantity of water each year, and (2) whether annual storage of this quantity of water is feasible.

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For projects located at sites with Hydrologic Soil Group "A" or "B" soils, the LID Design Guide requires remaining runoff be routed to one of the following types of facilities:

- Dry well
- Bioretention
- Cistern + Bioretention
- Bioretention + Vault

All of these facilities are designed to infiltrate at least the flow of runoff specified in Provision C.3.d. when sized and configured for "treatment only" and a greater volume when sized and configured for "treatment and flow control."

For projects located at sites with "tight clay soils that significantly limit the infiltration of stormwater" (Hydrologic Soil Group "C" and "D" soils), the LID Design Guide requires remaining runoff be routed to one of the following facilities:

- Bioretention
- Cistern + Bioretention
- Bioretention + Vault

In these soil conditions, the amount of infiltration and evapotranspiration achieved by a bioretention facility is subject to unpredictable variation based on location-specific soil, slopes, and subsurface drainage patterns. Bioretention facilities are designed to facilitate infiltration and evapotranspiration to the extent feasible given conditions at the location.

Flow-through planters may be used where facilities are located on upper-story plazas, adjacent to building foundations, where mobilization of pollutants in soil or groundwater is a concern, and where potential geotechnical hazards are associated with infiltration. Flow-through planters facilitate evapotranspiration and, like bioretention facilities, reuse runoff to promote growth of plants within the facility.

Pending Actions

MRP Provision C.3.c.iii.(1) requires the municipal permitees to submit proposed feasibility and infeasibility criteria for runoff storage/reuse and infiltration to the Water Board by May 1, 2011.

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► NON-LID TREATMENT FACILITIES

MRP Provision C.3.e.ii.(1) states:

> When considered at the watershed scale, certain types of smart growth, high density and transit-oriented development can either reduce existing impervious surfaces, or create less "accessory" impervious areas and automobile-related pollutant impacts. Incentive LID treatment reduction credits approved by the Water Board may be applied to these types of Special Projects.

Pending Actions
MRP Provision C.3.e.ii.(2) requires the municipal permitees to submit types of projects proposed for consideration of "LID treatment reduction credits" to the Water Board by December 1, 2010.

Through experience, Contra Costa municipalities have determined the LID facilities in Chapter 4 can be implemented on most "smart growth, high-density, and transit-oriented development," and have decided LID facilities should be incorporated on those projects. Contra Costa municipalities have set an overall goal of incorporating LID treatment for runoff from at least 95% of impervious area created or replaced, and incorporating non-LID treatment for runoff from the remaining 5% of impervious area created or replaced.

Projects where LID may not always be feasible generally fall into one of the following two categories:

- Portions of sites which are not being developed or redeveloped, but which must be retrofit to meet treatment requirements in accordance with the "50% rule."

- Sites smaller than one acre approved for lot-line to lot-line development or redevelopment as part of a municipality's stated objective to preserve or enhance a pedestrian-oriented "smart-growth" type of urban design.

In these special situations, municipal staff may—based on evidence that 100% LID treatment is infeasible—allow non-LID treatment to be used to treat runoff from some or all impervious surfaces. The non-LID treatment must include media filtration.

Regional Water Board staff has found oil/water separators ("water quality inlets") and storm drain inlet filters do not meet the "maximum extent practicable"

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standard.* When used as a sole method of stormwater treatment, hydrodynamic separators, including vortex separators and continuous deflection separators ("CDS units"), do not meet the "maximum extent practicable" requirement, although they may be used in series with other facilities.†

Criteria for Infiltration Devices

MRP Provision C.3.d.iv. restricts the design and location of "infiltration devices" that, as designed, may bypass filtration through surface soils before reaching groundwater. These devices include dry wells, infiltration basins, and infiltration trenches, but do not include bioretention facilities or other facilities that treat runoff before allowing it to infiltrate.

Infiltration devices may not be used in areas of industrial or light industrial activity; areas subject to high vehicular traffic (25,000 or greater average daily traffic on main roadway or 15,000 or more average daily traffic on any intersecting roadway); automotive repair shops; car washes; fleet storage areas (bus, truck, etc.); nurseries, or other areas with pollutant sources that could pose a high threat to water quality, as determined by municipal staff.

The vertical distance from the base of any infiltration device to the seasonal high groundwater mark shall be at least 10 feet. Infiltration devices shall be located a minimum of 100 feet horizontally from any known water supply wells.

In addition, infiltration devices are not recommended where:

- The infiltration device would receive drainage from areas where chemicals are used or stored, where vehicles or equipment are washed, or where refuse or wastes are handled.
- Surface soils or groundwater are polluted.
- The facility could receive sediment-laden runoff from disturbed areas or unstable slopes.
- Increased soil moisture could affect the stability of slopes of foundations.

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* "Use of Storm Drain Inlet Filters and Oil/Water Separators to Meet the Requirements of NPDES Municipal Stormwater Permits," letter from Regional Water Board Executive Officer Bruce Wolfe to Bay Area Stormwater Management Agencies Association managers, August 5, 2004

† *Policy on the Use of Hydrodynamic Separators to Achieve Compliance with NPDES Provision C.3*, November 16, 2005

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- Soils are insufficiently permeable to allow the device to drain within 72 hours.

► MOST LID FEATURES AND FACILITIES ARE NOT INFILTRATION DEVICES

Self-treating and self-retaining areas, pervious pavements, bioretention facilities, and flow-through planters are not considered to be infiltration devices because they do not bypass filtration through surface soils before reaching groundwater.

Bioretention facilities work by percolating runoff through 18 inches or more of engineered soil. This removes most pollutants before the runoff is allowed to seep into native soils below or discharge through the outlet. Further pollutant removal typically occurs in the unsaturated (vadose) zone before moisture reaches groundwater. Self-treating and self-retaining areas allow removal of pollutants in surface soils before runoff mixes with groundwater.

Where there is concern about the effects of increased soil moisture on slopes or foundations, an impermeable barrier may be added so the facility is "flow through" and all treated runoff is underdrained away from the facility. See the design sheets for Bioretention Facilities and Flow-Through Planters in Chapter 4.

Environmental Benefit Perspective

The diverse natural geography of Contra Costa County includes tidal and freshwater wetlands, alluvial plains, and mountain slopes. Average annual rainfall varies from 12.5 inches in Brentwood to 30 inches in Orinda.

The climate, soils, slope, and vegetation give each Contra Costa stream a characteristic structure of riffles, pools, terraces, floodplains, and wetlands. In relatively undisturbed stream reaches, this geomorphic structure supports trees and other riparian vegetation. Trees provide shade (cooling stream temperatures), create root wads and undercut banks (refuge for fish) and produce falling leaves and detritus (the bottom of a food web). Fish, frogs, and other animals have evolved to thrive in riparian habitats. Because Contra Costa habitats are diverse and complex, some species are specialized, have limited ranges, and may be rare.

Contra Costa's landscape, like that of all the San Francisco Bay Area, has been repeatedly transformed since the Spanish arrived in the 1770s. Even before the area was developed, European grasses, weeds, and other plants replaced much of the native vegetation. Creek flows were diverted to irrigate farms, and wetlands were diked or filled for farmland.

Suburbs and former farm towns developed rapidly during and after the Second World War. In many places, to make flood-prone land suitable for development, creeks were channelized or confined within levees. Buildings, streets, and pavement now cover much of the land, and storm drains pipe runoff from urban

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neighborhoods directly into the creeks. Urbanization has changed the timing and intensity of stream flows and has set off a chain of unanticipated consequences. These consequences include more frequent flooding, destabilized stream banks, armoring of streambanks with riprap and concrete, loss of streamside trees and vegetation, and the destruction of stream habitat.

The remaining habitat, even where it has been disturbed and reduced to remnants, is an important refuge for various species. The U.S. and California have listed some of these species, including steelhead (*Oncorhyncus mykiss),* as endangered. Other species are listed as threatened, rare, or having other special status.

Once altered, natural streams and their ecosystems cannot be fully restored. However, it is possible to stop, and partially reverse, the trend of declining habitat and preserve and enhance some ecosystem values for the benefit of future generations.

This is an enormous, long-term effort. Managing runoff from a single development site may seem inconsequential, but by changing the way most sites are developed (and redeveloped), we may be able to preserve and enhance existing stream ecosystems in urban and urbanizing areas.

References and Resources

- *The Importance of Imperviousness* (Tom Scheuler, 1995)
  Site Planning for Urban Stream Protection, available from the Center for Watershed Protection)
- California Stormwater BMP Handbooks
- *Urban Runoff Quality Management,* Water Environment Federation and American Society of Civil Engineers, 1998. ISBN 1-57278-039-8 ISBN 0-7844-0174-8.
- *Policy on Selection of Stormwater Treatment Facilities for Maximum Extent Practicable Effectiveness in Compliance with NPDES Provision C.3* (CCCWP, 2007)
- Use of Storm Drain Inlet Filters and Oil/Water Separators to Meet the Requirements of NPDES Municipal Stormwater Permits," letter from Regional Water Board Executive Officer Bruce Wolfe to Bay Area Stormwater Management Agencies Association managers, August 5, 2004
- *Stormwater Infiltration,* Bruce K. Ferguson, 1994. ISBN 0-87371-987-5
- Municipal Regional Permit Provisions C.3.c., C.3.d., C.3.e.
- RWQCB Water Quality Control Plan for the San Francisco Bay Basin (Basin Plan)
- RWQCB Water Quality Control Plan for the Central Valley Region (Basin Plan)
- Clean Water Act Section 402(p)
- 40 CFR 122.26(d)(2)(iv)(A)(2) – Stormwater Regulations for New Development
- *Restoring Streams in Cities* (Riley, 1998)
- *Stream Restoration: Principles, Processes, and Practices*
  (Federal Interagency Stream Restoration Working Group, 1998, revised 2001)
- *Contra Costa County Watershed Atlas* (Contra Costa County, 2003

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Chapter 3

Preparing Your Stormwater Control Plan

Step-by-step assistance to document compliance.

Your Stormwater Control Plan will demonstrate your project complies with all applicable requirements in the stormwater NPDES permit—to minimize imperviousness, retain or detain stormwater, slow runoff rates, incorporate required source controls, treat stormwater prior to discharge from the site, control runoff rates and durations if required, and provide for operation and maintenance of treatment and flow-control facilities.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

The Plan must be submitted with your application for discretionary approvals and must have sufficient detail to ensure the stormwater design, site plan, and landscaping plan are congruent.

A complete and thorough Stormwater Control Plan will facilitate quicker review and fewer cycles of review. Every Contra Costa municipality requires a Stormwater Control Plan for every applicable project.

Your Stormwater Control Plan will consist of a report and an exhibit.

Municipal staff will use the checklist on the following page to evaluate your Plan:

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STORMWATER CONTROL PLAN CHECKLIST

CONTENTS OF EXHIBIT

Show all of the following on drawings:

- ❒ Existing natural hydrologic features (depressions, watercourses, relatively undisturbed areas) and significant natural resources. (Step 1 in the following step-by-step instructions)
- ❒ Existing and proposed site drainage network and connections to drainage off-site. (Step 3)
- ❒ Layout of buildings, pavement, and landscaped areas. (Step 3)
- ❒ Impervious areas proposed (roof, plaza/sidewalk, and streets/parking) and area of each. (Step 3)
- ❒ Entire site divided into separate Drainage Management Areas, with each DMA identified as self-treating, self-retaining (zero-discharge), draining to a self-retaining area, or draining to an IMP. Each DMA has one surface type (roof, paving, or landscape), is labeled, and square footage noted. (Step 3)
- ❒ Locations and sizes of proposed treatment and flow-control facilities. (Step 3)
- ❒ Potential pollutant source areas, including refuse areas, outdoor work and storage areas, etc. listed in Appendix D and corresponding required source controls. (Step 4)

CONTENTS OF REPORT

Include all of the following in a report:

- ❒ Narrative analysis or description of site features and conditions that constrain, or provide opportunities for, stormwater control. Include soil types (including Hydrologic Soil Group), slopes, and depth to groundwater (Step 2)
- ❒ Narrative description of site design characteristics that protect natural resources. (Step 3)
- ❒ Narrative description and/or tabulation of site design characteristics, building features, and pavement selections that minimize imperviousness of the site. (Step 3)
- ❒ Evaluation of the feasibility of storage and use, infiltration, and evapotranspiration (Step 3).
- ❒ Tabulation of DMAs, including self-treating areas, self-retaining areas, areas draining to self-retaining areas, and areas tributary to Integrated Management Practices (IMPs), in the format shown in Chapter 4. Output from the IMP Sizing Calculator may be used. (Step 3)
- ❒ Sketches and/or descriptions showing there is sufficient hydraulic head to route runoff into, through, and from each IMP to an approved discharge point. (Step 3)
- ❒ A table of identified pollutant sources and for each source, the source control measure(s) used to reduce pollutants to the maximum extent practicable. See worksheet in Appendix D. (Step 4)
- ❒ General maintenance requirements for infiltration, treatment, and flow-control facilities. (Step 5)
- ❒ Means by which facility maintenance will be financed and implemented in perpetuity. (Step 5)
- ❒ Statement accepting responsibility for interim operation & maintenance of facilities. (Step 5)
- ❒ Identification of any conflicts with codes or requirements or other anticipated obstacles to implementing the Stormwater Control Plan. (Step 6)
- ❒ Construction Plan C.3 Checklist. (Step 6)
- ❒ Certification by a civil engineer, architect, and landscape architect. (Step 6)
- ❒ Appendix: Compliance with flow-control requirements (if using an HMP compliance option other than Option 2, Integrated Management Practices).

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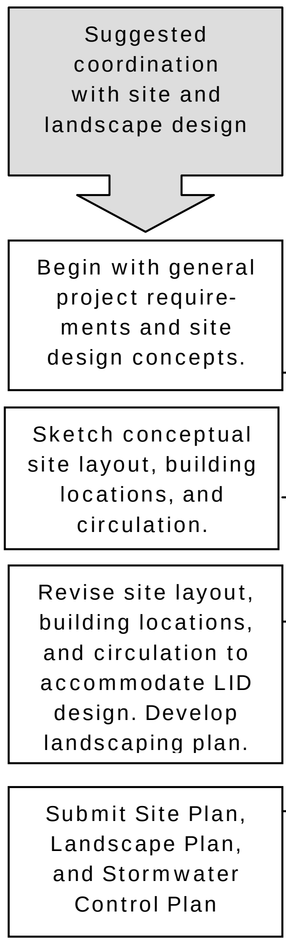
Step by Step



Plan and design your stormwater controls integrally with the site planning and landscaping for your project. It's best to start with general project requirements and preliminary site design concepts; then prepare the detailed site design, landscape design, and Stormwater Control Plan simultaneously. This will help ensure that your site plan, landscape plan, and Stormwater Control Plan are congruent.

The following step-by-step procedure should optimize your design by identifying the best opportunities for stormwater controls early in the design process.

The recommended steps are:

1. Assemble needed information.
2. Identify site opportunities and constraints.
3. Follow the LID design guidance in Chapter 4 to analyze your project for LID and to develop and document your drainage design.
4. Specify source controls using the table in Appendix D.
5. Plan for ongoing maintenance of treatment and flow-control facilities.
6. Complete the Stormwater Control Plan.

Municipal staff may recommend you prepare and submit a preliminary site design prior to formally applying for planning and zoning approvals. Your preliminary site design should incorporate a conceptual plan for site drainage, including self-treating and self-retaining areas and the location and approximate sizes of any treatment and flow-control facilities. This additional up-front design effort will save time and avoid potential delays later in the review process.

Step 1: Assemble Needed Information

To select types and locations of treatment and flow-control facilities, the designer needs to know the following site characteristics:

- Existing natural hydrologic features and natural resources, including any contiguous natural areas, wetlands, watercourses, seeps, or springs.
- Existing site topography, including contours of any slopes of 4% or steeper, general direction of surface drainage, local high or low points or depressions, any outcrops or other significant geologic features.

- Zoning, including requirements for setbacks and open space.

- Soil types (including hydrologic soil groups) and depth to groundwater, which may determine whether infiltration is a feasible option for managing site runoff. Depending on site location and characteristics, and on the selection of treatment and flow-control facilities, site-specific information (e.g. from boring logs or geotechnical studies) may be required.

- Existing site drainage. For undeveloped sites, this should be obtained by inspecting the site and examining topographic maps and survey data. For previously developed sites, site drainage and connection to the municipal storm drain system can be located from site inspection, municipal storm drain maps, and plans for previous development.

- Existing vegetative cover and impervious areas, if any.

Step 2: Identify Constraints & Opportunities

Review the information collected in Step 1. Identify the principal constraints on site design and selection of treatment and flow-control facilities as well as opportunities to reduce imperviousness and incorporate facilities into the site and landscape design. For example, constraints might include impermeable soils, high groundwater, groundwater pollution or contaminated soils, steep slopes, geotechnical instability, high-intensity land use, heavy pedestrian or vehicular traffic, utility locations, or safety concerns. Opportunities might include existing natural areas, low areas, oddly configured or otherwise unbuildable parcels, easements and landscape amenities including open space and buffers (which can double as locations for bioretention facilities), and differences in elevation (which can provide hydraulic head).

Prepare a brief narrative describing site opportunities and constraints. This narrative will help you as you proceed with LID design and explain your design decisions to others.

Step 3: Prepare and Document Your LID Design

Use the Low Impact Development Design Guide (Chapter 4) to analyze your project for LID, design and document drainage, and specify preliminary design details for integrated management practices.

Chapter 4 includes calculation procedures and formats for presenting your calculations.

As shown in the checklist (page 24), your Exhibit must show:

- The entire site divided into separate Drainage Management Areas (DMAs), with each area identified as self-treating, self-retaining, draining to a self-retaining area, or draining to an IMP. Each area should be clearly marked with a unique identifier.

- For each drainage area, the types of impervious area proposed, and the area of each.

- Proposed locations and sizes of treatment and flow-control facilities. Each facility should be clearly marked with a unique identifier.

Your Stormwater Control Plan report must include:

- An assessment of the feasibility of storing runoff and using it for irrigation or other non-potable use as a means of achieving criteria for treatment or treatment-and-flow-control. Use the equations and questions in Chapter 4.

- Tabulation of proposed self-treating areas, self-retaining areas, areas draining to self-retaining areas, and areas draining to IMPs, and the corresponding IMPs identified on the Exhibit.

- Calculations, in the format shown in Chapter 4, showing the minimum square footage required and proposed square footage for each IMP. If flow-control requirements apply, the required storage volume or volumes must also be shown.

- Preliminary designs for each IMP. The design sheets and accompanying drawings in Chapter 4 may be used or adapted for this purpose.

Also include in your Stormwater Control Plan report:

- A narrative overview of your design and how your design decisions optimize the site layout, use pervious surfaces, disperse runoff from impervious surfaces, and drain impervious surfaces to engineered IMPs. See Chapter 4.

- A narrative briefly describing each DMA, its drainage, and where drainage will be directed.

- A narrative briefly describing each IMP. Include any special characteristics or features distinct from the design sheets in Chapter 4.

Group and consolidate descriptions, or provide additional detail, as necessary to help the reviewer understand your drainage design.

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References and Resources

- Chapter 4
- *Start at the Source* (BASMAA, 1999).
- Your municipality's *General Plan*
- Your municipality's Zoning Ordinance and Development Codes
- *Low Impact Development Manual* (Prince George's County, Maryland, 1999).
- *Bioretention Manual* (Prince George's County, Maryland, rev. 2002)
- *Low Impact Development Technical Guidance Manual for Puget Sound* (Puget Sound Action Team, 2005)
- *LID for Big Box Retailers* (Low Impact Development Center, 2006)

Step 4. Specify Source Control BMPs

Some everyday activities – such as trash recycling/disposal and washing vehicles and equipment – generate pollutants that tend to find their way into storm drains. These pollutants can be minimized by applying **source control BMPs.**

Source control BMPs include **permanent**, structural features that may be required in your project plans—such as roofs over and berms around trash and recycling areas—and **operational** BMPs, such as regular sweeping and "housekeeping," that must be implemented by the site's occupant or user. The maximum extent practicable standard typically requires both types of BMPs. In general, operational BMPs cannot be substituted for a feasible and effective permanent BMP.

Use the following procedure to specify source control BMPs for your site:

► IDENTIFY POLLUTANT SOURCES

Review the first column in the **Pollutant Sources/Source Control Checklist** (Appendix D). Check off the potential sources of pollutants that apply to your site.

► NOTE LOCATIONS ON STORMWATER CONTROL PLAN EXHIBIT

Note the corresponding requirements listed in Column 2 of the Pollutant Sources/Source Control Checklist (Appendix D). Show the location of each pollutant source and each permanent source control BMP in your Stormwater Control Plan Exhibit.

► PREPARE A TABLE AND NARRATIVE

Check off the corresponding requirements listed in Column 3 in the Pollutant Sources/Source Control Checklist (Appendix D). Now, create a table using the format in Table 3-1. In the left column, list each potential source on your site (from Appendix E, Column 1). In the middle column, list the corresponding permanent, structural BMPs (from Columns 2 and 3, Appendix D) used to prevent pollutants from entering runoff. Accompany this table with a narrative that explains any special features, materials, or methods of construction that will be used to implement these permanent, structural BMPs.

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TABLE 3-1. Format for table of permanent and operational source control measures.

Potential source of runoff pollutants	*Permanent source control BMPs*	*Operational source control BMPs*

► IDENTIFY OPERATIONAL SOURCE CONTROL BMPS

To complete your table, refer once again to the Pollutant Sources/Source Control Checklist (Appendix D, Column 4). List in the right column of your table the operational BMPs that should be implemented as long as the anticipated activities continue at the site. The local stormwater ordinance requires that these BMPs be implemented; the same BMPs may also be required as a condition of a use permit or other revocable discretionary approval for use of the site.

References and Resources

- Appendix D, Stormwater Pollutant Sources/Source Control Checklist
- Municipal Regional Permit Provision C.3.c.
- *Start at the Source*, Section 6.7: Details, Outdoor Work Areas
- *California Stormwater Industrial/Commercial Best Management Practice Handbook*
- *Urban Runoff Quality Management* (WEF/ASCE, 1998) Chapter 4: Source Controls

Step 5: Stormwater Facility Maintenance

As required by MRP Provision C.3.h, your local municipality will periodically verify that treatment and flow-control facilities on your site are maintained and continue to operate as designed.

To make this possible, your municipality will require that you include in your Stormwater Control Plan:

1. A means to finance and implement facility maintenance in perpetuity.

2. Acceptance of responsibility for maintenance from the time the facilities are constructed until responsibility for operation and maintenance is legally transferred. A warranty covering a period following construction may also be required.

3. An outline of general maintenance requirements for the treatment and flow-control facilities you have selected.

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Your local municipality will also require that you prepare and submit a detailed Stormwater Facilities Operation and Maintenance Plan that sets forth a maintenance schedule for each of the treatment and flow-control facilities built on your site. An agreement assigning responsibility for maintenance and providing for inspections and certification may also be required.

Details of these requirements, and instructions for preparing a Stormwater Facilities Operation and Maintenance Plan, are in Chapter 6.

References and Resources

- *Chapter 6*
- *Model Stormwater Ordinance (CCCWP, 2005)*
- Operation, Maintenance, and Management of Stormwater Management Systems (Watershed Management Institute, 1997)

Step 6: Stormwater Control Plan Exhibit & Report

Your Stormwater Control Plan should document the information gathered and decisions made in Steps 1-5. A clear, complete, well-organized Plan will make it possible to confirm your design meets the minimum requirements of the Municipal Regional Permit, the municipal stormwater pollution prevention ordinance, and this *Guidebook*.

► COORDINATION WITH SITE, ARCHITECTURAL, AND LANDSCAPING PLANS

Before completing your Stormwater Control Plan exhibit and report, ensure your stormwater control design is fully coordinated with the site plan, grading plan, and landscaping plan being proposed for the site.

Information submitted and presentations to design review committees, planning commissions, and other decision-making bodies must incorporate relevant aspects of the stormwater design. In particular, ensure:

- Curb elevations, elevations, grade breaks, and other features of the drainage design are consistent with the delineation of DMAs.
- The top edge (overflow) of each bioretention facility is level all around its perimeter—this is particularly important in parking lot medians.
- The resulting grading and drainage design is consistent with the design for parking and circulation.
- Bioretention facilities and other IMPs do not create conflicts with pedestrian access between parking and building entrances.

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- Vaults and utility boxes will be accommodated outside bioretention facilities and will not be placed within bioretention facilities.
- The visual impact of stormwater facilities, including planter boxes at building foundations and any terracing or retaining walls required for the stormwater control design, is shown in renderings and other architectural drawings.
- Landscaping plans, including planting plans, show locations of bioretention facilities, and the plant requirements are consistent with the engineered soils and conditions in the bioretention facilities.
- Renderings and representation of street views incorporate any stormwater facilities located in street-side buffers and setbacks.
- Any potential conflicts with local development standards have been identified and resolved.

Review Chapter 5, IMP Construction, to anticipate additional requirements for construction of IMPs.

► CONSTRUCTION PLAN C.3 CHECKLIST

When you submit construction plans for City review and approval, the plan checker will compare that submittal with your Stormwater Control Plan. By creating a Construction Plan C.3 Checklist for your project, you will facilitate the plan checker's comparison and speed review of your project.

TABLE 3-2. Format for Construction Plan C.3 Checklist.

Stormwater Control Plan Page #	*BMP Description*	*See Plan Sheet #s*

Here's how:

1. Create a table similar to Table 3-2. Number and list each measure or BMP you have specified in your Stormwater Control Plan in Columns 1 and 2 of the table. Leave Column 3 blank. Incorporate the table into your Stormwater Control Plan.

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2. When you submit construction plans, duplicate the table (by photocopy or electronically). Now fill in Column 3, identifying the plan sheets where the BMPs are shown. List all plan sheets on which the BMP appears. Submit the updated table with your construction plans.

Note that the updated table—or Construction Plan C.3 Checklist—is only a reference tool to facilitate comparison of the construction plans to your Stormwater Control Plan. Local municipal staff can advise you regarding the process required to propose changes to the approved Stormwater Control Plan.

See Chapter 5 for details of IMP construction to be included in construction plans.

► CERTIFICATION

Your local municipality may require that your Stormwater Control Plan be certified by an architect, landscape architect, or civil engineer. See Appendix A.

Your certification should state: "The selection, sizing, and preliminary design of stormwater treatment and other control measures in this plan meet the requirements of Regional Water Quality Control Board Order R2-2009-0074 and subsequent amendments."

► STORMWATER CONTROL PLAN REPORT SAMPLE OUTLINE AND CONTENTS

I. Project Setting

A. Project Name, Location, Description

B. Existing site features and conditions

C. Opportunities and constraints for stormwater control

II. Low Impact Development Design Strategies

A. Optimization of site layout

(1) Limitation of development envelope

(2) Preservation of natural drainage features

(3) Setbacks from creeks, wetlands, and riparian habitats

(4) Minimization of imperviousness

(5) Using drainage as a design element

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B. Use of permeable pavements

C. Dispersal of runoff to pervious areas

D. Assessment of the feasibility of short-term and seasonal storage and reuse to meet treatment and flow-control requirements.

(1) Identification of impervious areas where runoff might be feasibly captured and stored.

(2) Calculation of minimum required storage and use rates for non-irrigation and irrigation uses for each such area.

(3) Storage for non-irrigation uses –Is there within the project site a reliable, accessible, implementable on-site non-potable demand to fully and reliably use the calculated supply during the rainy season?

(4) Storage for irrigation uses – Is there sufficient landscape within or near the project to ensure demand to the calculated quantity of water each year, and if so, is annual storage of this quantity of water feasible?

E. Use of Integrated Management Practices

III. Documentation of Drainage Design

A. Drainage Management Areas

(1) Tabulation

(2) Descriptions

B. Integrated Management Practices

(1) Tabulation and Sizing Calculations

(2) Descriptions

IV. Source Control Measures

A. Description of site activities and potential sources of pollutants

B. Table showing sources, permanent source controls, and operational source controls

V. Facility Maintenance Requirements

A. Ownership and responsibility for maintenance in perpetuity.

(1) Commitment to execute any necessary agreements and/or annex into a fee mechanism, per local requirements.

(2) Statement accepting responsibility for operation and maintenance of facilities until that responsibility is formally transferred.

B. Summary of maintenance requirements for each stormwater facility.

VI. Construction Plan C.3 Checklist

VII. Certifications

Attachment: Stormwater Control Plan Exhibit

Appendix: Compliance with Flow-Control (Hydrograph Modification Management) requirements (if IMPs are not used).

► STORMWATER CONTROL PLAN TEMPLATE

A template with the above format and headings is available on the CCCWP website.

► EXAMPLE STORMWATER CONTROL PLANS

Example Stormwater Control Plans can be accessed via the CCCWP's website. Because of the pace at which the Regional Water Board has issued new requirements, some of these plans may have been prepared under requirements that have now been superseded. Your Stormwater Control Plan will reflect the unique character of your own project and should meet the requirements identified in this *Guidebook*. Municipal staff can assist you to determine how specific requirements apply to your project.

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Chapter

4

Low Impact Development Design Guide

Guidance for designing and documenting your LID site drainage, stormwater treatment facilities, and flow-control facilities, including feasibility of storage for later use

Your Stormwater Control Plan—to be submitted with your application for planning and zoning approvals (entitlements)—must show how your project will comply with the applicable Low Impact Development, stormwater treatment, and flow-control (hydrograph modification management) standards in the Municipal Regional Permit (MRP).

This will require careful documentation of:

- Pervious and impervious areas in the planned project.
- Drainage from each of these areas.
- Locations, sizes, and types of proposed LID, stormwater treatment, and flow-control facilities.

Your Stormwater Control Plan must include calculations showing the site drainage and proposed treatment and flow-control facilities meet the criteria in this Guidebook.

This Low Impact Development Design Guide will help you:

- Analyze your project and identify and select options for meeting LID requirements and runoff treatment requirements—and flow-control requirements, if they apply.

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- Design and document drainage for the whole site and document how that design meets this Guidebook's stormwater treatment and flow-control criteria.

- Specify preliminary design details and integrate your LID drainage design with your paving and landscaping design.

For most projects, you will need to iterate these three steps to converge on a workable design that complements site conditions and project objectives. Non-LID facilities are discussed in the final section of this chapter.

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

Before beginning your LID design, determine whether flow-control requirements apply to your site. See Table 1.1 in Chapter 1. If flow-control requirements apply, review Appendix C to understand your options for meeting those requirements. The calculation procedures in this Design Guide enable you to comply with flow-control requirements using "Option 2" in Appendix C. If flow-control requirements do not apply, or if you are using another option to meet flow-control requirements, then you may use the treatment-only factors to size your facilities.

Analyze Your Project for LID

Conceptually, there are five LID strategies for managing runoff from buildings and paving:

1. Optimize the site layout by preserving natural drainage features and designing buildings and circulation to minimize the amount of roofs and paving.

2. Use pervious surfaces such as turf, gravel, or pervious pavement—or use surfaces that retain rainfall, such as "green roofs."

3. Disperse runoff from impervious surfaces on to adjacent pervious surfaces (e.g., direct a roof downspout to disperse runoff onto a lawn).

4. Store runoff and use it later for irrigation or other non-potable use.

5. Drain impervious surfaces to engineered Integrated Management Practices (IMPs), such as bioretention facilities, flow-through planters, or dry wells. IMPs evapotranspirate some runoff, infiltrate

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runoff to groundwater, and/or percolate runoff through engineered soil and allow it to drain away slowly.

A combination of two or more strategies may work best for your project. Table 4-1 includes ideas for applying LID strategies to site conditions and types of development. It may be useful as a starting point for thinking through application of the five strategies.

With forethought in design, the five LID strategies can provide multiple, complementary benefits to your development. Pervious surfaces reduce heat island effects and temperature extremes. Landscaping improves air quality, creates a better place to live or work, and upgrades value for rental or sale. Retaining natural hydrology helps preserve and enhance the natural character of the area. LID drainage design can also conserve water and reduce the need for drainage infrastructure.

TABLE 4-1. Ideas for Runoff Management

Site Features/Issues	*Pervious Pavement*	*Green Roof*	*Disperse Runoff to Landscape*	*Storage for Later Use*	*Bioretention Facility*	*Flow-through Planter*	*Dry Well*	*Cistern + bioretention*	*Bioretention + Vault*
Clayey native soils		✓	✓	✓	✓	✓		✓	✓
Permeable native soils	✓	✓	✓	✓	✓	✓	✓		
Very steep slopes		✓		✓		✓			
Shallow depth to groundwater		✓		✓		✓			
Roof drainage			✓	✓	✓	✓	✓	✓	
Parking lots	✓		✓	✓	✓		✓		✓
Extensive landscaping			✓	✓	✓				
Densely developed sites with limited space/landscape	✓	✓		✓		✓	✓	✓	✓

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► OPTIMIZE THE SITE LAYOUT

To minimize stormwater-related impacts, apply the following design principles to the layout of newly developed and redeveloped sites:

- Define the development envelope and protected areas, identifying areas that are most suitable for development and areas that should be left undisturbed.
- Set back development from creeks, wetlands, and riparian habitats.
- Preserve significant trees.

Where possible, conform the site layout along natural landforms, avoid excessive grading and disturbance of vegetation and soils, and replicate the site's natural drainage patterns.

Concentrate development on portions of the site with less permeable soils, and preserve areas that can promote infiltration.

Coordination
Chapter One includes a presentation of how review of your project's site design and landscape design is coordinated with review for compliance with Provision C.3.

For all types of development, **limit overall coverage** of paving and roofs. This can be accomplished by designing compact, taller structures, narrower and shorter streets and sidewalks, smaller parking lots (fewer stalls, smaller stalls, and more efficient lanes), and indoor or underground parking. Examine site layout and circulation patterns and identify areas where landscaping can be substituted for pavement.

Detain and retain runoff throughout the site. On flatter sites, it typically works best to intersperse landscaped areas and IMPs among the buildings and paving. On hillside sites, drainage from upper areas may be collected in conventional catch basins and piped to landscaped areas and IMPs in lower areas. Or use low retaining walls to create terraces that can accommodate IMPs. Wherever possible, direct drainage from landscaped slopes offsite and not to IMPs.

Use drainage as a design element. Use depressed landscape areas, vegetated buffers, and bioretention areas as amenities and focal points within the site and landscape design. Bioretention areas can be almost any shape and should be located at low points.

► USE PERVIOUS SURFACES

Consider a green roof. Green roofs are growing (in popularity), and many have been built in the Bay Area in the last few years. Benefits include longer roof life, lower heating and cooling costs, and better sound insulation, in addition to air quality and water quality benefits.

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However, initial costs are higher than for conventional roofs, and green roofs may add to the complexity of permitting, financing, and insuring new buildings. For C.3 compliance purposes, green roofs are considered not to produce increased runoff or runoff pollutants (i.e., any runoff from a green roof requires no further treatment or detention).

Pending Actions
MRP Provision C.3.c.i.(2)(b)(vii) requires the municipal permitees to submit proposed minimum specifications for green roofs to the Water Board by December 1, 2010.

Green roof designs with growing media 4 inches or deeper are encouraged but not required. Where possible, drainage from green roofs should be routed to landscaping rather than being tied directly into storm drains. This is because drain water may be high in organics due to extended contact with soils and plant roots.

Consider permeable pavements and surface treatments. Inventory paved areas on your preliminary site plan. Identify where permeable pavements, such as crushed aggregate, turf block, unit pavers, pervious concrete, or pervious asphalt could be substituted for impervious concrete or asphalt paving.

► DISPERSE RUNOFF TO ADJACENT PERVIOUS AREAS

Look for opportunities to direct runoff from impervious areas to adjacent landscaping. The design, including slopes and soils, must reflect a reasonable expectation that an inch of rainfall will soak into the soil and produce no runoff. For example, a lawn or garden depressed 3-4" below surrounding walkways or driveways provides a simple but functional landscape design element.

For sites subject to stormwater treatment requirements only, a 2:1 maximum ratio of impervious to pervious area is acceptable. If flow-control requirements apply, the impervious-to-pervious ratio must be limited to 1:1. Be sure soils will drain adequately.

Under some circumstances, it may be allowable to direct runoff from impervious areas to pervious pavement (for example, from roof downspouts to a parking lot paved with crushed aggregate or turf block). The pore volume of pavement and base course must be enough to retain an inch of rainfall, including runoff from the tributary area. The slopes and soils must be compatible with infiltrating that volume without producing runoff. This solution is most practical on flat sites with permeable soils.

► STORE RUNOFF FOR LATER USE

Use the following instructions and equations for a preliminary screening of the potential for storing runoff for later use on the site. As noted in Chapter 3, this determination of feasibility must be included in your Stormwater Control Plan.

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First, identify all specific impervious areas (for example, a roof or portion of a roof) from which runoff might be feasibly captured and stored. Consider direction of drainage and potential locations for runoff storage. Calculate the square footage of each area.

Pending Actions
MRP Provision C.3.c.iii.(1) requires the municipal permittees to submit proposed feasibility and infeasibility criteria for runoff storage/reuse and infiltration to the Water Board by May 1, 2011.

Then use the isohyetal diagram (County Public Works Drawing B-166) to estimate the Mean Annual Precipitation (MAP) at the project location.

Apply the following analysis for each specific impervious area identified. You will need to identify the Hydrologic Soil Group (A, B, C, or D) of the native soil underlying each specific impervious area.

Storing for a later use other than irrigation. If treatment-only requirements apply to your project (Table 1-1), use the following regression equation to estimate the storage volume for 80% capture:

Required volume (ft^3) = Impervious area (ft^2) × (0.0032 × MAP (in) + 0.0058)
(Eq 4-1)

This volume must be used (i.e., storage must be fully drained) each 48 hours.

If flow-control requirements also apply, use Equation 4-5, p. 51, to calculate the required storage volume. Referring to Table 4-8, use the factor for the upstream volume V of a "cistern + bioretention" facility. Then use the appropriate equation for the site soil group (Equation 4-17, 4-12, 4-10, or 4-11 from Table 4-9 on p. 51) to calculate the required use rate.

Given the calculated use rate, answer the following question and include the answer in your Stormwater Control Plan:

Is there within or near the project site a reliable, accessible, implementable on-site non-potable demand to fully use this supply during the rainy season?

Consider opportunities to use stored runoff for:

- Toilet flushing.
- Industrial use.
- Washing.
- Other uses.

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Storing for irrigation use. To be sure of diverting 80% of runoff for irrigation, it is necessary to store runoff during periods when there is little to no irrigation demand (approximately November through April) so that it may be used during the dry season. If treatment-only requirements apply, use the following equation to estimate the required storage:

Required volume (ft^3) = Impervious area (ft^2) × MAP (in)/12 × 0.6) *(Eq 4-2)*

Answer the following questions and include the answers in your Stormwater Control Plan: (1) Is there sufficient landscape within or near the project to ensure demand for this quantity of water each year? (2) If yes, is annual storage of this quantity of water feasible?

If flow-control requirements also apply, seasonal storage is not likely to be a feasible solution and need not be evaluated. Flow-control facilities are designed to store and release runoff flows which occur more rarely than once per year, and the facilities must be drained between storms.

If short-term or seasonal use of runoff from a specific impervious area is feasible, identify that area as a self-retaining drainage management area (DMA), as described on page 45.

Storage of a smaller volume of runoff for later use. Runoff storage that is less than the minimum calculated by Equations 4-1 and 4-2 is encouraged for water conservation. However, facilities for treatment and flow control must be sized independently of and in addition to storage for later use.

References and Resources

- *Municipal Handbook, Rainwater Harvesting Policies* (USEPA, 2008)
- *Green Roofs for Stormwater Runoff Control* (USEPA, 2009a)
- *Porous Pavements* (Ferguson, 2005)
- Municipal Regional Permit Provision C.3.c.

► DIRECT RUNOFF TO INTEGRATED MANAGEMENT PRACTICES

The CCCWP has developed design criteria for the following IMPs:

- Bioretention facilities, which can be configured as swales, free-form areas, or planters to integrate with your landscape design.

- Flow-through planters, which can be used near building foundations and other locations where infiltration to native soils is not desired.

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- Cistern + bioretention facilities, which use an upstream storage volume and metered flow to reduce the required square footage of a bioretention facility or flow-through planter.

- Bioretention + vault facilities, which capture a volume downstream of bioretention and meter outflows.

- Dry wells and other infiltration facilities, which can be used only where soils are permeable. See restrictions on page 20.

See the design sheets at the end of this chapter.

Finding the right location for treatment and flow-control facilities on your site involves a careful and creative integration of several factors:

- To make the most efficient use of the site and to maximize aesthetic value, integrate IMPs with site landscaping. Many local zoning codes may require landscape setbacks or buffers, or may specify that a minimum portion of the site be landscaped. It may be possible to locate some or all of your site's treatment and flow-control facilities within this same area, or within utility easements or other non-buildable areas.

- Planter boxes and bioretention facilities must be level or nearly level all the way around. Linear bioretention facilities (swales) may be gently sloped end to end, but opposite sides must be at the same elevation. Facilities on steeper slopes must be terraced or provided with check dams.

- For effective, low-maintenance operation, locate facilities so drainage into and out of the device is by gravity flow. Pumped systems are feasible, but are expensive, require more maintenance, are prone to untimely failure, and can cause mosquito control problems. Most IMPs require 3 feet or more of head.

- Bioretention facilities and other IMPs require excavations three or more feet deep, which can conflict with underground utilities.

- If the property is being subdivided now or in the future, the facility should be in a common, accessible area. In particular, avoid locating facilities on private residential lots. Even if the facility will serve only one site owner or operator, make sure the facility is located for ready access by inspectors from the local municipality and the Contra Costa Mosquito and Vector Control District.

- The facility must be accessible to equipment needed for its maintenance. Access requirements for maintenance will vary with

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the type of facility selected. Bioretention facilities will typically need access for the same types of equipment used for landscape maintenance.

To complete your analysis, include in your Stormwater Control Plan a brief narrative documenting the site layout and site design decisions you made. This will provide background and context for how your design meets the quantitative LID design criteria.

Develop and Document Your Drainage Design

The CCCWP's design documentation procedure begins with careful delineation of pervious areas and impervious areas (including roofs) throughout the site. The procedure accounts for how runoff from each delineated area is managed. For areas draining to IMPs, the procedure ensures each IMP is appropriately sized.

The procedure results in a space-efficient, cost-efficient LID design for meeting C.3 requirements on most residential and commercial/industrial developments. The procedure arranges documentation of drainage design and IMP sizing in a consistent format for presentation and review.

This procedure is intended to facilitate, not substitute for, creative interplay among site design, landscape design, and drainage design. Several iterations may be needed to optimize your drainage design as well as aesthetics, circulation, and use of available area for your site.

You should be able to complete the needed calculations using only the project's site development plan, hydrologic soil group (A, B, C, or D) and mean annual precipitation. Mean annual precipitation at locations in Contra Costa County can be determined using isohyetal maps accessible from the CCCWP's C.3 web page.

The CCCWP has created an IMP Sizing Calculator to facilitate the iterative calculations needed to create an optimal site design. The calculator is a stand-alone application and is available, along with instructions for its use, on the CCCWP's C.3 web pages. In addition to performing calculations, the IMP Sizing Calculator formats calculation results into a summary report. The summary report can be attached to your Stormwater Control Plan submittal.

Should you decide to use the calculator, be sure to read through the following instructions, as they include key information you will need for design.

The following formulas and procedures can be used without the sizing calculator to complete calculations and prepare a report suitable for submittal with your Stormwater Control Plan. The same formulas and procedures should be used to check and verify calculations made with the IMP Sizing Calculator.

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► STEP 1: DELINEATE DRAINAGE MANAGEMENT AREAS

This is the key first step. You must divide the entire project area into individual, discrete Drainage Management Areas (DMAs). Typically, lines delineating DMAs follow grade breaks and roof ridge lines. The Exhibit, tables, text, and calculations in your Stormwater Control Plan will illustrate, describe, and account for runoff from each of these areas.

Use separate DMAs for each surface type (e.g., landscaping, pervious paving, or roofs). Each DMA must be assigned a single hydrologic soil group. Assign each DMA an identification number and determine its size in square feet.

► STEP 2: CLASSIFY DMAS AND DETERMINE RUNOFF FACTORS

Next, determine how drainage from each DMA will be handled. Each DMA will be one of the following four types:

1. Self-treating areas.
2. Self-retaining areas (also called "zero-discharge" areas).
3. Areas that drain to self-retaining areas.
4. Areas that drain to IMPs.

Self-treating areas are landscaped or turf areas that do not drain to IMPs, but rather drain directly off site or to the storm drain system. Examples include upslope undeveloped areas which are ditched and drained around a development and grassed slopes that drain off-site to an existing public street or storm drain. In general, self-treating areas include no impervious areas, unless the impervious area is very small (5% or less) in relationship to the receiving pervious area and slopes are gentle enough to ensure runoff from impervious areas will be absorbed into the vegetation and soil.

Rationale
Pollutants in rainfall and windblown dust will tend to become entrained in the vegetation and soils of landscaped areas, so no additional treatment is needed. It is assumed the self-treating landscaped areas will produce runoff less than or equal to the pre-project site condition.

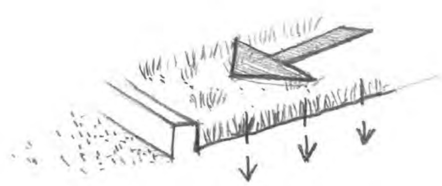

FIGURE 4-1. SELF-TREATING AREAS are entirely pervious and drain directly off-site or to the storm drain system.

Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. The technique works best on flat, heavily landscaped sites. It may be used on mild slopes if there is a reasonable expectation that a one-inch rainfall event would produce no runoff.

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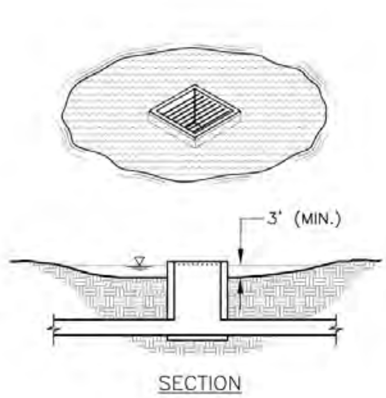

FIGURE 4-2. SELF-RETAINING AREAS. Berm or depress the grade to retain at least an inch of rainfall and set inlets of any area drains at least 3 inches above low point to allow ponding.

To create self-retaining turf and landscape areas in flat areas or on terraced slopes, berm the area or depress the grade into a concave cross-section so that these areas will retain the first inch of rainfall. Grade slopes, if any, toward the center of the pervious area. Inlets of area drains, if any, should be set 3 inches above the low point to allow ponding.

Under some circumstances, pervious pavement (e.g., crushed stone, pervious asphalt, or pervious concrete) can be self-retaining. Adjacent roofs or impervious pavement may drain on to the pervious pavement in the same maximum ratios as described below. A gravel base course four or more inches deep will ensure an adequate proportion of rainfall is infiltrated into native soils (including clay soils) rather than producing runoff. Consult with a qualified engineer regarding infiltration rates, pavement stability, and suitability for the intended traffic.

Drainage from green roofs is considered to be self-retained. An emergency overflow should be provided for extreme events. Areas draining to storage for later use may be considered "self-retained" if facilities with the required storage volumes and release rates are provided and reliable demand is documented in the Stormwater Control Plan.

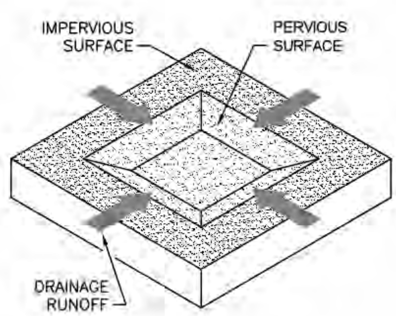

FIGURE 4-3. RELATIONSHIP OF IMPERVIOUS TO PERVIOUS area for self-retaining areas.
Where flow-control requirements apply: ***pervious ≥ impervious***
Where only treatment requirements apply : ***pervious ≥ ½ impervious***

Areas draining to self-retaining areas. Runoff from impervious or partially pervious areas can be managed by routing it to self-retaining pervious areas. For example, roof downspouts can be directed to lawns, and driveways can be sloped toward landscaped areas. The maximum ratio is 2 parts impervious area for every 1 part pervious area if only treatment requirements apply to the development project. If flow-control requirements also apply, the maximum ratio is 1 part impervious area for every 1 part pervious area.

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The drainage from the impervious area must be directed to and dispersed within the pervious area, and the entire area must be designed to retain an inch of rainfall without flowing off-site. For example, if the maximum ratio of 2 parts impervious area into 1 part pervious area is used, then the pervious area must absorb 3 inches of water over its surface before overflowing to an off-site drain.

A partially pervious area may be drained to a self-retaining area. For example, a driveway composed of unit pavers may drain to an adjacent lawn. In this case, the maximum ratios are, for treatment-only sites:

Derivation of Criteria

A computer model was used to continuously simulate rainfall, infiltration, and runoff at an hourly time-step over 30 years. Results indicate drainage areas using the 1:1 ratio will not exceed pre-project peaks and durations.

(Runoff factor) x (tributary area) $\leq$ 2 x (self-retaining area) *Equation 4-3*

For sites subject to flow-control requirements:

(Runoff factor) x (tributary area) $\leq$ 1 x (self-retaining area) *Equation 4-4*

Use the runoff factors in Table 4-2.

TABLE 4-2. RUNOFF FACTORS for evaluating drainage to self-retaining areas and for sizing IMPs.

Surface	Treatment and Flow Control	Treatment only
Roofs	1.0	1.0
Concrete or Asphalt	1.0	1.0
Pervious Concrete	0.1	0.1
Porous Asphalt	0.1	0.1
Grouted Unit Pavers	1.0	1.0
Solid Unit Pavers Set in Sand	0.5	0.2
Open and Porous Pavers	0.1	0.1
Crushed Aggregate	0.1	0.1
Turfblock	0.1	0.1
Landscape, Group A Soil	0.1	0.1
Landscape, Group B Soil	0.3	0.1
Landscape, Group C Soil	0.5	0.1
Landscape, Group D Soil	0.7	0.1

Prolonged ponding is a potential problem at higher impervious/pervious ratios. In your design, ensure that the pervious area soils can handle the additional run-on and are sufficiently well-drained.

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Runoff from self-treating and self-retaining areas does not require any further treatment or flow control. Further, there is no requirement for operation and maintenance inspections (see Chapter 6).

Areas draining to IMPs are used to calculate the required size of the IMP. On most densely developed sites—such as commercial and mixed-use developments and small-lot residential subdivisions—most DMAs will drain to IMPs.

The CCCWP has developed sizing factors (ratios of IMP area to impervious DMA area). For each IMP design, factors are provided for:

- Treatment-only.
- Treatment-plus-flow-control.

Treatment-only IMPs are smaller and in some cases are simpler in design.

More than one drainage management area can drain to the same IMP. However, because the minimum IMP sizes are determined by ratio to drainage area size, one drainage area may not drain to more than one IMP. See Figures 4-4 and 4-5.

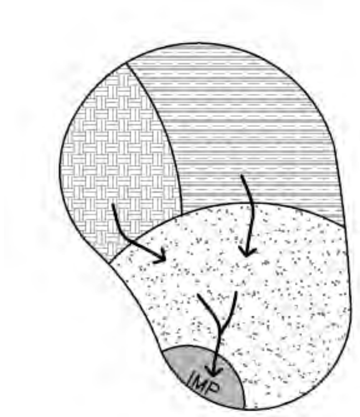

FIGURE 4-4. MORE THAN ONE
Drainage Management Area can drain to a single IMP.

Where possible, design site drainage so only impervious roofs and pavement drain to IMPs. This yields a simpler, more efficient design and also helps protect IMPs from becoming clogged by sediment.

If it is necessary to include turf, landscaping, or pervious pavements within the area draining to an IMP, list each surface as a separate DMA. A runoff factor (similar to a "C" factor used in the rational method) is applied to account for the reduction in the quantity of runoff. For example, when a turf or landscaped drainage management area drains to an IMP, the resulting increment in IMP size is:

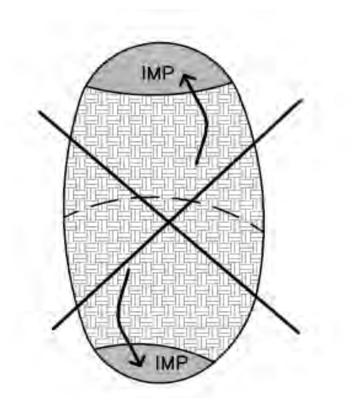

FIGURE 4-5. ONE DRAINAGE
Management Area cannot rain to more than one IMP.
Use a grade break to divide the DMA.

(pervious area) × (runoff factor) × (sizing factor).

Use the runoff factors in Table 4-2.

► STEP 3: TABULATE DRAINAGE MANAGEMENT AREAS

- Tabulate self-treating areas in the format shown in Table 4-3.
- Tabulate self-retaining areas in the format shown in Table 4-4.
- Tabulate areas draining to self-retaining areas in the format shown in Table 4-5. Check to be sure the total amount of (square feet of tributary area × runoff factor) for all DMAs draining to a receiving self-retaining area is no greater than a 1:1 ratio to the square footage of the receiving self-retaining area itself. A 2:1 ratio may be used on sites not subject to flow-control requirements.

Compile a list of DMAs draining to IMPs. Proceed to Step 4 to check the sizing of the IMPs.

TABLE 4-3. FORMAT FOR TABULATING Self-Treating Areas

DMA Name	*Area (square feet)*

TABLE 4-4. FORMAT FOR TABULATING Self-Retaining Areas

DMA Name	*Area (square feet)*

TABLE 4-5. FORMAT FOR TABULATING Areas Draining to Self-Retaining Areas

DMA Name	*Area (square feet)*	*Post-project surface type*	*Runoff factor*	*Product (Area × runoff factor)[A]*	*Receiving self-retaining DMA*	*Receiving self-retaining DMA Area (square feet) [B]*	*Ratio [A]/[B]*

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► STEP 4: SELECT AND LAY OUT IMPS ON SITE PLAN

Select from the IMPs in Table 4-6.

TABLE 4-6. IMP SELECTION

	Treatment Only				Treatment + Flow Control			
Hydrologic Soil Group	A	B	C	D	A	B	C	D
Bioretention	✓	✓	✓	✓	✓	✓	✓	✓
Flow-through Planter	✓	✓	✓	✓			✓	✓
Dry Well	✓	✓			✓	✓		
Cistern + Bioretention					✓	✓	✓	✓
Bioretention + Vault					✓	✓	✓	✓

Descriptions, illustrations, designs, and design criteria for the IMPs are in the design sheets at the end of this chapter. Once you have laid out the IMPs, calculate the square footage you have set aside on your site plan for each IMP.

► STEP 5: CALCULATE MINIMUM IMP AREA AND VOLUMES

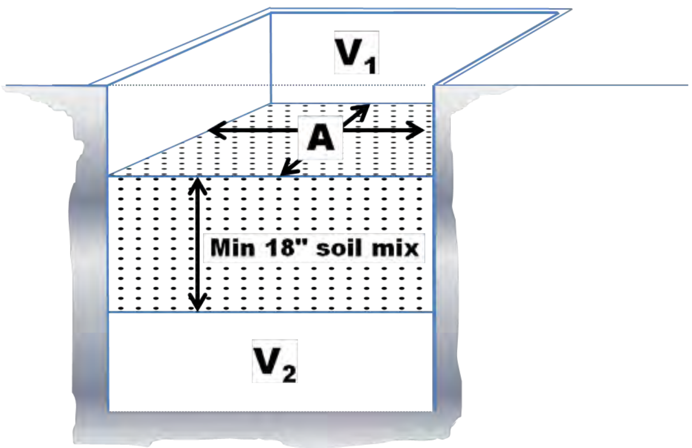
For treatment only, the minimum IMP areas and volumes are determined by summing up the contributions of each tributary DMA and multiplying times the factors shown in Table 4-7. Criteria for IMPs, including surface reservoir depths, underdrain bedding requirements, and depths and characteristics of planting soils, are in design sheets in this chapter.

TABLE 4-7. MINIMUM IMP AREAS AND VOLUMES for treatment only

Hydrologic Soil Group	A	B	C	D
Bioretention Facility A	0.04	0.04	0.04	0.04
Flow-through Planter A	0.04	0.04	0.04	0.04
Dry Well (treatment only) A V	0.02 0.068	0.04 0.136	N/A N/A	N/A N/A
A = ft² of IMP footprint per ft² of tributary area (unitless) V = ft³ per ft² of tributary area (ft.) Apply runoff factors from Table 4-2 for landscape or other pervious surfaces.				

For treatment-and-flow-control, the minimum area and minimum storage volumes are found by summing up the contributions of each tributary DMA and applying sizing factors and equations. The configuration of area (A), surface reservoir volume (V_1) and subsurface reservoir volume (V_2) for bioretention facilities and flow-through planters is shown in Figure 4-6.

FIGURE 4-6. A, V_1, and V_2.



Note: V_2 is the free volume. For gravel, multiply by an assumed porosity of 0.4.

V_1 is the floodable volume above the soil layer (that is, the total volume of surface storage when the facility just begins to overflow). V_2 is the storage volume below the soil layer. If gravel fill is used to provide subsurface volume, only the free pore volume is considered and is calculated by multiplying the volume of gravel by an assumed porosity of 0.4.

Sizing factors for treatment-only IMPs do not require any adjustment for differing rainfall patterns. Both area (A) and volume (V_1, V_2) sizing factors for treatment-plus-flow-control IMPs, however, must be adjusted to account for the effects of differing rainfall patterns on pre-project and post-project runoff. Cisterns and dry wells have a single storage volume.

Note these volumes can be configured in a variety of practical combinations of depth and area to best fit into your landscape design. For example, if a bioretention facility were designed with double the minimum value of A, then the depth of the surface reservoir and the depth of the subsurface reservoir could both be halved. Some other strategies to achieve the required minimum values of V1 and V2 are described in the design sheets in this chapter.

The minimum values of A, V_1, and V_2 are calculated by Equation 4-5.

Equation 4-5

$$Min.\,IMP\,Area\,or\,Volume = \sum \begin{pmatrix} DMA & & DMA \\ Square & \times & Runoff \\ Footage & & Factor \end{pmatrix} \times \begin{pmatrix} IMP \\ Sizing \\ Factor \end{pmatrix} \times \begin{pmatrix} Rain \\ Adjustment \\ Factor \end{pmatrix}$$

IMP Sizing Factors and equations for calculating Rain Adjustment Factors are in Tables 4-8 and 4-9.

TABLE 4-8. FACTORS FOR CALCULATING IMP Area and Storage Volumes (Treatment-and-flow-control)

Facility Design	Soil Group	Area (ft^2/ft^2)	Volume V_1 (ft^3/ft^2)	Volume V_2 (ft^3/ft^2)	Rainfall Adjustment for Surface Area	Rainfall Adjustment for Storage Volume	Maximum Release Rate
Bioretention Facility	A	0.07	0.058	No min.	Eq. 4-6	Eq. 4-6	No orifice
	B	0.11	0.092	No min.	Eq. 4-7	Eq. 4-7	No orifice
	C	0.06	0.050	0.066	Eq. 4-8	Eq. 4-8	Eq. 4-10
	D	0.05	0.042	0.055	Eq. 4-9*	Eq. 4-9	Eq. 4-11
Flow-through Planter	A	Not permitted in "A" soils					
	B	Not permitted in "B" soils					
	C	0.06	0.050	0.066	Eq. 4-8	Eq. 4-8	Eq. 4-10
	D	0.05	0.042	0.055	Eq. 4-9*	Eq. 4-9	Eq. 4-11
Dry Well	A	0.05	0.130	N/A	Eq. 4-6	Eq. 4-6	No release
	B	0.06	0.204	N/A	Eq. 4-7	Eq. 4-7	No release
	C	Not permitted in "C" soils					
	D	Not permitted in "D" soils					
Cistern + Bioretention	A	0.020	0.193	N/A	Eq. 4-13	Eq. 4-6	Eq. 4-17
	B	0.009	0.210	N/A	Eq. 4-14	Eq. 4-7	Eq. 4-12
	C	0.013	0.105	N/A	Eq. 4-15	Eq. 4-8	Eq. 4-10
	D	0.017	0.063	N/A	Eq. 4-16	Eq. 4-9	Eq. 4-11
Bioretention + Vault	A	0.04	N/A	0.096	N/A	Eq. 4-6	No release
	B	0.04	N/A	0.220	N/A	Eq. 4-7	Eq. 4-12
	C	0.04	N/A	0.152	N/A	Eq. 4-8	Eq. 4-10
	D	0.04	N/A	0.064	N/A	Eq. 4-9	Eq. 4-11

A = ft^2 of IMP footprint per ft^2 of tributary impervious area (unitless)
V_1, V_2 = ft^3 per ft^2 of equivalent tributary impervious area (ft.) Cisterns, dry wells, and vaults have only one volume.
*If MAP is 25 inches or greater, this equation will yield a rainfall adjustment less than 0.8 and a bioretention facility area less than 0.04 times the tributary area. In that case, use 0.04 times the tributary area to calculate the minimum allowable bioretention facility area. Equation 4-9 may still be used to adjust minimum required storage volumes.

TABLE 4-9. EQUATIONS TO BE USED in calculating IMP sizes and outflow rates.

Eq. 4-6	$Rain\ Adjustment = \frac{0.0009 \times (MAP_{project\ site} - 20.2) + 0.07}{0.07}$
Eq. 4-7	$Rain\ Adjustment = \frac{-0.0005 \times (MAP_{project\ site} - 20.2) + 0.11}{0.11}$
Eq. 4-8	$Rain\ Adjustment = \frac{-0.0022 \times (MAP_{project\ site} - 20.2) + 0.06}{0.06}$
Eq. 4-9	$Rain\ Adjustment = \frac{-0.0022 \times (MAP_{project\ site} - 20.2) + 0.05}{0.05}$
Eq. 4-10	$Flow\ (cfs\ per\ ft^2) = \frac{0.093 \times (MAP_{project\ site} - 20.2) + 1.42}{10^6}$
Eq. 4-11	$Flow\ (cfs\ per\ ft^2) = \frac{0.122 \times (MAP_{project\ site} - 20.2) + 1.85}{10^6}$
Eq. 4-12	$Flow\ (cfs\ per\ ft^2) = \frac{0.071 \times (MAP_{project\ site} - 20.2) + 0.91}{10^6}$
Eq. 4-13	$Area\ Ratio = \frac{0.151 \times (MAP_{project\ site} - 20.2) + 2.30}{2.30}$
Eq. 4-14	$Area\ Ratio = \frac{0.071 \times (MAP_{project\ site} - 20.2) + 0.91}{0.91}$
Eq. 4-15	$Area\ Ratio = \frac{0.093 \times (MAP_{project\ site} - 20.2) + 1.42}{1.42}$
Eq. 4-16	$Area\ Ratio = \frac{0.122 \times (MAP_{project\ site} - 20.2) + 1.85}{1.85}$
Eq. 4-17	$Flow\ (cfs\ per\ ft^2) = \frac{0.151 \times (MAP_{project\ site} - 20.2) + 2.30}{10^6}$

MAP = Mean Annual Precipitations, determined from Contra Costa County Public Works Figure B-166.

Use the format of Table 4-10 to present the calculations of the required minimum area and volumes of the receiving IMP.

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TABLE 4-10. FORMAT FOR PRESENTING CALCULATIONS of minimum IMP Areas and Volumes

DMA Name	*DMA Area (square feet)*	*Post-project surface type*	*DMA Runoff factor*	*DMA Area × runoff factor*
			Total	

Soil Type:	*IMP Name*			
IMP Sizing factor	*Rain Adjust-ment Factor*	*Minimum Area or Volume*	*Proposed Area or Volume*	
				IMP Area
				V or V1
				V2
			Orifice Size:	

► STEP 6: DETERMINE IF IMP AREA AND VOLUME ARE ADEQUATE

Sizing and configuring IMPs may be an iterative process. After computing the minimum IMP area using Steps 1–6, review the site plan to determine if the reserved IMP area is sufficient.

If so, the planned IMPs will meet the Provision C.3 sizing requirements. If not, revise the plan accordingly. Revisions may include:

- Reducing the overall imperviousness of the project site.
- Changing the grading and drainage to redirect some runoff toward other IMPs which may have excess capacity.
- Making tributary landscaped DMAs self-treating or self-retaining (may require changes to grading).
- Expanding IMP surface area.

- Using a different IMP—the cistern + bioretention and bioretention + vault options were created to achieve flow control in a smaller footprint than bioretention alone. Note these options are more costly and complex to build and operate.

Note revisions to square footage of an IMP typically require a corresponding revision to the square footage of the surrounding or adjacent DMA area.

Once a design with adequate area is achieved, review the IMP configuration to confirm the required minimum volumes are met. If not, revisions to V_1 may include adjusting depth or side slopes and extending the floodable storage area to include adjacent paved or landscaped areas. Revisions to V_2 may include adjusting width or depth, or incorporating buried pipes or arches in the gravel layer.

► STEP 7: COMPUTE MAXIMUM ORIFICE FLOW RATE

This step applies only to treatment-and-flow-control bioretention facilities and flow-through planters built on native Group C and Group D soils, cistern + bioretention-facilities built in all soils, and bioretention + vault facilities built on Group B, Group C, and Group D native soils. See Table 4-6.

Treatment-only bioretention facilities and flow-through planters in Group C and Group D soils are equipped with underdrains, but there is no restriction on the rate of outflow.

For treatment-and-flow-control IMPs, the underdrain has a flow control orifice sized to ensure rates and durations of flows do not exceed pre-project conditions.

For a cistern + bioretention-facility, the flow-control orifice is placed on the outlet from the cistern where it discharges to the bioretention facility. The bioretention facility must have an underdrain in B, C, and D soils, but no flow-control orifice is required on the underdrain.

For a bioretention + vault facility, the flow-control orifice is placed on the discharge from the vault.

Find the appropriate equation in Tables 4-8 and 4-9 to determine the maximum underdrain flow. Sum the total area draining to an IMP (including all tributary DMAs; do not use runoff factors. Compute the maximum orifice release rate, and then apply the orifice equation (Eq. 4-18) to determine the required orifice area. Then use Eq. 4-19 to determine the diameter of the flow control orifice.

Equation 4-18

$$Orifice\ Area\,(in\ \ feet) = \frac{UnderdrainMaxFlow}{c \times \sqrt{64.4 \times H}}$$

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where c is the orifice coefficient, which may be approximated as 0.6. H is the height of the storage above the orifice.

Equation 4-19

$$Orifice\ Diameter\ (in\ inches) = 12 \times \sqrt{\frac{4 \times Orifice\ Area}{\pi}}$$

STEP 8: COMPLETE YOUR SUMMARY REPORT

Present your IMP sizing calculations in tabular form. Adapt the following format as appropriate to your project. (Note: the IMP Sizing Calculator produces this output for you.) Coordinate your presentation of DMAs and calculation of minimum IMP sizes with the Stormwater Control Plan exhibit (labeled to show delineation of DMAs and locations of IMPs) and with your Stormwater Control Plan report, which should incorporate a brief description of each DMA and each IMP.

Tabulate and sum the total area of all DMAs and IMPs listed and show it is equal to the total project area. This step may include adjusting the square footage of some DMAs to account for area used for IMPs.

Format:

Project Name:

Project Location:

APN or Subdivision Number:

Total Project Area (square feet):

Mean Annual Precipitation at Project Site:

IMPs designed for (treatment only or treatment-and-flow-control):

I. Self-treating areas:

DMA Name	*Area (square feet)*

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II. Self-retaining areas:

DMA Name	*Area (square feet)*

III. Areas draining to self-retaining areas:

DMA Name	*Area (square feet)*	*Post-project surface type*	*Runoff factor*	*Product (Area × runoff factor)[A]*	*Receiving self-retaining DMA*	*Receiving self-retaining DMA Area (square feet) [B]*	*Ratio [A]/[B]*

IV. Areas draining to IMPs (repeat for each IMP):

DMA Name	*DMA Area (square feet)*	*Post-project surface type*	*DMA Runoff factor*	*DMA Area × runoff factor*	*Soil Type:*	*IMP Name*			
					IMP Sizing factor	*Rain Adjust-ment Factor*	*Minimum Area or Volume*	*Proposed Area or Volume*	
			Total						***IMP Area***
									V or V1
									V2
								Orifice Size:	

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Specify Preliminary Design Details

In your Stormwater Control Plan, describe your features and facilities in sufficient detail to demonstrate the area, volume, and other criteria of each can be met within the constraints of the site.

Ensure these details are consistent with preliminary site plans, landscaping plans, and architectural plans submitted with your application for planning and zoning approvals.

Following are design sheets for:

- Self-treating and self-retaining areas
- Pervious pavements
- Bioretention
- Flow-through planter
- Dry well
- Cistern + bioretention
- Bioretention + vault

These design sheets include recommended configurations and details, and example applications, for these features and facilities. **The information in these design sheets must be adapted and applied to the conditions specific to the development project**. Local planning, building, and public works officials have final review and approval authority over the project design.

Keep in mind that proper and functional design of features and facilities is the responsibility of the applicant. Effective operation of facilities throughout the project's lifetime will be the responsibility of the property owner.

Alternatives to LID Design

LID has been found to be feasible for nearly all development sites. If you believe LID design may be infeasible for your development site, review the criteria for the selection of stormwater treatment facilities on page 16. If flow-control requirements apply, also review the options for compliance in Appendix C. Then consult with municipal staff before preparing an alternative design for stormwater treatment or flow-control.

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Pending Actions
MRP Provision C.3.e.ii.(2) requires the municipal permitees to submit types of projects proposed for consideration of "LID treatment reduction credits" to the Water Board by December

For all alternative designs, the applicant must submit a complete Stormwater Control Plan, including an exhibit showing the entire site divided into discrete Drainage Management Areas, text and tables showing how drainage is routed from each DMA to a treatment facility, and calculations demonstrating the design achieves the applicable design criteria for each facility.

▶ TREATMENT CONTROL ALTERNATIVES

Here are criteria and design considerations for alternatives that may be used under the conditions allowed by the permit and by the municipality:

Sand Filters. To ensure effectiveness is not compromised by compacting or clogging of the filter surface, sand filters must be maintained frequently.

The following criteria apply to sand filters:

- Calculate the design flow using the rational method with an intensity of 0.2"/hour and the runoff factors for treatment only from Table 4-2.
- To determine the required filter surface area, divide the design flow by an allowable maximum design surface loading rate of 5"/hour.
- The minimum depth of filter media is 18". The media should be washed sand, with gradation similar to that specified for fine aggregate in ASTM C-33.
- The entire filter area must be accessible for easy maintenance without the need to enter a confined space.

A typical filter design includes a gravel drain layer and a perforated pipe underdrain. Filter fabric may be used to prevent the filter media from entering the gravel layer.

The design should not include any permanent pool or other standing water. Instead of including a pretreatment basin, consider the following features in the area tributary to the filter to reduce the potential for filter clogging:

- Limit the size of the Drainage Management Area.
- Include only impervious areas in the DMA.
- Stabilize slopes and eliminate sources of sediment in the DMA.
- Provide screens for trash and leaves at storm drain inlets.

For additional design considerations and details, see *Design of Stormwater Filtering Systems* by Richard A. Claytor and Thomas R. Schueler, The Center for Watershed Protection, 1996, and *California Stormwater BMP Handbooks* Fact Sheet TC-40, Media Filter.

"Wet" Detention Ponds and Constructed Wetlands. The required detention volume is determined using the "Unit Basin Storage Size for 80% Capture" chart available on the CCCWP's website and the mean annual precipitation determined from Contra Costa County Public Works Drawing B-166. . Before proceeding with design, contact the Contra Costa Mosquito and Vector Control District to coordinate the design and plan ongoing inspection and maintenance of the facility for mosquito control. For design considerations and details, see the *California Stormwater Best Management Practices Handbooks*, Fact Sheet TC-20, "Wet Ponds," and Fact Sheet TC-21, "Constructed Wetlands."

Higher-rate surface filters and vault-based filters. As described on page 16, these facilities may be used only in specific types of projects where other alternatives have proven infeasible. For surface filters, the grading and drainage design should minimize the area draining to each unit and maximize the number of discrete drainage areas and units. Proprietary facilities should be installed and maintained consistent with the manufacturer's instructions.

► TREATMENT AND FLOW CONTROL ALTERNATIVES

By using the CCCWP's design procedure, including LID IMPs, your project will meet requirements to minimize imperviousness, treat runoff, and control runoff peaks and durations. If the use of LID IMPs is not feasible, compliance with each of these requirements must be demonstrated individually. Separate facilities may be needed for treatment and for flow control.

If flow-control compliance is achieved by Options #1 or #4 in Appendix C, treatment compliance may be achieved by use of LID IMPs sized using treatment-only criteria.

Cistern with sand filter. Treatment and flow-control requirements can be met by using the cistern, including the volume calculated using Equation 4-5 and the discharge rate calculated using Equation 4-5 and Equation 4-17, 4-12, 4-10 or 4-11, and a sand filter sized to achieve a maximum surface loading rate of 5"/hour based on the calculated maximum discharge of the cistern orifice.*

* This option would not occur under the Program's current policy. All development projects subject to HMP requirements are also subject to LID requirements. It is retained here for information pending further Water Board action.

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Treatment-and-flow-control detention basin, wet pond, or wetland. A detention basin may be sized and configured to achieve treatment and flow control:

- The facility must contain a volume calculated using the "Unit Basin Storage Size for 80% capture" chart which has a drawdown time of 48 hours. To achieve maximum treatment effectiveness, this volume and discharge rate should be as close to the criteria as possible, neither oversized nor undersized.
- The facility must also match pre-project peak flows and durations as must be shown using the modeling procedure described under Option #3 in Appendix C.

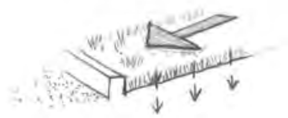
Applicants considering this option should consult with municipal staff and with the Contra Costa Mosquito and Vector Control District before proceeding with design.*

* This option would not occur under current policy. Detention basins and wetlands are suitable for drainage management areas larger than an acre; projects creating or replacing an acre or more of impervious area are always subject to LID requirements.

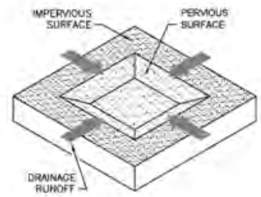
RB-AR34328

Self-Treating and Self-Retaining Areas

► CRITERIA



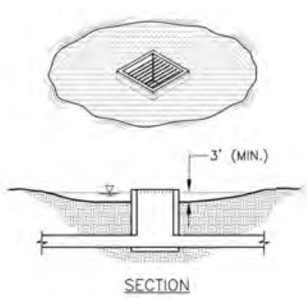
Rainfall on self-treating areas infiltrates or—during intense storms— drains directly off-site or to the storm drain system.



Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. During intense storms, runoff may drain off-site, to the storm drain system, or to IMPs.

LID design seeks to manage runoff from roofs and paving so effects on water quality and hydrology are minimized. Runoff from landscaping, however, does not need to be managed the same way. Runoff from landscaping can be managed by creating self-treating and self-retaining areas.

Self-treating areas are natural, landscaped, or turf areas that drain directly off site or to the storm drain system. Examples include upslope undeveloped areas from which runoff is piped or ditched and drained around a development and grassed slopes that drain offsite to a street or storm drain. Self-treating areas may not drain on to adjacent paved areas within the project.



Set overflows and area drain inlets (if any) high enough to ensure ponding (3" deep) over the surface of the self-retaining area.

Where a landscaped area is upslope from or surrounded by paved areas, a **self-retaining area** (also called a zero-discharge area) may be created. Self-retaining areas are designed to retain the first one inch of rainfall without producing any runoff. The technique works best on flat, heavily landscaped sites. It may be used on mild slopes if there is a reasonable expectation that the first inch of rainfall would produce no runoff.

Best Uses

- Sites with extensive landscaping

Advantages

- No maintenance verification requirement
- Complements site landscaping

Limitations

- Requires substantial square footage
- Grading requirements must be coordinated with landscape design

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Areas draining to self retaining areas. Drainage from roofs and paving can be directed to self-retaining areas and allowed to infiltrate into the soil. The maximum ratios are:

Site requirement	Maximum allowable ratio
Treatment only	2 parts impervious: 1 pervious
Treatment and flow-control	1 part impervious: 1 pervious

The self-retaining area must be bermed or depressed to retain an inch of rainfall including the flow from the tributary impervious area.

► DETAILS

Drainage from self-treating areas must flow to off-site streets or storm drains without flowing on to paved areas within the project.

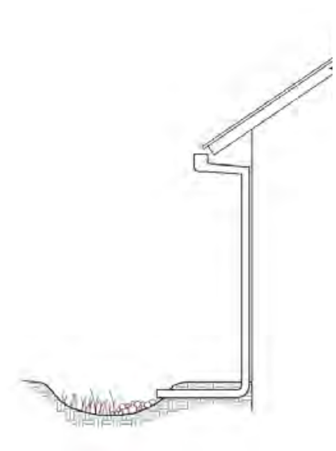
To create self-retaining turf and landscape areas in flat areas or on terraced slopes, berm the area or depress the grade into a concave cross-section so that these areas will retain the first inch of rainfall. Inlets of area drains, if any, should be set 3 inches above the low point to allow ponding.

Pavement within a self-treating area cannot exceed 5% of the total area.

In self-retaining areas, overflows and area drain inlets should be set high enough to ensure ponding over the entire surface of the self-retaining area.

Self-retaining areas should be designed to promote even distribution of ponded runoff over the area.

Leave enough reveal (elevation difference) to accommodate buildup of turf or mulch.



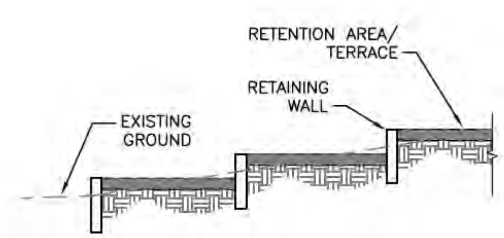
Connecting a roof leader to a self-retaining area. The head from the eave height makes it possible to route roof drainage some distance away from the building.

► APPLICATIONS

Lawn or landscaped areas adjacent to streets can be considered self-treating areas.

Self-retaining areas can be created by depressing lawn and landscape below surrounding sidewalks and plazas.

Runoff from walkways or driveways in parks and park-like areas can sheet-flow to self-retaining areas.



Mild slopes can be terraced to create self-retaining areas.

Roof leaders can be connected to self-retaining areas by piping beneath plazas and walkways. If necessary, a "bubble-up" can be used.

Self-retaining areas can be created by terracing mild slopes. The elevation difference promotes subsurface drainage.

► DESIGN CHECKLIST FOR SELF-TREATING AREAS

- ❒ The self-treating area is at least 95% lawn or landscaping (not more than 5% impervious).
- ❒ Re-graded or re-landscaped areas have amended soils, vegetation, and irrigation as may be required to maintain soil stability and permeability.
- ❒ Runoff from the self-treating area does not enter an IMP or another drainage management area, but goes directly offsite or to the storm drain system.

► DESIGN CHECKLIST FOR SELF-RETAINING AREAS

- ❒ Area is bermed all the way around or graded concave.
- ❒ Slopes do not exceed 4%.
- ❒ Entire area is lawn, landscaping, or pervious pavement (see criteria in Chapter 4).
- ❒ Area has amended soils, vegetation, and irrigation as may be required to maintain soil stability and permeability.
- ❒ Any area drain inlets are at least 3 inches above surrounding grade.

► DESIGN CHECKLIST FOR AREAS DRAINING TO SELF-RETAINING AREAS

- ❒ Ratio of tributary impervious area to self-retaining area is not greater than 2:1 (1:1 if flow-control requirements apply).
- ❒ Roof leaders collect runoff and route it to the self-retaining area.
- ❒ Paved areas are sloped so drainage is routed to the self-retaining area.
- ❒ Inlets are designed to protect against erosion and distribute runoff across the area.

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Pervious Pavements

▶ CRITERIA

Impervious roadways, driveways, and parking lots account for much of the hydrologic impact of land development. In contrast, pervious pavements allow rainfall to collect in a gravel or sand base course and infiltrate into native soil.

Pervious pavements are designed to transmit rainfall through the surface to storage in a base course. For example, a 4-inch-deep base course provides approximately 1.6 inches of storage. Runoff stored in the base course infiltrates to native soils over time. Except in the case of solid pavers, the surface course provides additional storage.

When configured to drain directly off-site, areas with the following pervious pavements may be regarded as "self-treating" and require no additional treatment or flow control.

- Pervious concrete
- Porous asphalt
- Porous pavers
- Crushed aggregate (gravel)
- Open pavers with grass or plantings
- Open pavers with gravel
- Artificial turf

Areas with pervious pavements can be self-retaining areas receiving runoff from impervious areas if they are bermed or

Best Uses

- Flat areas
- Areas with permeable native soils
- Low-traffic areas
- Where aesthetic quality can justify higher cost

Advantages

- No maintenance verification requirement
- Variety of surface treatments can complement landscape design

Limitations

- Initial cost
- Placement requires specially trained crews
- Geotechnical concerns, especially in clay soils
- Concerns about pavement strength and surface integrity

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depressed to retain the first one inch of rainfall, including runoff from any tributary impervious areas.

Solid unit pavers—such as bricks, stone blocks, or precast concrete shapes—are considered to reduce runoff compared to impervious pavement, when the unit pavers are set in sand or gravel with $\frac{3}{8}$" gaps between the pavers. Joints must be filled with an open-graded aggregate free of fines.

Use the runoff factors in Table 4-2.

► DETAILS

Permeable pavements can be used in clay soils; however, special design considerations, including an increased depth of base course, typically apply and will increase the cost of this option. Geotechnical fabric between the base course and underlying clay soil is recommended.

Permeable pavements are best used on grades from flat to approximately 2%. Installations on steeper grades, particularly on clay soils, require cut-off trenches lateral to the slope to intercept, store, and infiltrate drainage from the base course.

Pavement strength and durability typically determines the required depth of base course. If underdrains are used, the outlet elevation must be a minimum of 3 inches above the bottom elevation of the base course.

Pervious concrete and porous asphalt must be installed by crews with special training and tools. Industry associations maintain lists of qualified contractors.

Parking lots with crushed aggregate or unit pavers may require signs or bollards to organize parking.

DESIGN CHECKLIST FOR PERVIOUS PAVEMENTS

- ❒ No erodible areas drain on to pavement.
- ❒ Subgrade is uniform. Compaction is minimal.
- ❒ Reservoir base course is of open-graded crushed stone. Base depth is adequate to retain rainfall and support design loads.
- ❒ If a subdrain is provided, outlet elevation is a minimum of 3 inches above bottom of base course.
- ❒ Subgrade is uniform and slopes are not so steep that subgrade is prone to erosion.
- ❒ Rigid edge is provided to retain granular pavements and unit pavers.
- ❒ Solid unit pavers are set in sand or gravel with minimum $\frac{3}{8}$" gaps between the pavers. Joints are filled with an open-graded aggregate free of fines.
- ❒ Permeable pavements are installed by industry-certified professionals according to vendor's recommendations.
- ❒ Selection and location of pavements incorporates Americans with Disabilities Act requirements, site aesthetics, and uses.

RESOURCES

Concrete Promotion Council of Northern California www.concreteresources.net.

California Asphalt Pavement Association
http://www.californiapavements.org/stormwater.html

Interlocking Concrete Pavement Institute
http://www.icpi.org/

Start at the Source Design Manual for Water Quality Protection, pp. 47-53.

Porous Pavements, by Bruce K. Ferguson. 2005. ISBN 0-8493-2670-2.

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Bioretention Facilities

Bioretention facilities can rectangular, linear, or nearly any shape.
Photo by Scott Wikstrom

Bioretention detains runoff in a surface reservoir, filters it through plant roots and a biologically active soil mix, and then infiltrates it into the ground. Where native soils are less permeable, an underdrain conveys treated runoff that does not infiltrate to a storm drain or to surface drainage.

Bioretention facilities can be configured as in-ground or above-ground planter boxes, with the bottom open to allow infiltration to native soils underneath. *If infiltration cannot be allowed, use the sizing factors and criteria for the Flow-Through Planter.*

► CRITERIA

For development projects subject only to runoff treatment requirements, the following criteria apply:

Parameter	**Criterion**
Soil mix depth	18 inches minimum
Soil mix requirements	See Appendix B
Soil mix surface area	0.04 times tributary impervious area (or equivalent)
Surface reservoir depth	6 inches minimum; may be sloped to 4 inches where adjoining walkways.
Underdrain	Required in Group "C" and "D" soils. Perforated pipe (PVC SDR 35 or approved equivalent) embedded in gravel ("Class 2 permeable" recommended), connected to storm drain or other accepted discharge point.

Best Uses

- Commercial areas
- Residential subdivisions
- Industrial developments
- Roadways
- Parking lots
- Fit in setbacks, medians, and other landscaped areas

Advantages

- Can be any shape
- Low maintenance
- Can be landscaped

Limitations

- Require 4%-15% of tributary impervious square footage
- Require 3-4 feet of head
- Irrigation may be required

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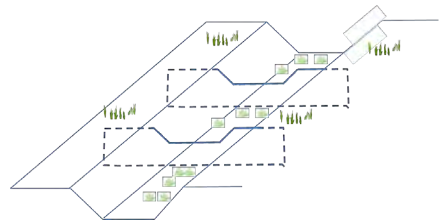
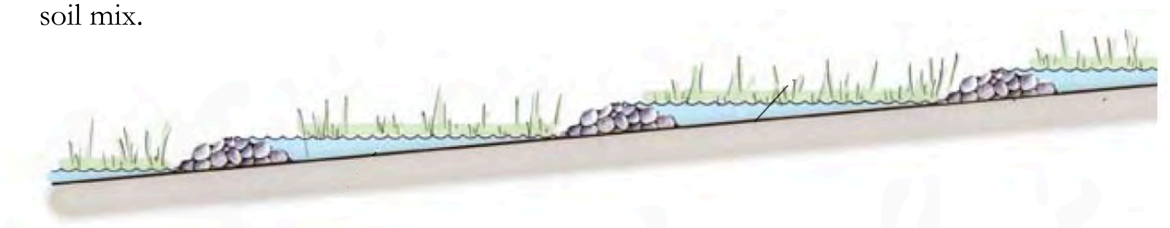
Where flow-control requirements also apply, the bioretention facility mutt be designed to meet the minimum surface area (A), surface volume (V_1), and subsurface volume (V_2) using the sizing factors and equations in Tables 4-8 and 4-9.



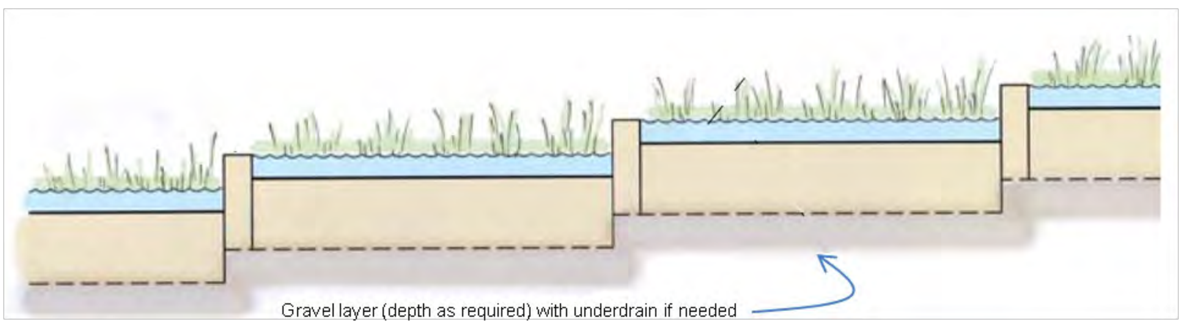
Key check dams into bottom and side slopes.

► DETAILS

Plan and Profile. On the surface, a bioretention facility should be one level, shallow basin—or a series of basins. As runoff enters each basin, it should flood and fill throughout before runoff overflows to the outlet or to the next downstream basin. This will help prevent movement of surface mulch and soil mix.



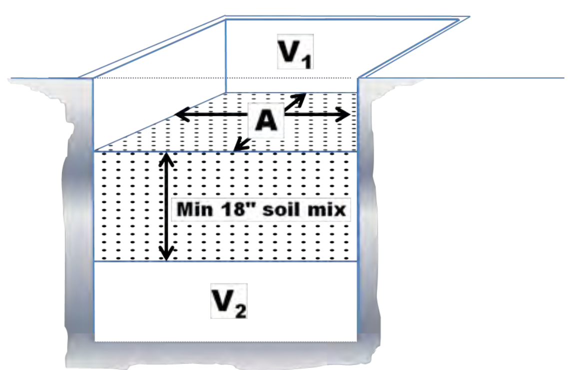
Swale with check dams. Provides limited storage; not suitable for slopes 6% and greater.



Planter on slope provides more storage. Check dams should be keyed into planter sides. (USEPA 2009b)

In a linear swale, check dams should be placed for every 4 to 6 inches of elevation change and so that the lip of each dam is at least as high as the toe of the next upstream dam. A similar principle applies to bioretention facilities built as terraced roadway shoulders.

Minimum Surface Volume. For a treatment-and-flow-control facility, the sizing factor V_1 is equivalent to the sizing factor A flooded to a 12" depth (10" overflow plus 2" freeboard). Surrounding the facility with a 12" vertical wall minimizes the required surface area as shown in (a). However, alternatives include:



(a) A, V_1 and V_2

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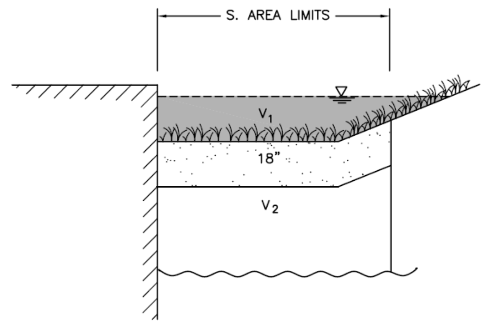
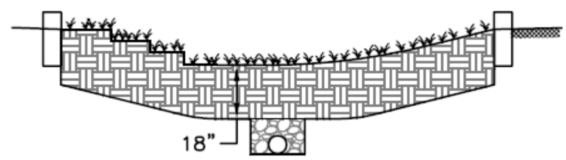
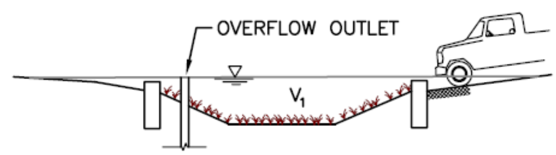
- Increasing the facility area and reducing the surface depth accordingly.
- Sloping the soil mix surface to be deeper than 12" at the middle, but less deep at the edges, so the average 12" depth is achieved (works best on larger facilities).
- Sloping or stepping back the wall as shown in (b) and (c) (requires additional area).
- Allowing shallow flooding on a portion of adjacent landscape or paving when the facility is at peak capacity as shown in (d) (rare and relatively brief events).



(b) Sloped side wall



(c) Stepped back side wall

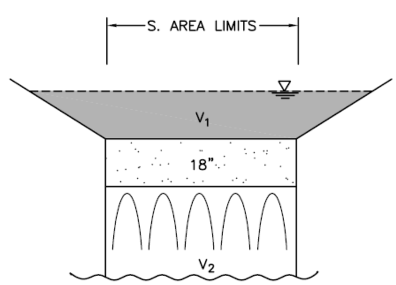


(d) allowing occasional flooding of adjacent landscaping and pavement.

Soil mix. The required soil mix is similar to a loamy sand. It must maintain a minimum percolation rate of 5" per hour throughout the life of the facility, and it must be suitable for maintaining plant life with a minimum of fertilizer use. Typically, on-site soils will not be suitable due to clay content. See Appendix B and check with local staff for further guidance.

Storage and drainage layer. "Class 2 permeable," Caltrans specification 68-1.025, is preferred. Open-graded crushed rock, washed, may be used, but requires 4"-6" washed pea gravel be substituted at the top of the crushed rock gravel layers. Do not use filter fabric to separate the soil mix from the gravel drainage layer or the gravel drainage layer from the native soil.

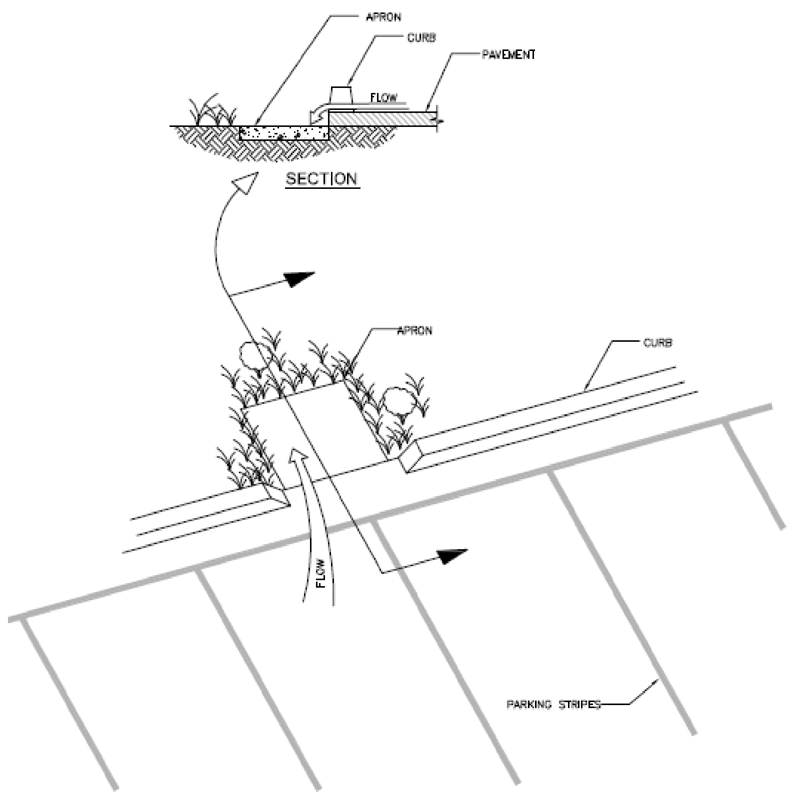
Minimum subsurface volume. No minimum subsurface volume is required for treatment-only facilities. The gravel layer must be extensive enough and deep enough to ensure the soil mix is well-drained. For treatment-a nd-flow-control facilities where the native soils are Hydrologic Soil Group C or D, the minimum subsurface volume V_2 specified in Table 4-8 is equivalent to the minimum area times a 30" deep layer of gravel of 40% porosity (V_2 is the void space, not the entire volume of gravel.) Note that if the facility area is increased, the required depth is correspondingly decreased. If desired, voids created by buried structures such as pipes or arches may be substituted, as long as the voids are



Buried pipes or arches may be used to achieve the required subsurface volume V_2

hydraulically interconnected and the minimum subsurface volume calculated by Equation 4-5 is achieved.

Inlets. Paved areas draining to the facility should be graded, and inlets should be placed, so that runoff remains as sheet flow or as dispersed as possible. Curb cuts should be wide (12" is recommended) to avoid clogging with leaves or debris. Allow for a minimum reveal of 4"-6" between the inlet and soil mix elevations to ensure turf or mulch buildup does not block the inlet. In addition, place an apron of stone or concrete, a foot square or larger, inside each inlet to prevent vegetation from growing up and blocking the inlet.



Recommended design details for bioretention facility inlets (see text).

Where runoff is collected in pipes or gutters and conveyed to the facility, protect the landscaping from high-velocity flows with energy-dissipating rocks. In larger installations, provide cobble-lined channels to better distribute flows throughout the facility.

"Bubble ups" can be used to dissipate energy when runoff is piped from roofs and upgradient paved areas.

Underdrains. In locations where native soils beneath the facility are Hydrologic Soil Group A or B, underdrains are optional but municipal reviewers may require them as a preventative against poor drainage. For treatment-only facilities where native soils are Group C or D, a perforated pipe must be bedded in the gravel layer and must terminate at a storm drain or other approved discharge point. Underdrains must be constructed of rigid pipe and provided with a cleanout.

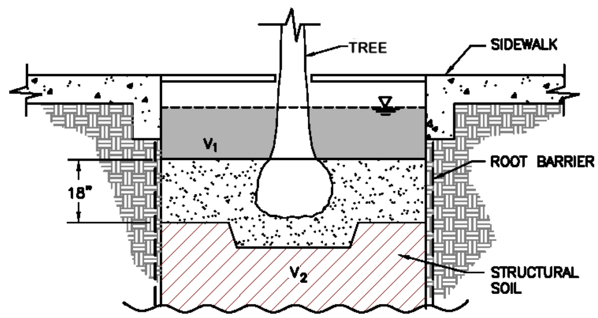
Flow-control orifice. For treatment-and-flow-control facilities, the underdrain must be routed through a device designed to limit flows to that specified in Equation 4-10 or 4-11. Details of combined outlet-and-underdrain facilities are shown on page 76.

Overflow outlets. In treatment-only facilities, overflow outlets must be set high enough to ensure the surface reservoir fills and the entire surface area of soil mix is flooded before the outlet elevation is reached. In swales, this can be achieved with appropriately placed check dams.

In treatment-and-flow-control facilities, the outlet elevation must be set to achieve the minimum surface storage volume calculated using Equation 4-5 and the V_1 sizing factor.

The outlet should be designed to exclude floating mulch and debris.

Vaults, utility boxes and light standards. It is best to locate utilities outside the bioretention facility—in adjacent walkways or in a separate area set aside for this purpose. If utility structures are to be placed within the facility, the locations should be anticipated and adjustments made to ensure the minimum bioretention surface area and volumes are achieved. Leaving the final locations to each individual utility can produce a haphazard, unaesthetic appearance and make the bioretention facility more difficult to maintain.

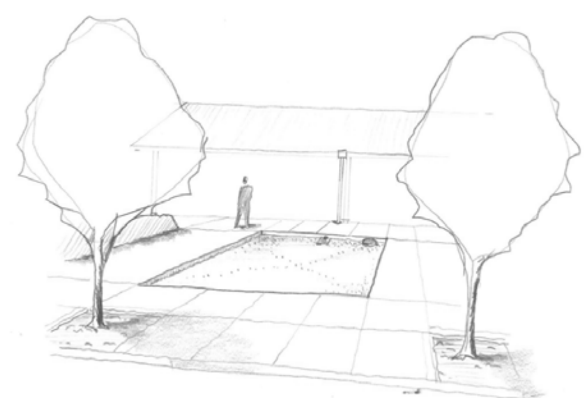


Bioretention facility configured as a tree well.
The root barrier is optional.

Emergency overflow. The site grading plan should anticipate extreme events and potential clogging of the overflow and route emergency overflows safely.

Trees. Bioretention areas can accommodate small or large trees within the minimum areas and volumes calculated by Equation 4-5. Tree canopies intercept rain, and extensive tree roots maintain soil permeability and help retain runoff. Normal maintenance of a bioretention facility should not affect tree lifespan.

The bioretention facility can be integrated with a tree pit of the required depth and filled with structural soil. If a root barrier is used, it can be located to allow tree roots to spread throughout the bioretention facility while protecting adjacent pavement. Locations and planting elevations should be selected to avoid blocking the facility's inlets and outlets as trees mature.



Bioretention facility configured as a recessed decorative lawn with hardscaped edge.

► APPLICATIONS

Multi-purpose landscaped areas. Bioretention facilities are easily adapted to serve multiple purposes. The loamy sand soil mix will support turf or a plant palette suitable to the location and a well-drained soil. See Appendix B for additional guidance on soil, plant selection, and irrigation.

Example landscape treatments:

- Lawn with sloped transition to adjacent landscaping.
- Swale in setback area
- Swale in parking median
- Lawn with hardscaped edge treatment
- Decorative garden with formal or informal plantings
- Traffic island with low-maintenance landscaping
- Raised planter with seating
- Bioretention on a terraced slope

Residential subdivisions. In the design of many subdivisions, it has proven easiest and most effective to drain roofs and driveways to the streets (in the conventional manner) and then drain the streets to bioretention areas, with one bioretention area for each 1 to 6 lots, depending on subdivision layout and topography.

Bioretention facility configured and planted as a lawn/ play area.

Bioretention areas can be placed on one or more separate, dedicated parcels with joint ownership.

Sloped sites. Bioretention facilities must be constructed as a basin or series of basins, with the circumference of each basin level. It may be necessary to add curbs or low retaining walls during final grading if elevations have not been determined with sufficient precision during design.

Design Checklist for Bioretention

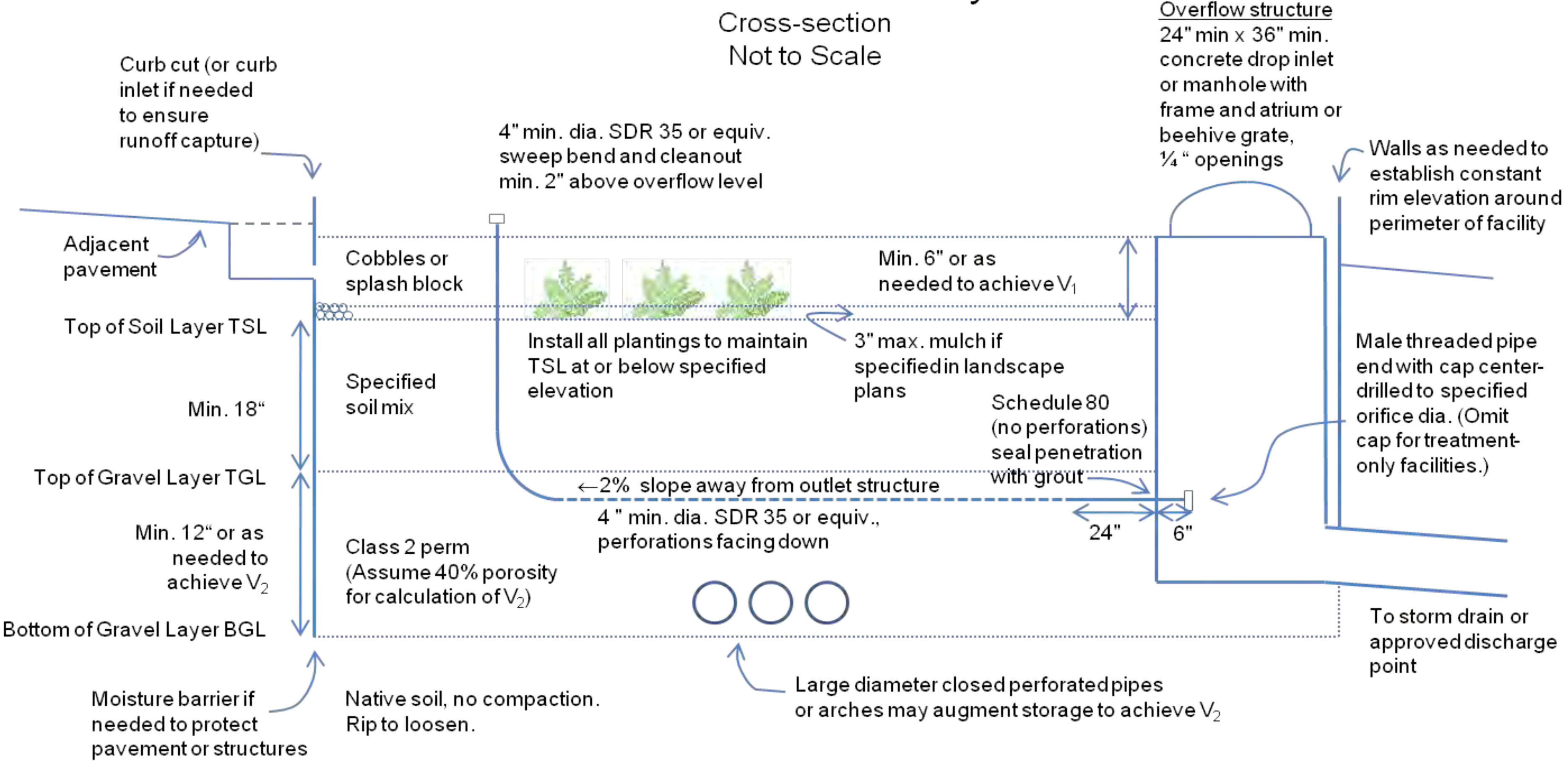
- ❒ Volume or depth of surface reservoir meets or exceeds minimum.
- ❒ 18" depth "loamy sand" soil mix with minimum long-term percolation rate of 5"/hour. See Appendix B.
- ❒ Area of soil mix meets or exceeds minimum.
- ❒ Perforated pipe (PVC SDR 35 or approved equivalent) underdrain bedded in "Class 2 perm" with holes facing downward. Connection and sufficient head to storm drain or approved discharge point (except in "A" or "B" soils).
- ❒ No filter fabric.
- ❒ Underdrain has a clean-out port consisting of a vertical, rigid, non-perforated PVC pipe, with a minimum diameter of 4 inches and a watertight cap.
- ❒ Location and footprint of facility are shown on site plan, landscaping plan, and grading plan.
- ❒ Bioretention area is designed as a basin (level edges) or a series of basins, and grading plan is consistent with these elevations. If facility is designed as a swale, check dams are set so the lip or weir of each dam is at least as high as the toe of the next upstream dam.
- ❒ Curb inlets are 12" wide, have 4"-6" reveal and an apron or other provision to prevent blockage when vegetation grows in, and energy dissipation as needed.
- ❒ Overflow connected to a downstream storm drain or approved discharge point.
- ❒ Emergency spillage will be safely conveyed overland.
- ❒ Plantings are suitable to the climate, exposure, and a well-drained soil, and occasional inundation during large storm events.
- ❒ Irrigation system with connection to water supply, on a separate zone.
- ❒ Vaults, utility boxes, and light standards are located outside the minimum soil mix surface area.
- ❒ When excavating, avoid smearing of the soils on bottom and side slopes. Minimize compaction of native soils and "rip" soils if clayey and/or compacted. Protect the area from construction site runoff.

For treatment-and-flow-control facilities only

- ❒ Volume of subsurface storage meets or exceeds minimum.
- ❒ In "C" and "D" native soils, underdrain is connected to discharge through an appropriately sized orifice or other flow-limiting device.

Bioretention Facility

Cross-section
Not to Scale

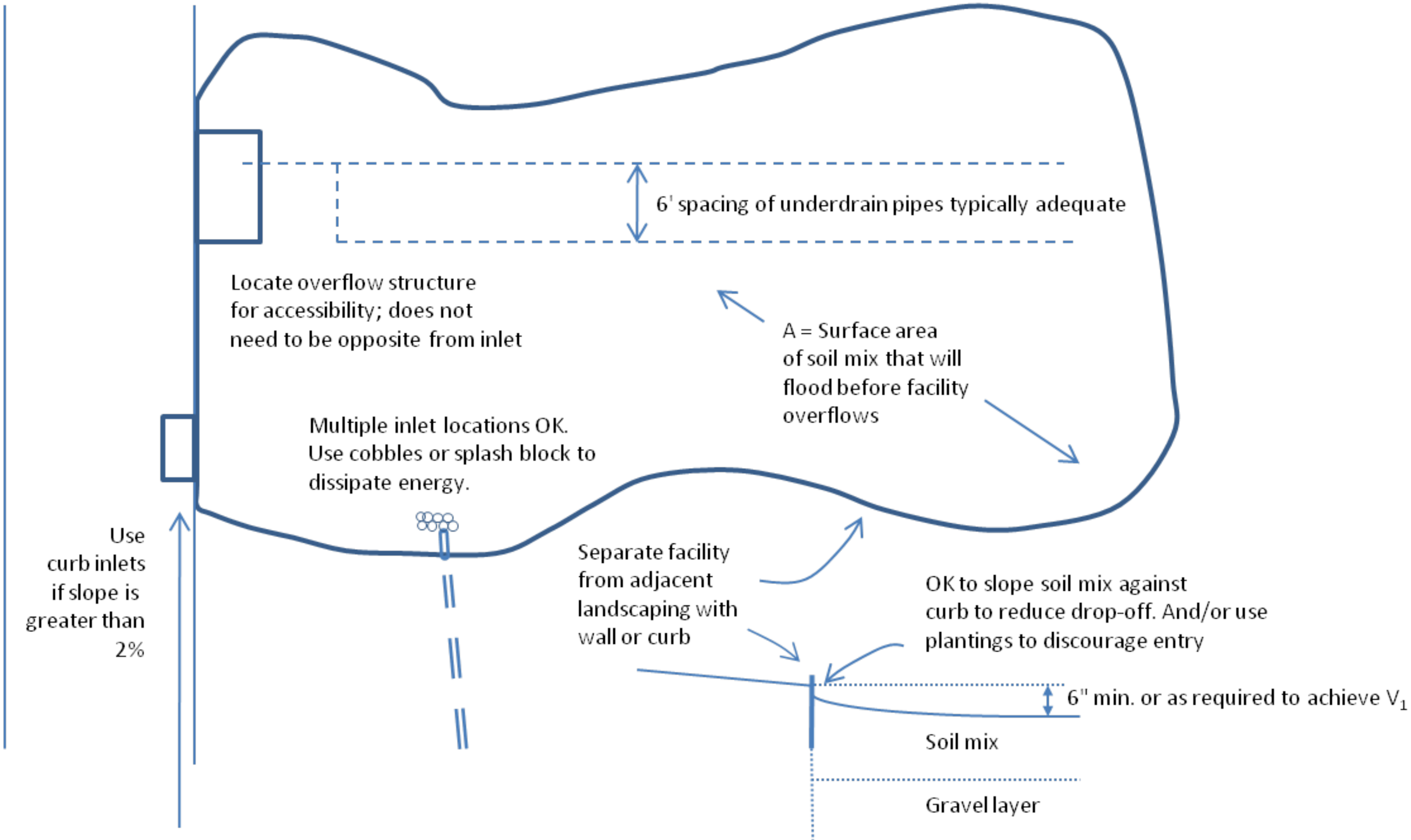


Notes:

- No liner, no filter fabric, no landscape cloth.
- Maintain BGL. TGL, TSL throughout facility area at elevations to be specified in plan.
- Class 2 perm layer may extend below and underneath drop inlet.
- Preferred elevation of perforated pipe underdrain is near top of gravel layer.
- See Appendix B for soil mix specification, planting and irrigation guidance.
- See Chapter 4 for factors and equations used to calculate V_1, V_2 and orifice diameter.

Bioretention Facility

Plan (Not to Scale)



Note: Call out elevations of curb, pavement, inlet, top of soil layer (TSL), bottom of soil layer (BSL), and bottom of gravel layer (BGL) at all inlets and outlets and at key points along edge of facility.

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Flow-through Planter

Planter prior to planting

Flow-through planters treat and detain runoff without allowing seepage into the underlying soil. They can be used next to buildings and on slopes where stability might be affected by adding soil moisture.

Flow-through planters typically receive runoff via downspouts leading from the roofs of adjacent buildings. However, they can also be set in-ground or fit into terraces and receive sheet flow from adjacent paved areas.

Flow-through planters may be used where facilities are located on upper-story plazas, adjacent to building foundations, where seasonal high groundwater would be within 10 feet of the facility, where mobilization of pollutants in soil or groundwater is a concern, and where potential geotechnical hazards are associated with infiltration.

5th Edition

The restriction on where flow-through planters may be used applies to sites subject to treatment-only requirements as well as those subject to treatment-plus-flow-control requirements.

Pollutants are removed as runoff passes through the soil layer and is collected in an underlying layer of gravel or drain rock. A perforated-pipe underdrain must be connected to a storm drain or other discharge point. An overflow outlet conveys flows which exceed the capacity of the planter.

► CRITERIA

Treatment only. For development projects subject only to runoff treatment requirements, the following criteria apply:

Best Uses

- Management of roof runoff
- Next to buildings or on building plazas
- Dense urban areas
- Where infiltration is not desired

Advantages

- Can be used on or next to structures and on slopes
- Versatile
- Can be any shape
- Low maintenance

Limitations

- Can be used only on sites with "C" and "D" soils
- Requires underdrain
- Requires 3-4 feet of head

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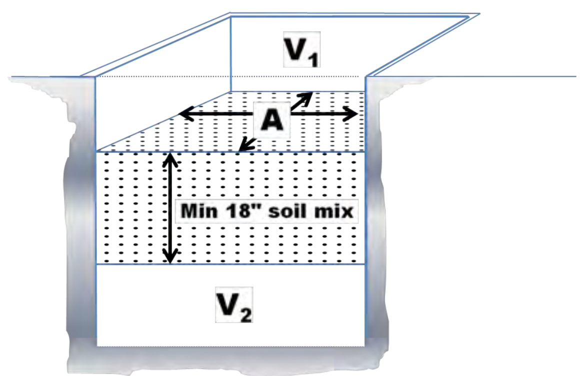
Parameter	Criterion
Soil mix depth	18 inches minimum
Soil mix	See Appendix B
Soil mix surface area	0.04 times tributary impervious area (or equivalent)
Surface reservoir depth	6" minimum; may be sloped to 4" where adjoining walkways.
Underdrain	Required. Perforated pipe (PVC SDR 35 or approved equivalent) embedded in gravel ("Class 2 permeable" recommended), connected to storm drain or other accepted discharge point.

Treatment and flow control. In addition to the treatment requirements above, the flow-through planter must be designed to meet the minimum surface area (A), surface volume (V_1), and subsurface volume (V_2) calculated using the sizing factors and Equation 4-5. In addition, the planter underdrain must be equipped with an orifice or other device to limit flow to that calculated by Equation 4-10 or 4-11. A suggested outlet design is on page 83.

► DETAILS

Configuration. In a vertical-sided box-like planter for treatment-and-flow-control with the minimum surface area A, the minimum surface volume V_1 can be achieved with an overflow height of 10" (12" total height of walls with 2" of freeboard). The minimum subsurface volume V_2 can be achieved with a gravel (Class 2 permeable) depth of 30". This combination results in a planter approximately 5' high. The planter height can be reduced by incorporating void-creating structures into a shallower Class 2 permeable layer or by increasing the planter area so that the minimum V_2 is achieved.



Parameters for flow-through planters for treatment and flow-control: A, V1, and V2.

The planter must be level. To avoid standing water in the subsurface layer, set the perforated pipe underdrain and orifice as nearly flush with the planter bottom as possible.

Inlets. Protect plantings from high-velocity flows by adding rocks or other energy-dissipating structures at downspouts and other inlets.

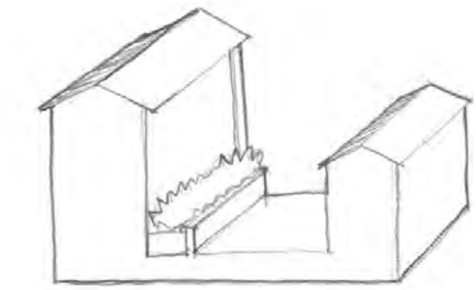
Soil mix. The required soil mix is similar to a loamy sand. It must maintain a minimum percolation rate of 5" per hour throughout the life of the facility, and it must be suitable for maintaining plant life. Typically, on-site soils will not be suitable due to clay content. Various local suppliers have identified mixes which meet these criteria. Check with local staff regarding acceptable soil mixes. See Appendix B for further guidance.

Gravel storage and drainage layer. "Class 2 permeable," Caltrans specification 68-1.025, is recommended. Open-graded crushed rock, washed, may be used, but requires 4"-6" of washed pea gravel be substituted at the top of the crushed rock layer. Do not use filter fabric to separate the soil mix from the gravel drainage layer.

Emergency overflow. The planter design and installation should anticipate extreme events and potential clogging of the overflow and route emergency overflows safely.

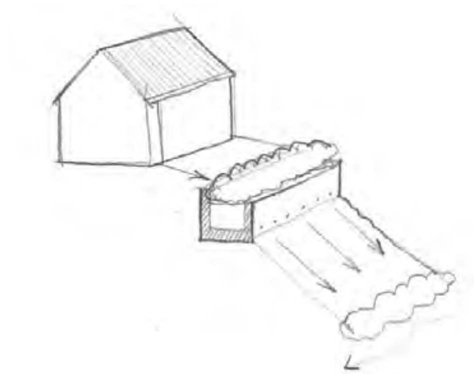
► APPLICATIONS

Adjacent to buildings. Flow-through planters may be located adjacent to buildings, where the planter vegetation can soften the visual effect of the building wall. A setback with a raised planter box may be appropriate even in some neo-traditional pedestrian-oriented urban streetscapes.



Flow-through planter on the plaza level of a podium-style development.

At plaza level. Flow-through planters have been successfully incorporated into podium-style developments, with the planters placed on the plaza level and receiving runoff from the tower roofs above. Runoff from the plaza level is typically managed separately by additional flow-through planters or bioretention facilities located at street level.



Flow-through planter built into a hillside. Flows from the underdrain and overflow must be directed in accordance with local requirements.

Steep slopes. Flow-through planters provide a means to detain and treat runoff on slopes that cannot accept infiltration from a bioretention facility. The planter can be built into the slope similar to a retaining wall. The design should consider the need to access the planter for periodic maintenance. Flows from the planter underdrain and overflow must be directed in accordance with local requirements. It is sometimes possible to disperse these flows to the downgradient hillside.

Design Checklist for Flow-through Planter

- ❒ Location is on an upper-story plaza, adjacent to a building foundation, where seasonal high groundwater would be within 10 feet of the facility, where mobilization of pollutants in soil or groundwater is a concern, or where potential geotechnical hazards are associated with infiltration
- ❒ Reservoir depth is 4"-6" minimum.
- ❒ 18" depth "loamy sand" soil mix with minimum long-term infiltration rate of 5"/hour.
- ❒ Surface area of soil mix meets or exceeds minimum.
- ❒ "Class 2 perm" drainage layer.
- ❒ No filter fabric.
- ❒ Perforated pipe (PVC SDR 35 or approved equivalent) underdrain with outlet located flush or nearly flush with planter bottom.
- ❒ Connection with sufficient head to storm drain or discharge point.
- ❒ Underdrain has a clean-out port consisting of a vertical, rigid, non-perforated PVC pipe, with a minimum diameter of 4" and a watertight cap.
- ❒ Overflow outlet connected to a downstream storm drain or approved discharge point.
- ❒ Location and footprint of facility are shown on site plan and landscaping plan.
- ❒ Planter is set level.
- ❒ Emergency spillage will be safely conveyed overland.
- ❒ Plantings are suitable to the climate, exposure, and a well-drained soil.
- ❒ Irrigation system with connection to water supply, on a separate zone.

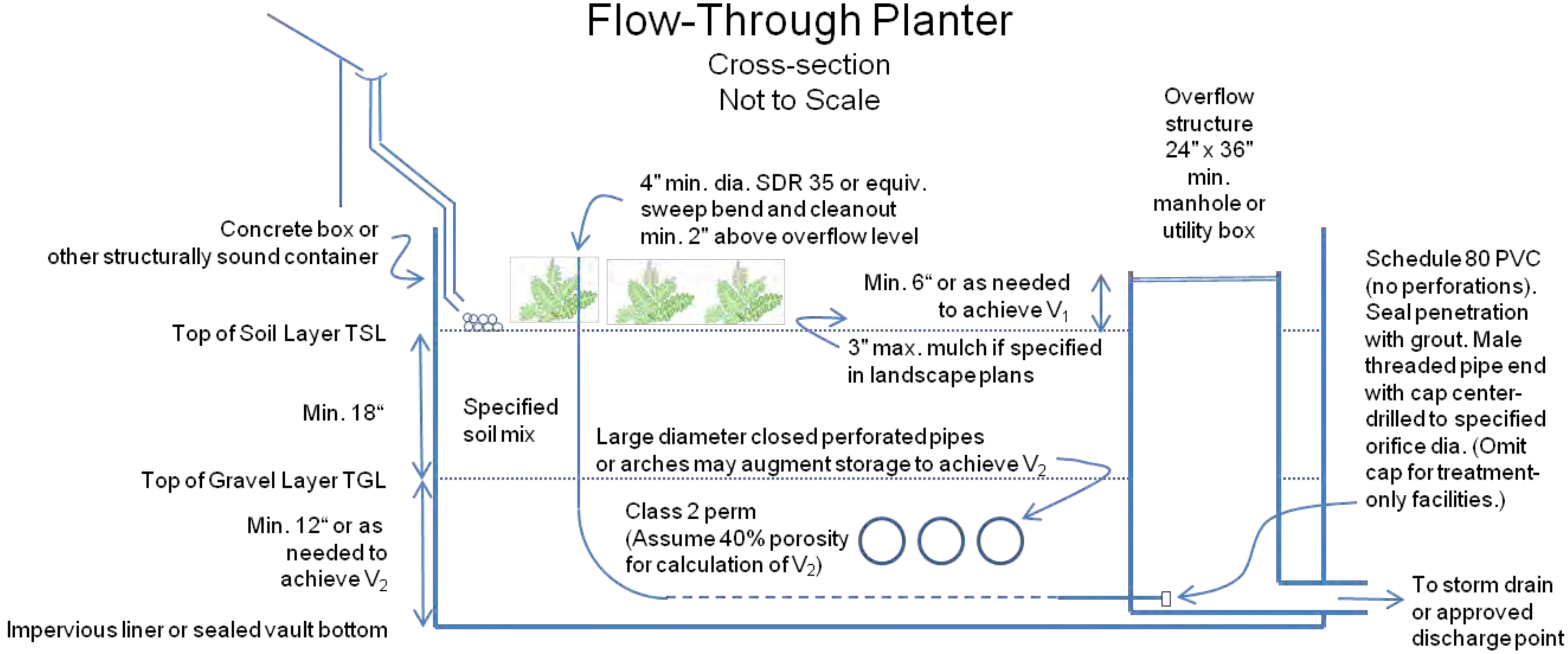
For treatment-and-flow-control flow-through planters only

- ❒ Volume of surface storage meets or exceeds minimum.
- ❒ Volume of subsurface storage meets or exceeds minimum.
- ❒ Underdrain is connected via an appropriately sized orifice or other flow-limiting device.

Flow-Through Planter

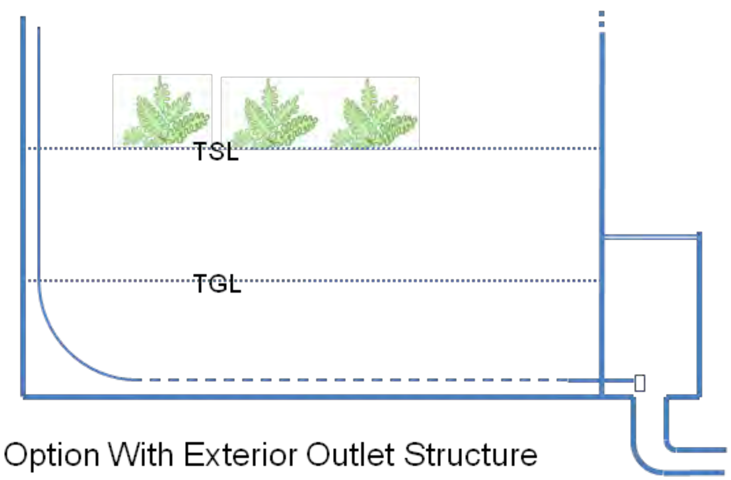
Cross-section

Not to Scale

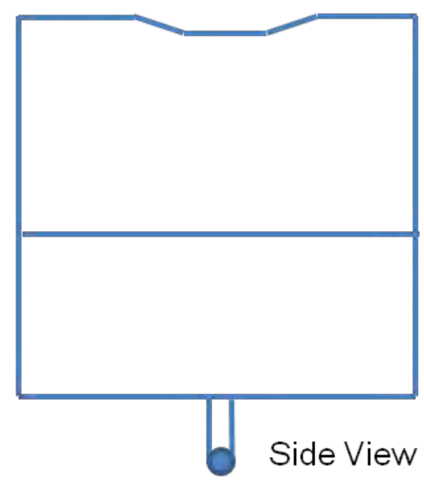


Notes:

- Underdrain to be min. 4" PVC SDR 35 or equiv. with holes facing down.
- Locate underdrain as close as possible to bottom.
- No filter fabric, no landscape cloth.
- See Appendix B for soil specification and planting guidance.
- See Chapter 4 for factors and equations used to calculate V_1, V_2 and orifice diameter



Option With Exterior Outlet Structure
suitable for smaller planters



Side View

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Dry Wells and Infiltration Basins

The typical dry well is a prefabricated structure, such as an open-bottomed vault or box, placed in an excavation or boring. The vault may be empty, which provides maximum space efficiency, or may be filled with rock.

An infiltration basin has the same functional components—a volume to store runoff and sufficient area to infiltrate that volume into the native soil—but is open rather than covered.

► CRITERIA

Dry wells and infiltration basins must be designed with the minimum volume and infiltrative area calculated by Equation 4-5 using the sizing factors in Table 4-8.

Consult with the local municipal engineer regarding the need to verify soil permeability and other site conditions are suitable for dry wells and infiltration basins. Some proposed criteria are on Page 5-12 of Caltrans' 2004 *BMP Retrofit Pilot Study Final Report* (CTSW-RT-01-050).

► DETAILS

Dry wells should be sited to facilitate maintenance and allow for the potential future need for removal and replacement.

In locations where native soils are coarser than a medium sand, the area directly beneath the facility should be over-excavated by two feet and backfilled with sand as a groundwater protection measure.

Best Uses

- Projects on sites with permeable soils

Advantages

- Compact footprint
- Can be installed in paved areas

Limitations

- Can be used only on sites with Group "A" or Group "B" soils
- Requires minimum of 10' from bottom of facility to seasonal high groundwater
- Not suitable for drainage from some industrial areas or arterial roads
- Must be maintained to prevent clogging.
- Typically not as aesthetically pleasing as bioretention facilities

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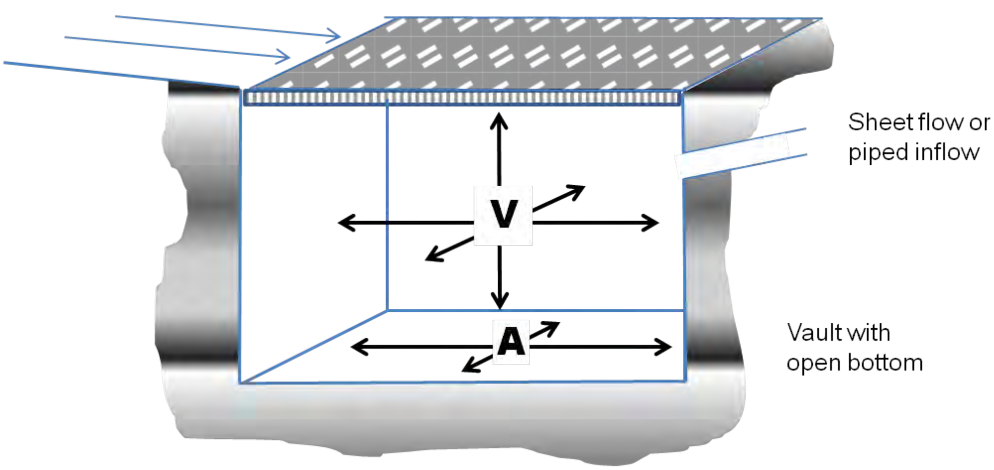
Design Checklist for Dry Wells and Infiltration Basins

- ❐ Volume (V) and infiltrative area (A) meet or exceed minimum.
- ❐ Overflow connected to a downstream storm drain or approved discharge point.
- ❐ Emergency spillage will be safely conveyed overland.
- ❐ Depth from bottom of the facility to seasonally high groundwater elevation is ≥10'.
- ❐ Areas tributary to the facility do not include automotive repair shops; areas subject to high vehicular traffic (25,000 or greater average daily traffic on main roadway or 15,000 or more average daily traffic on intersecting roadway), car washes; fleet storage areas (bus, truck, etc.); nurseries, or other uses that may present an exceptional threat to groundwater quality.
- ❐ Underlying soils are in Hydrologic Soil Group A or B. Infiltration rate is sufficient to ensure a full basin will drain completely within 72 hours. Soil infiltration rate has been confirmed.
- ❐ 10' setback from structures or as recommended by structural or geotechnical engineer



Cistern + Bioretention Facility

In this functional sculpture, a cistern captures roof runoff and drains it slowly to a landscaped area. Photo courtesy of the City of Seattle.

A cistern in series with a bioretention facility or flow-through planter can meet treatment and flow-control requirements where space is limited. The cistern includes an orifice for flow control. The downstream bioretention facility or flow-through planter is sized to accommodate the maximum flow from the cistern orifice.

▶ CRITERIA

Cistern. Size the cistern using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9. The cistern must also include an orifice or other device to limit outflow to the calculated maximum release rate.

Bioretention facility. Size the bioretention facility or flow-through planter using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9.

▶ DETAILS

Preventing mosquito harborage. Cisterns should be designed to drain completely, leaving no standing water. Drains should be located flush with the bottom of the cistern. Alternatively—or in addition—all entry and exit points should be provided with traps or sealed or screened to prevent mosquito entry. Note mosquitoes can enter through

Best Uses

- To meet flow-control requirements in limited space.
- Management of roof runoff
- Dense urban areas

Advantages

- Storage volume can be in any configuration
- Small footprint

Limitations

- Somewhat complex to design, build, and operate
- Requires head for both cistern and bioretention facility

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openings $\frac{1}{16}$" or larger and will fly for many feet through pipes as small as ¼".

Exclude debris. Provide leaf guards and/or screens to prevent debris from accumulating in the cistern.

Ensure access for maintenance. Design the cistern to allow for cleanout. Avoid creating the need for maintenance workers to enter a confined space. Ensure the outlet orifice can be easily accessed for cleaning and maintenance.

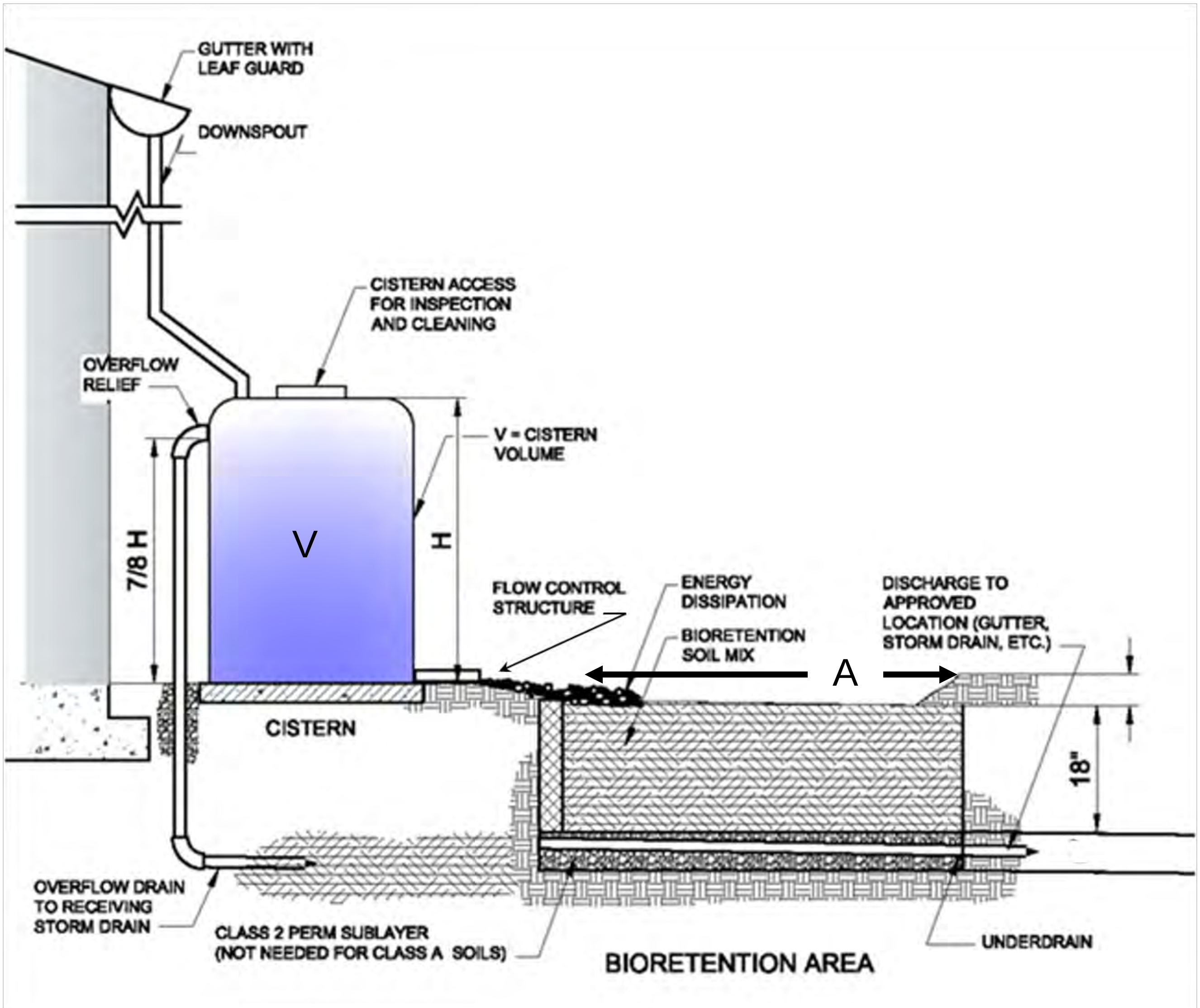
► APPLICATIONS

Shallow ponding on a flat roof. The "cistern" storage volume can be designed in any configuration, including simply storing rainfall on the roof where it falls and draining it away slowly. In sites with Group "D" soils, the required average depth amounts to about ¾".

Cistern attached to a building and draining to a planter. This arrangement allows the flow-through planter to be constructed at a height as low as 30".

Design Checklist for Cistern + Bioretention

- ❐ Cistern volume meets or exceeds calculated minimum V_1.
- ❐ Cistern outlet with orifice or other flow-control device restricts flow to calculated maximum. A center-drilled threaded cap is suggested for easy maintenance.
- ❐ Cistern outlet is piped to bioretention area or flow-through planter.
- ❐ Bioretention surface area meets or exceeds the calculated minimum.
- ❐ Except for surface area, bioretention facility is designed to the criteria for "treatment only" in the "Bioretention Facility" design sheet (p. 69) or "Flow-through Planter" design sheet (p. 79).
- ❐ Cistern is designed to drain completely and/or sealed to prevent mosquito harborage.
- ❐ Design provides for exclusion of debris and accessibility for maintenance.
- ❐ Overflow connected to a downstream storm drain or approved discharge point.
- ❐ Emergency spillage will be safely conveyed overland.


GUTTER WITH LEAF GUARD
DOWNSPOUT
CISTERN ACCESS FOR INSPECTION AND CLEANING
OVERFLOW RELIEF
V = CISTERN VOLUME
7/8 H
V
H
FLOW CONTROL STRUCTURE
ENERGY DISSIPATION
BIORETENTION SOIL MIX
DISCHARGE TO APPROVED LOCATION (GUTTER, STORM DRAIN, ETC.)
A
CISTERN
18"
OVERFLOW DRAIN TO RECEIVING STORM DRAIN
CLASS 2 PERM SUBLAYER (NOT NEEDED FOR CLASS A SOILS)
BIORETENTION AREA
UNDERDRAIN

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Bioretention + Vault

A bioretention facility in series with a vault can meet treatment and flow-control requirements where space is limited. In this configuration, the bioretention facility is sized to a minimum of 4% of the tributary impervious area. The underdrain and overflow from the bioretention facility are routed to a storage vault, which can be located beneath a plaza, sidewalk, or parking area. An orifice limits the rate of discharge from the vault to the storm drain system.

▶ CRITERIA

Bioretention facility. Size and design the bioretention facility to the treatment-only criteria (see Bioretention Facility design sheet, p. 69.)

Vault. Size the vault using Equation 4-5 and the factors and rainfall adjustment equations in Tables 4-8 and 4-9. The vault must include an orifice or other device to limit outflow.

▶ DETAILS

Preventing mosquito harborage. Vaults should be designed to drain completely, leaving no standing water. Where possible, vaults should have an open bottom to allow infiltration into the native soil. If the vault is sealed, then drains should be located flush with the bottom of the vault. Alternatively—or in addition—all entry and exit points, should be provided with traps or sealed or screened to prevent mosquito entry. Note mosquitoes can enter through openings $\frac{1}{16}$" or larger and will fly for many feet through pipes as small as ¼".

Ensure access for maintenance. Design the vault to allow for cleanout. Avoid creating the need for maintenance workers to enter a confined space. Ensure the outlet orifice can be easily accessed for cleaning and maintenance.

▶ APPLICATIONS

Parking lot. Because the required landscaped bioretention facilities is only 4% of the tributary impervious area, the bioretention component can in many cases be integrated into parking lot medians and islands. The vault component can be located beneath aisles or driveways.

Best Uses

- To meet flow-control requirements in limited space
- Parking lots
- Dense urban areas

Advantages

- Smaller footprint than bioretention facility sized for flow control

Limitations

- Somewhat complex to design, build, and operate
- Requires head for both bioretention facility and vault

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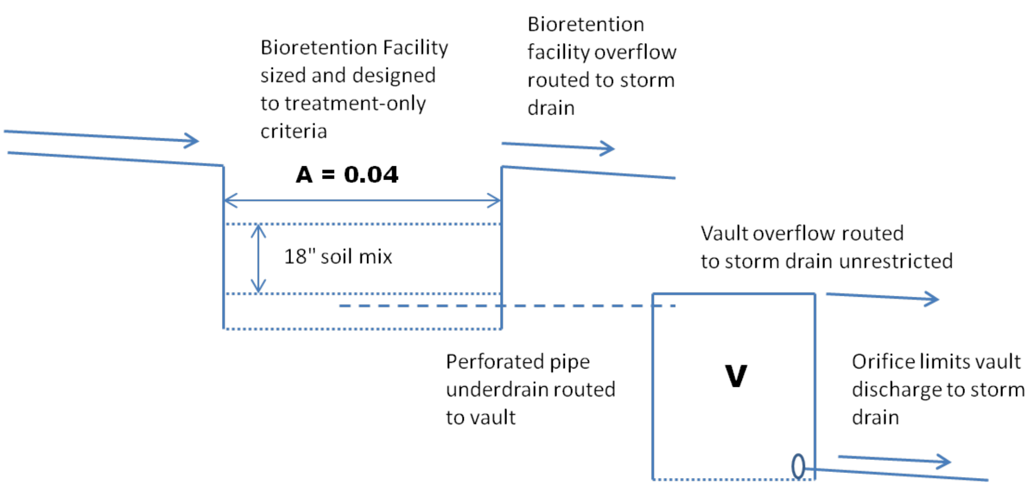
Multiple bioretention facilities draining to a single vault. Two or more bioretention areas can be connected to a single vault. The vault minimum volume and outlet maximum flow rate are the sum of those calculated for each individual bioretention facility.

Vault with pumped discharge. Where insufficient head exists, vaults may be equipped with pumps to discharge (at a rate no greater than the calculated maximum) to a storm drain or approved discharge point.

Design Checklist for Bioretention + Vault

- ❒ Bioretention facility is designed to the treatment-only criteria in the "Bioretention Facility" design sheet (pp. 69-78).
- ❒ Vault volume meets or exceeds calculated minimum.
- ❒ Vault outlet with orifice or other flow-control device restricts flow to calculated maximum.
- ❒ Bioretention facility underdrain is routed to the vault.
- ❒ Bioretention facility overflow is routed to the vault.
- ❒ Sufficient head exists to convey flow from the underdrain to the vault and from the vault to the discharge point.
- ❒ Vault is designed to drain completely and/or sealed to prevent mosquito harborage.
- ❒ Vault design provides for exclusion of debris and accessibility for maintenance.
- ❒ Vault outlet and overflow are connected to a downstream storm drain or approved discharge point.
- ❒ Emergency spillage will be safely conveyed overland.

Bioretention + Vault
Schematic



RB-AR34360

Chapter 5

Construction of Integrated Management Practices

Guidance for preparing construction documents and overseeing construction of Integrated Management Practices

Details of construction are critical to ensuring stormwater facilities work properly. A misplaced inlet, an overflow at the wrong elevation, or the wrong soil mix can make a bioretention facility useless or ineffective even before it comes on-line, and could result in delays to project approvals and additional expense.

Your Stormwater Control Plan must contain enough detail to demonstrate your planned LID features and facilities are feasible and are coordinated with the project site plan, architectural renderings, landscape design, and other information submitted with your application for development approvals. Additional detail must be shown on plans submitted with applications for building and grading permits. During construction, municipal inspectors will check the work against the approved plans.

The Design Sheets in Chapter 4 include details, many of which are critical to proper functioning of the IMP. This chapter describes specific items to be checked during review of construction documents and during construction.

ICON KEY
☞ Helpful Tip
Submittal Requirement
Terms to Look Up
🕮 References & Resources

LID features and facilities have been routinely incorporated into development projects for only a few years. The community of land development professionals and municipal staff continue to compile and analyze "lessons learned" from their experience. The following guidance is based on those lessons.

RB-AR34361

What to Show on Construction Plans

With few exceptions, the plan set should include separate sheets specifically incorporating the features and facilities described in the Stormwater Control Plan. The information on these sheets must be carefully coordinated and made consistent with grading plans, utility plans, landscaping plans, and (in many cases) architectural plans. Consider including the grading plan (screened) as background for the stormwater sheets. It may also be appropriate to show portions of the roofing plan wherever roof ridges define Drainage Management Areas (DMAs).

Design Note

Avoid creating bioretention areas that are deeper than necessary, and avoid having landscaped slopes draining on to the top of bioretention soil. Use surface drainage, such as valley gutters or trench drains, to keep drainage within a few inches below top of pavement. Or use a "bubble up" to bring drainage back up closer to the surface.

► GRADING IS KEY

Municipal staff will typically require plans showing the outline of each bioretention facility or other IMP, along with the delineation of DMAs. Call out elevations, including the following:

- At curb cut inlets, show elevations for top of paving, top of curb, and top of the bioretention soil layer.
- At overflow grates, show the grate elevation and the adjacent top of soil elevation.
- Call out elevations of piped inlets.

Show how DMAs follow grade breaks, consistent with the grading plan and the Stormwater Control Plan.

For treatment-and-flow-control IMPs, demonstrate how the minimum surface volume V_1 is attained by the design.

► SHOW HOW RUNOFF MOVES

As needed for clarity, show the direction of runoff flow across roofs and pavement and into IMPs. For runoff conveyed via pipes or channels, show locations, slopes, and elevations at the beginning and end of each run.

For roof drainage, show the routing of roof leaders. Use drawings or notes to make clear how drainage from leaders is routed under walkways, across pavement, through drainage pipes, or by other means to reach the IMP.

Show pipes or channels connecting the IMP underdrain and overflow to the site drainage system, municipal storm drain system, or other approved discharge point. Call out slopes and key elevations.

RB-AR34362

► SHOW IMPS IN CROSS-SECTION

Use one or more cross-section drawings to illustrate details and key IMP elevations, including bottom of excavation, top of gravel layer, top of soil layer, edge treatments, inlet elevations, overflow grate elevations, rim elevations, locations of rock for energy dissipation, moisture barriers, and other information. Call out specifications or refer to specifications elsewhere for gravel (Class 2 perm) and soil mix.

Show the arrangement and details of outlet structures, particularly for treatment-plus-flow-control IMPs. The details in the Chapter 4 design sheets for bioretention and flow-through planters may be used as a general guide.

Items to Be Inspected During Construction

Successful construction of IMPs requires attention to detail during every stage of the construction process, from initial layout to rough grading, installation of utilities, construction of buildings, paving, landscaping, and final clean-up and inspection.

Construction project managers need to understand the purpose and function of IMPs and know how to avoid common missteps that can occur during construction. For bioretention facilities, the following operating principles should be noted at a pre-construction meeting.

- Runoff flow from the intended tributary drainage management area must flow into the facility.
- The surface reservoir must fill to its intended volume during high inflows.
- Runoff must filter rapidly through the layer of imported soil mix.
- Filtered runoff must infiltrate into the native soil to the extent possible (or allowable).
- Remaining runoff must be captured and drained to a storm drain or other approved location.

See the model construction inspection checklist on the following pages.

IMP CONSTRUCTION CHECKLIST

LAYOUT (to be confirmed prior to beginning excavation)

- ❐ Square footage of the facility meets or exceeds minimum shown in Stormwater Control Plan
- ❐ Site grading and grade breaks are consistent with the boundaries of the tributary Drainage Management Area(s) (DMAs) shown in the Stormwater Control Plan
- ❐ Inlet elevation of the facility is low enough to receive drainage from the entire tributary DMA
- ❐ Locations and elevations of overland flow or piping, including roof leaders, from impervious areas to the facility have been laid out and any conflicts resolved
- ❐ Rim elevation of the facility is laid out to be level all the way around, or elevations are consistent with a detailed cross-section showing location and height of interior dams
- ❐ Locations for vaults, utility boxes, and light standards have been identified so that they will not conflict with the facility
- ❐ Facility is protected as needed from construction-phase runoff and sediment

EXCAVATION (to be confirmed prior to backfilling or pipe installation)

- ❐ Excavation conducted with materials and techniques to minimize compaction of soils within the facility area
- ❐ Excavation is to accurate area and depth
- ❐ Slopes or side walls protect from sloughing of native soils into the facility
- ❐ Moisture barrier, if specified, has been added to protect adjacent pavement or structures.
- ❐ Native soils at bottom of excavation are ripped or loosened to promote infiltration

OVERFLOW OR SURFACE CONNECTION TO STORM DRAINAGE
(to be confirmed prior to backfilling with any materials)

- ❐ Overflow is at specified elevation (typically no lower than two inches below facility rim)
- ❐ No knockouts or side inlets are in overflow riser
- ❐ Overflow location selected to minimize surface flow velocity (near, but offset from, inlet recommended)
- ❐ Grating excludes mulch and litter (beehive or atrium-style grates with ¼" openings recommended)
- ❐ Overflow is connected to storm drain via appropriately sized piping

UNDERGROUND CONNECTION TO STORM DRAIN/OUTLET ORIFICE
(to be confirmed prior to backfilling IMP with any materials)

- ❐ Perforated pipe undedrain (PVC SDR 35 or approved equivalent) is installed with holes facing down
- ❐ Perforated pipe is connected to storm drain (treatment only) or orifice (treatment-and-flow-control)
- ❐ Underdrain pipe is at elevation shown in plans. In facilities allowing infiltration, preferred elevation is above native soil but low enough to be covered by at least 2 inches of Class 2 perm; in sealed planter boxes or bioretention facilities with liners, preferred elevation is as near bottom as possible
- ❐ Cleanouts are in accessible locations and connected via sweeps
- ❐ Structures (arches or large diameter pipes) for additional surface storage are installed as shown in plans and specifications and have the specified volume

(continued)

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IMP CONSTRUCTION CHECKLIST (CONTINUED)

DRAIN ROCK/SUBDRAIN (to be confirmed prior to installation of soil mix)

- ❒ Rock is installed as specified. Class 2 permeable, Caltrans specification 68-1.025 recommended, or 4"-6" pea gravel is installed at the top of the crushed rock layer
- ❒ Rock is smoothed to a consistent top elevation. Depth and top elevation are as shown in plans
- ❒ Slopes or side walls protect from sloughing of native soils into the facility
- ❒ No filter fabric is placed between the subdrain and soil mix layers

SOIL MIX

- ❒ Soil mix is as specified. Quality of mix is confirmed by delivery ticket or on-site testing as appropriate to the size and complexity of the facility
- ❒ Mix installed in lifts not exceeding 12"
- ❒ Mix is not compacted during installation but may be thoroughly wetted to encourage consolidation
- ❒ Mix is smoothed to a consistent top elevation. Depth of mix (18" min.) and top elevation are as shown in plans, accounting for depth of mulch to follow and required reservoir depth

IRRIGATION

- ❒ Irrigation system is installed so it can be controlled separately from other landscaped areas. Smart irrigation controllers and drip emitters are recommended
- ❒ Spray heads, if any, are positioned to avoid direct spray into outlet structures

PLANTING

- ❒ Plants are installed consistent with approved planting plan
- ❒ Any trees and large shrubs are staked securely
- ❒ No fertilizer is added; compost tea may be used
- ❒ No native soil or clayey material are imported into the facility with plantings
- ❒ 1"-2" mulch may be applied following planting; mulch selected to avoid floating
- ❒ Final elevation of soil mix maintained following planting
- ❒ Curb openings are free of obstructions

FINAL ENGINEERING INSPECTION

- ❒ Drainage Management Area(s) are free of construction sediment and landscaped areas are stabilized
- ❒ Inlets are installed to provide smooth entry of runoff from adjoining pavement, have sufficient reveal (drop from the adjoining pavement to the top of the mulch or soil mix, and are not blocked
- ❒ Inflows from roof leaders and pipes are connected and operable
- ❒ Temporary flow diversions are removed
- ❒ Rock or other energy dissipation at piped or surface inlets is adequate
- ❒ Overflow outlets are configured to allow the facility to flood and fill to near rim before overflow
- ❒ Plantings are healthy and becoming established
- ❒ Irrigation is operable
- ❒ Facility drains rapidly; no surface ponding is evident
- ❒ Any accumulated construction debris, trash, or sediment is removed from facility

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Chapter

6

Operation & Maintenance of Stormwater Facilities

How to prepare a customized Stormwater Facilities Operation & Maintenance Plan for the treatment BMPs on your site.

Stormwater NPDES Permit Provision C.3.e requires each municipality verify stormwater treatment and flow-control facilities are adequately maintained. Municipalities must report the results of inspections to the Water Boards annually.

Facilities you install as part of your project will be incorporated into the local municipality's verification program. This is a six-stage process:

1. Determine who will own the facility and be responsible for its maintenance in perpetuity and document this in your Stormwater Control Plan. The Stormwater Control Plan must also identify the means by which ongoing maintenance will be assured (for example, a maintenance agreement that runs with the land).

2. Identify typical maintenance requirements, allow for these requirements in your project planning and preliminary design, and document the typical maintenance requirements in your Stormwater Control Plan.

3. Prepare an Operation and Maintenance Plan (O&M Plan) for the site incorporating detailed requirements for each treatment and flow-control facility. Typically, a draft O&M Plan must be submitted with the building permit application, and a final O&M Plan must be submitted for review and approved by the municipality prior to building permit final and issuance of a certificate of occupancy. Local requirements vary as to schedule. Check with municipal staff.

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4. Maintain the facilities from the time they are constructed until ownership and maintenance responsibility is formally transferred.

5. Formally transfer operation and maintenance responsibility to the site owner or occupant. A warranty, secured by a bond, or other financial instrument, may be required to secure against lack of performance due to flaws in design or construction. A typical warranty period will cover two rainy seasons.

6. Maintain the facilities in perpetuity and comply with your municipality's self-inspection, reporting, and verification requirements.

See the schedule for these stages in Table 6-1. Again, local requirements will vary.

TABLE 6-1. SCHEDULE FOR PLANNING operation and maintenance of stormwater treatment and flow-control faciliites

Stage	*Description*	*Where documented*	*Schedule*
1	Determine facility ownership and maintenance responsibility	Stormwater Control Plan	Discuss with planning staff at pre-application meeting
2	Identify typical maintenance requirements	Stormwater Control Plan	Submit with planning & zoning application
3	Develop detailed operation and maintenance plan	O&M Plan	Submit draft with Building Permit application; final due before building permit final and applying for a Certificate of Occupancy
4	Interim operation and maintenance of facilities	As required by municipal O&M verification program	During and following construction including warranty period
5	Formal transfer of operation & maintenance responsibility	As required by municipal O&M verification program	On sale and transfer of property or permanent occupancy
6	Ongoing maintenance and compliance with inspection & reporting requirements	As required by municipal O&M verification program	In perpetuity

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Stage 1: Ownership and Responsibility

Your Stormwater Control Plan must specify a means to finance and implement maintenance of treatment and flow-control facilities in perpetuity.

Depending on the intended use of your site and the policies of the local municipality, this may require one or more of the following:

- Execution of a maintenance agreement that "runs with the land."
- Creation of a homeowners association (HOA) and execution of an agreement by the HOA to maintain the facilities as well as an annual inspection fee.
- Formation of a new community facilities district or other special district, or addition of the properties to an existing special district.
- Dedication of fee title or easement transferring ownership of the facility (and the land under it) to the municipality.

Ownership and maintenance responsibility for treatment and flow-control facilities should be discussed at the beginning of project planning, typically at the pre-application meeting for planning and zoning review. Experience has shown provisions to finance and implement maintenance of treatment and flow-control facilities can be a major stumbling block to project approval, particularly for small residential subdivisions. (See "Applying C.3 to New Subdivisions" in Chapter 1.)

► PRIVATE OWNERSHIP AND MAINTENANCE

The municipality may require—as a condition of project approval—that a maintenance agreement be executed.

The CCCWP has prepared the following model agreements:

- Operation and Maintenance Agreement for a Single Parcel with a Stormwater Management Facility
- Operation and Maintenance Agreement for Subdivisions with Stormwater Management Facilities
- Operation and Maintenance Agreement for Subdivisions with Stormwater Management Facilities and a Homeowners Association
- CC&R and Subdivision Map Provisions for Subdivisions with Stormwater Management Facilities

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- CC&R Provisions for Subdivisions with Stormwater Management Facilities and a Homeowners Association

The model agreements "run with the land," so the agreement executed by a developer is binding on the owners of the subdivided lots. The agreement must be recorded prior to conveyance of the subdivided property.

ICON KEY

☞	Helpful Tip
✍	Submittal Requirement
👓	Terms to Look Up
📖	References & Resources

The model agreements provide the municipality may collect a management and/or inspection fee established by the standard fee schedule. In addition, the agreements provide that, if the property owner fails to maintain the stormwater facility, the municipality may enter the property, restore the stormwater facility to good working order and obtain reimbursement, including administrative costs, from the property owner.

To augment and enforce maintenance requirements, the County established a two-tiered Community Facilities District (Mello-Roos) throughout the unincorporated area to cover the costs of inspections, reporting to the Water Board and, if necessary, code enforcement and maintenance and repair of individual facilities. Some cities and towns may have similar districts.

► TRANSFER TO PUBLIC OWNERSHIP

Municipalities may sometimes choose to have a treatment and flow-control facility deeded to the public in fee or as an easement and maintain the facility as part of the municipal storm drain system. The municipality may recoup the costs of maintenance through a special tax, assessment district, or similar mechanism.

Locating an IMP in a public right-of-way or easement creates an additional design constraint—along with hydraulic grade, aesthetics, landscaping, and circulation. However, because sites typically drain to the street, it may be possible to locate a bioretention swale parallel with the edge of the parcel. The facility may complement, or substitute for, an underground storm drain system.

Local Requirements

Cities, towns, or the County may have requirements that differ from, or are in addition to, this countywide Guidebook. See Appendix A and check with local planning and community development staff.

Even if the facility is to be deeded or transferred to the municipality after construction is complete, it is still the responsibility of the builder to identify general operation and maintenance requirements, prepare a detailed operation and maintenance plan, and to maintain the facility until that responsibility is formally transferred.

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Stage 2: General Maintenance Requirements

Include in your Stormwater Control Plan a general description of anticipated facility maintenance requirements. This will help ensure that:

- Ongoing costs of maintenance have been considered in your facility selection and design.
- Site and landscaping plans provide for access for inspections and by maintenance equipment.
- Landscaping plans incorporate irrigation requirements for facility plantings.
- Initial maintenance and replacement of facility plantings is incorporated into landscaping contracts and guarantees.

Fact sheets available on the CCCWP C.3 web page describe general maintenance requirements for the types of stormwater facilities featured in the LID Design Guide (Chapter 4). You can use this information to specify general maintenance requirements in your Stormwater Control Plan.

Maintenance fact sheets for conventional stormwater facilities are available in the California Stormwater BMP Handbooks.

Stage 3: Stormwater Facilities O&M Plan

Submit a draft O&M Plan with construction documents when you apply for permits to begin grading or construction on the site. Revise your draft O&M plan in response to any comments from your municipality, and incorporate new information and changes developed during project construction. Submit a revised, final O&M plan before construction is complete.

Your Final Stormwater Control O&M Plan must be submitted to and approved by your municipality before your building permit can be made final and a certificate of occupancy issued.

Your O&M Plan must be kept on-site for use by maintenance personnel and during site inspections. It is also recommended that a copy of the Stormwater Control Plan be kept onsite as a reference.

Municipal Regional Permit Provision C.3.h requires Contra Costa municipalities periodically verify operation and maintenance (O&M) of facilities installed in their jurisdiction. Each year, they must report to the Water Board the facilities inspected that year and the status of each.

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The final O&M plan should incorporate solutions to any problems noted or changes that occurred during construction. For this reason, the final O&M plan may be submitted at the end of the construction period, before the application for final building permit and Certificate of Occupancy.

► TOOLS AND ASSISTANCE

The following step-by-step instructions—and forms available on the CCCWP website—will help you prepare your Stormwater Control Operation and Maintenance Plan. You may use, adapt, and assemble these documents to prepare your own Plan, which will be customized to the specific needs of your site.

These include:

- A form for stating or updating key contact information.
- An example Inspection and Maintenance Log.
- A format for an independent inspector's annual inspection report.
- An example maintenance matrix including necessary maintenance activities, recommended frequency of inspections of maintenance, and indications that maintenance is necessary.

Additional useful references, including links to additional documents, are available in "References and Resources" at the end of this chapter.

► YOUR O&M PLAN: STEP BY STEP

The following step-by-step guidance will help you prepare each required section of your Stormwater Control Operation and Maintenance Plan.

Preparation of the plan will require familiarity with your stormwater facilities as they have been constructed and a fair amount of "thinking through" plans for their operation and maintenance. The text and forms provided here will assist you, but are no substitute for thoughtful planning.

► STEP 1: DESIGNATE RESPONSIBLE INDIVIDUALS

To begin creating your O&M Plan, your organization must designate and identify:

- The individual who will have direct responsibility for the maintenance of stormwater controls. This individual should be the designated contact with municipal inspectors and should sign self-inspection reports and any correspondence with the municipality regarding verification inspections.

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- Employees or contractors who will report to the designated contact and are responsible for carrying out BMP operation and maintenance.
- The corporate officer authorized to negotiate and execute any contracts that might be necessary for future changes to operation and maintenance or to implement remedial measures if problems occur.
- Your designated respondent to problems, such as clogged drains or broken irrigation mains, that would require immediate response should they occur during off-hours.

It is recommended to use the form available on the CCCWP website to list this information. Updated contact information must be provided to the municipality immediately whenever a property is sold and whenever designated individuals or contractors change. Complete a new form—and mail or fax a copy to the municipality—whenever this occurs.

Draw or sketch an organization chart to show the relationships of authority and responsibility between the individuals responsible for O&M. This need not be elaborate, particularly for smaller organizations.

Describe how funding for BMP operation and maintenance will be assured, including sources of funds, budget category for expenditures, process for establishing the annual maintenance budget, and process for obtaining authority should unexpected expenditures for major corrective maintenance be required.

Describe how your organization will accommodate initial training of staff or contractors regarding the purpose, mode of operation, and maintenance requirements for the stormwater facilities on your site. Also, describe how your organization will ensure ongoing training as needed and in response to staff changes.

► STEP 2: SUMMARIZE DRAINAGE AND BMPS

Incorporate the following information from your Stormwater Control Plan into your O&M Plan:

- Figures delineating and designating pervious and impervious areas.
- Figures showing locations of stormwater facilities on the site.
- Tables of pervious and impervious areas served by each facility.

Review the Stormwater Control Plan narrative that describes each facility and its tributary drainage area and update the text to incorporate any changes that may have occurred during planning and zoning review, building permit review, or construction. Incorporate the updated text into your O&M Plan.

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► STEP 3: DOCUMENT FACILITIES "AS BUILT"

Include the following information from final construction drawings:

- Plans, elevations, and details of all facilities. Annotate if necessary with designations used in the Stormwater Control Plan.
- Design information or calculations submitted in the detailed design phase (i.e., not included in the Stormwater Control Plan)
- Specifications of construction for facilities, including sand or soil, compaction, pipe materials and bedding.

In the final O&M Plan, incorporate field changes to design drawings, including changes to any of the following:

- Location and layouts of inflow piping, flow splitter boxes, and piping to off-site discharge
- Depths and layering of soil, sand, or gravel
- Placement of filter fabric or geotextiles (not recommended between soil and gravel layers of bioretention facilities)
- Changes or substitutions in soil or other materials.
- Natural soils encountered (e.g. sand or clay lenses)

► STEP 4: PREPARE CUSTOMIZED MAINTENANCE PLANS

Prepare a maintenance plan, schedule, and inspection checklists (routine, annual, and after major storms) for each facility. Plans and schedules for two or more similar facilities on the same site may be combined.

Use the following resources to prepare your customized maintenance plan, schedule, and checklists.

- Specific information noted in Steps 2 and 3, above.
- Other input from the facility designer, municipal staff, or other sources.
- BMP Operation and Maintenance Fact Sheets (available on the CCCWP C.3 web page).

Note any particular characteristics or circumstances that could require attention in the future, and include any troubleshooting advice.

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Also include manufacturer's data, operating manuals, and maintenance requirements for any:

- Pumps or other mechanical equipment.
- Proprietary devices used as or in conjunction with BMPs.

Manufacturers' publications should be referenced in the text (including models and serial numbers where available). Copies of the manufacturers' publications should be included as an attachment in the back of your O&M Plan or as a separate document.

To better organize your maintenance plan, consider using the "O&M Maintenance Matrix" available on the Program's C.3 web page to present inspection frequencies, observations, and appropriate maintenance response.

► STEP 5: COMPILE O&M PLAN

Your O&M Plan should follow this general outline:

I. Inspection and Maintenance Log

II. Updates, Revisions and Errata

III. Introduction

A. Narrative overview describing the site; drainage areas, routing, and discharge points; and treatment and flow control facilities

IV. Responsibility for Maintenance

A. General

(1) Name and contact information for responsible individual(s).

(2) Organization chart or charts showing organization of the maintenance function and location within the overall organization.

(3) Reference to Operation and Maintenance Agreement (if any). A copy of the agreement should be attached.

(4) Maintenance Funding

(a) Sources of funds for maintenance

(b) Budget category or line item

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(c) Description of procedure and process for ensuring adequate funding for maintenance

B. Staff Training Program

C. Records

D. Safety

V. Summary of Drainage Areas and Stormwater Facilities

A. Drainage Areas

(1) Drawings showing pervious and impervious areas (copied or adapted from Stormwater Control Plan)

(2) Designation and description of each drainage area and how flow is routed to the corresponding facility.

B. Treatment and Flow Control Facilities

(1) Drawings showing location and type of each facility

(2) General description of each facility (Consider a table if more than two facilities)

(a) Area drained and routing of discharge.

(b) Facility type and size

VI. BMP Design Documentation

A. "As-built" drawings of each facility (design drawings in the draft Plan)

B. Manufacturer's data, manuals, and maintenance requirements for pumps, mechanical or electrical equipment, and proprietary facilities (include a "placeholder" in the draft plan for information not yet available).

C. Specific operation and maintenance concerns and troubleshooting

VII. Maintenance Schedule or Matrix

A. Maintenance Schedule for each facility with specific requirements for:

(1) Routine inspection and maintenance

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(2) Annual inspection and maintenance

(3) Inspection and maintenance after major storms

B. Service Agreement Information

Assemble and make copies of your O&M Plan. One or more copies must be submitted to the municipality, and at least one copy kept on-site. Here are some suggestions for formatting the O&M Plan:

- Format plans to 8½" x 11" to facilitate duplication, filing, and handling.
- Include the revision date in the footer on each page.
- Scan graphics and incorporate with text into a single electronic file. Keep the electronic file backed-up so that copies of the O&M Plan can be made if the hard copy is lost or damaged.

► STEP 6: UPDATES

Your Stormwater Control Operation and Maintenance Plan will be a living document.

Operation and maintenance personnel may change; mechanical equipment may be replaced, and additional maintenance procedures may be needed. Throughout these changes, the O&M Plan must be kept up-to-date.

Updates may be transmitted to your municipality at any time. However, at a minimum, updates to the O&M Plan must accompany the annual inspection report. These updates should reference the sections of the Plan being changed and should be placed in reverse chronological order (most recent at the top) in Section II of the binder. If the entire O&M Plan is updated, as it should be from time to time, these updates should be removed from the first section, but may be filed (perhaps in the back of the binder) for possible future reference.

Stage 4: Interim Operation & Maintenance

In accordance with NPDES Permit Provision C.3.e.ii, include the following statement in your Stormwater Control Plan:

> The property owner accepts responsibility for interim operation and maintenance of stormwater treatment and flow-control facilities until such time as this responsibility is formally transferred to a subsequent owner.

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Applicants will typically be required to warranty stormwater facilities against lack of performance due to flaws in design or construction for a minimum of two rainy seasons following completion of construction. The warranty may need to be secured by a bond or other financial instrument.

Stage 5: Transfer Responsibility

As part of the final O&M plan, note the expected date when responsibility for operation and maintenance will be transferred. Notify your municipality when this transfer of responsibility takes place.

Stage 6: Operation & Maintenance Verification

Each Contra Costa municipality will implement a Stormwater Treatment Measures Operation and Maintenance Verification Program, including periodic site inspections.

Local stormwater ordinances state municipalities may require an annual certificate of compliance certifying operation and maintenance of treatment and flow-control facilities. To obtain a certificate of compliance, the responsible party must request and pay for an inspection from the municipality each year. Alternatively, owners or lessees may arrange for inspection by a private company authorized by the municipality. Based on the results of the inspection, the municipality may issue a certificate, issue a conditional certificate requiring correction of noted deficiencies by a specific date, or deny the certificate.

Some municipalities have established alternative procedures. Check with local staff for requirements.

References and Resources

- *Model Stormwater Ordinance (CCCWP, 2005)*
- *Start at the Source* (BASMAA, 1999) pp. 139-145.
- *Urban Runoff Quality Management* (WEF/ASCE, 1998). pp 186-189.
- *Stormwater Management Manual* (Portland, 2004). Chapter 3.
- *California Storm Water Best Management Practice Handbooks* (CASQA, 2003).
- *Best Management Practices Guide* (Public Telecommunications Center for Hampton Roads, 2002).
- Contra Costa Clean Water Program *Vector Control Plan*
- Operation, Maintenance, and Management of Stormwater Management Systems (Watershed Management Institute, 1997)

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Appendix

A

Local Exceptions & Requirements

Municipality-specific procedures, policies, and submittal requirements.
Obtain from your municipal planning and community development department.

The Contra Costa Clean Water Program C.3 web page includes links to each Contra Costa municipality's C.3 information.

Appendix B

Soils, Plantings, and Irrigation for Bioretention Facilities

Additional guidance for design and construction of bioretention facilities and flow-through planters

Bioretention facility owners are responsible for ensuring the following standards of performance are achieved throughout the life of the facility:

- Runoff must percolate through the imported bioretention soil mix at a minimum rate of 5" per hour.
- Plantings must be maintained in a healthy condition without use of conventional fertilizers or pesticides.
- Irrigation systems must minimize water use and be controlled to prevent overwatering and underdrain flow during dry weather.

As described in Chapter 5, municipalities will periodically verify these standards continue to be achieved. Operation and maintenance verification is required by the municipalities' stormwater NPDES permit issued by the Regional Water Quality Control Board.

The design criteria and checklists and other guidance in Chapter 4—including the design sheets—aim to ensure new bioretention facilities and planter boxes can reliably meet these standards of performance.

The additional guidance in this Appendix will assist applicants and their designers as they proceed from

Appendix B Contents

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initial planning through design and construction.

Responsibility for design, construction, maintenance, and performance of stormwater treatment and flow-control facilities and their components rests with the applicant or property owner.

Soils

Soils for bioretention areas must meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Some native loamy sands may be suitable for both objectives; however, such soils are rare in Contra Costa and are not generally available from suppliers.

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

ICON KEY
Helpful Tip
Submittal Requirement
Terms to Look Up
References & Resources

The Contra Costa Clean Water Program has developed specifications for two bioretention soil mixes. Local soil products suppliers have expressed interest in developing "brand-name" mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a "brand-name" mix from a soil supplier. A list of suppliers who have submitted test results and certification to the Program is on the Program website. Updated soil and compost test results may be required; tests must be within 120 days prior to the delivery date of the bioretention soil to the project site.

Credit
This Appendix was prepared based on recommendations by WRA Environmental Consultants, Inc. www.wra-ca.com

Typically, batch-specific test results and certification will be required for projects installing more that 100 cubic yards of bioretention soil.

► SOIL SPECIFICATION

Bioretention soils should meet the following criteria.

1. General Requirements
   Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth.

Bioretention Soil shall be a mixture of topsoil or fine sand, and compost, measured on a volume basis.

Mix A – Topsoil Blend
10%-20% Topsoil
50%-60% Fine Sand
30%-40% Compost

Mix B – Fine Sand Blend
60%-70% Fine Sand
30%-40% Compost

1.1. Submittals
The applicant must submit to the municipality for approval:

A. A sample of mixed bioretention soil.

B. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

C. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

D. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 1.4.

E. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

F. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

G. Provide the following information about the testing laboratory(ies) name of laboratory(ies) including

1) contact person(s)

2) address(es)

3) phone contact(s)

4) e-mail address(es)

5) qualifications of laboratory(ies), and personnel including date of current certification by STA, ASTM, or approved equal

1.2. Sand for Bioretention Soil

A. General
Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be non-plastic.

B. Sand for Bioretention Soil Texture
Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40, #30, #16. #8, #4, and 3/8 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight)	
	Min	*Max*
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40	5	55
No. 100	0	15
No. 200	0	5

Note all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

1.3. Topsoil for Bioretention Soil

A. General
Topsoil shall be free of wood, waste, or any other deleterious material.

B. Topsoil for Bioretention Soil Texture
The overall topsoil texture shall be loamy sand as analyzed by an accredited laboratory. The overall dry weight percentages shall be 60-90% sand, with less than 20% passing than the #200 sieve and less than 5% clay of the total weight with no gravel.

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1.4. Composted Material

Compost shall be a well decomposed, stable, weed free organic matter source meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

A. Compost Quality Analysis

Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Evaluation of Composting and Compost (TMECC). The lab report shall verify:

1) Feedstock Materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.

2) Organic Matter Content: 35% - 75% by dry wt.

3) Carbon and Nitrogen Ratio: C:N < 25:1.

4) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable. In addition any one of the following is required to indicate stability:

a. Oxygen Test < 1.3 O2 /unit TS /hr

b. Specific oxy. Test < 1.5 O2 / unit BVS /

c. Respiration test < 8 C / unit VS / day

d. Dewar test < 20 Temp. rise (°C)

e. e. Solvita® > 5 Index value

5) Toxicity: any one of the following measures is sufficient to indicate non-toxicity.

a. NH4- : NO3-N < 3

b. Ammonium < 500 ppm, dry basis

c. Seed Germination > 80 % of control

d. Plant Trials > 80% of control

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e. e. Solvita® > 5 Index value

6) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.

a. Total Nitrogen content 0.9% or above preferred.

b. Boron: Total shall be <80 ppm; Soluble shall be <2.5 ppm

7) Salinity: Must be reported; < 6.0 mmhos/cm

8) pH shall be between 6.5 and 8. May vary with plant species.

B. Particle size: 95% passing a 1/2" screen.

C. Bulk density: shall be between 500 and 1100 dry lbs/cubic yard

D. Moisture Content shall be between 30% - 55% of dry solids.

E. Inerts: compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.

F. Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.

G. Select Pathogens: Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.

H. Trace Contaminants Metals (Lead, Mercury, Etc.) Product must meet US EPA, 40 CFR 503 regulations.

I. Compost Testing
The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

► PLACEMENT AND COMPACTION OF BIORETENTION SOILS

Place the bioretention soil in 8" to 12" lifts. Lifts are not to be compacted but are placed to reduce the possibility of excessive settlement. Allow time for natural compaction and settlement prior to planting. Bioretention soil may be watered to encourage compaction.

Plantings

► PLANT SELECTION GUIDELINES

The plants tabulated in Attachment B-1 were selected for the following characteristics:

- Adaptation to Contra Costa's climate
- Drought tolerance
- Adaptation to well-drained soils
- Adaptation to low soil fertility
- Allow infiltration
- Are not invasive weeds
- Do not have aggressive roots

Characteristics noted in the table, including irrigation preferences and ability to tolerate heat, coastal conditions, flooding, and wind should be considered when selecting plants.

This list is not comprehensive, nor will all these species succeed at every site. Selection for a particular site should be done by experienced professionals familiar with the plants and site conditions. Avoid planting species on the California Invasive Plant Council's invasive plant inventory list.

► PLANT INSTALLATION

Trees and large shrubs installed in bioretention facilities are susceptible to blowing over before roots are established. They should be staked securely. Three stakes per tree are recommended at windy sites. Straps should be inspected once or twice a year and removed once trees are established to prevent girdling.

► FERTILIZATION

Due to the potential for conveying nutrients to storm drains, no fertilizer should be added to bioretention facilities or planter boxes. Compost tea, available from various nurseries and garden supply retailers, may be applied at a recommended rate of 5 gallons mixed with 15 gallons of water per acre.

Compost tea can be applied up to two weeks prior to planting and once per year between March and June. Application is not recommended when temperatures are

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below 50°F or above 90°F or when rain is forecast in the next 48 hours. Additional applications may be made as needed to correct nutrient deficiencies.

► MULCH

Mulch is not required but is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. Apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

Compared to bark mulch, aged mulch has somewhat less of a tendency to float into overflow inlets during intense storms. To reduce mulch entering overflow inlets, it is recommended to use atrium or beehive grates with ¼" openings over overflow inlets.

► WEED CONTROL

Weeds should be controlled primarily by manual methods and soil amendment. In response to problem areas or threatening invasions, corn gluten, white vinegar, vinegar-based products such as Burn-out, or non-selective natural herbicides such as Safer's Sharpshooter may be used.

► PEST AND DISEASE CONTROL

Synthetic pesticides should not be used on bioretention facilities. Beneficial nematodes and non-toxic controls may be used. Acceptable natural pesticides include Safer® Aphid, Whitefly, and Mealybug Killer, Safer® Tree and Shrub Insect Attach, Safer® for Evergreens, and Neem oil.

Irrigation

Bioretention soils have a high infiltration rate and require a different irrigation system design than what is typically used for heavy clay soils in Contra Costa County. Irrigation systems must be designed to minimize water use, avoid overwatering, and prevent the underdrain discharges during dry weather.

Bioretention facilities and planter boxes may need to be irrigated more than once a day. Irrigation controls should allow separate control of times and durations of irrigation for bioretention facilities and planter boxes vs. other landscape areas.

Smart irrigation controllers are strongly encouraged. Available controllers may access weather stations, use sensors to measure soil temperature and moisture, and allow input of soil types, plant types, root depth, light conditions, slope, and usable rainfall.

Drip emitters are strongly recommended over spray irrigation. Use multiple, lower-flow (one-half to two gallons per hour) emitters in fast-draining bioretention soils. Use two or more emitters for perennials, ground covers, and bunchgrasses. Four to six emitters may be needed for larger shrubs and trees. Some types of emitters encourage horizontal distribution of water.

Spray heads must be positioned to avoid direct spray into bioretention facility or planter box outlet structures.

References and Resources

- *Recommendations for Soils Specification, Planting, and Irrigation of Bioretention Facilities*, WRA Environmental Consultants, November 5, 2008.
- US Composting Council
- ASTM International
- *Plant List and Planting Guidance for Landscape-Based Stormwater Measures.* Appendix B in the *Alameda County Clean Water Program C.3 Technical Guidance* (2006).
- *Plants and Landscapes for Summer Dry Climates.* Nora Harlow, Ed. East Bay Municipal Utility District, Oakland
- *California Native Plants for Your Garden and Wildlife*, Las Pilitas Nursery, 2008.
- *Native Treasures: Gardening with the Plants of California.* M. Nevin Smith, 2006. University of California Press.
- *The Califlora Database, 2008.*
- California Invasive Plant Council
- *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California*, University of California Cooperative Extension and California Department of Water Resources
- Our Water Our World, website to developed to assist consumers in managing home and garden pests in a way that helps protect water.
- Bay-Friendly Landscaping for Professionals, a whole systems approach to the design, construction, and maintenance of the landscape to support the integrity of the San Francisco Bay watershed.
- University of California Statewide Integrated Pest Management (IPM) Program

Grasses and Grass-like Plants

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Bromus carinatus California brome	✓			2	1	✓			ok	✓		✓	✓	✓	
Bouteloua gracilis blue grama	✓			1.5	1	✓				✓		✓	✓		Tolerates no summer water, good for non-irrigated remote sites
Carex densa dense sedge	✓			1	1		✓	✓	✓	✓		✓		✓	
Carex obnupta slough sedge	✓			2	1		✓	✓	✓	✓	✓	✓	✓	✓	
Carex praegracilis clustered field sedge	✓	✓		1.5	1.5		✓	✓	✓	✓	✓	✓	✓	✓	
Carex subfusca rusty sedge	✓	✓		1	1		✓		ok	✓	✓	✓	✓	✓	Great for swales
Carex divulsa Berkeley sedge		✓	✓	1	1		✓		ok		✓	✓	✓	✓	AKA *Carex tumulicola*,. Full sun along coast.
Deschampsia cespitosa tufted hairgrass	✓			2	1		✓		ok			✓	✓	✓	Can look weedy
Distichlis spicata salt grass	✓			0.3	3		✓	✓	✓	✓	✓	✓	✓	✓	Looks like bermuda grass, withstands foot traffic, for soils with high salt
Eleocharis palustris creeping spikerush	✓			1	1		✓	✓	ok	✓	✓	✓	✓	✓	
Elymus glaucus blue wildrye	✓			1.5	2		✓	✓	ok	✓	✓	✓	✓	✓	good for grazing, difficult to mow, messy looking lawn
Festuca californica California fescue	✓	✓	✓	2	2	✓			ok	✓	✓		✓	✓	
Festuca idahoensis Idaho fescue	✓	✓		1	1	✓	✓		ok	✓	✓		✓	✓	Can mow. Needs light summer water at hot sites
Festuca rubra red fescue	✓	✓		1	1.5	✓	✓		ok	✓	✓	✓	✓	✓	Can mow. Lawn alternative
Festuca rubra 'molate' molate fescue	✓	✓		1	1.5	✓	✓		ok	✓	✓		✓	c	Can mow. Lawn alternative
Hordeum brachyantherum	✓	✓		1.5	1		✓	✓	ok	✓	✓		✓	✓	

Plant Recommendations for Bioretention Facilities and Planter Boxes

meadow barley															
Juncus patens blue rush	✓			2	1		✓	✓	✓	✓		✓		✓	
Leymus triticoides creeping wildrye	✓	✓		3	1	✓	✓		ok	✓	✓	✓	✓	✓	Can mow. Recommended for swales.
Melica californica California melica	✓	✓		1	1	✓				✓			✓	✓	
Melica imperfect melic	✓	✓		1	1	✓			ok		✓	✓		✓	Part shade inland, light water in Summer to keep green or goes dormant
Muhlenbergia rigens deergrass	✓			3	3	✓	✓		ok	✓		✓		✓	
Nasella pulchra purple needlegrass	✓	✓		2	1	✓	✓		ok	✓		✓	✓	✓	
Nassella lepida foothill needlegrass	✓	✓	✓	1.5	1	✓	✓		ok	✓	✓		✓	✓	
Phalaris californica California canarygrass		✓	✓	1.5	1		✓	✓	ok		✓	✓	✓	✓	Can be aggressive spreader

Plant Recommendations for Bioretention Facilities and Planter Boxes

Herbaceous Perennials and Groundcovers

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Achillea filipendulina fernleaf yarrow	✓			3	3	✓			✓	✓					
Achillea millefolium common yarrow	✓			1.5	1	✓			ok	✓				✓	Good for hot sites
Achillea tomentosa woolly yarrow	✓	✓		1	1.5	✓	✓		ok	✓			✓		
Aloe striata coral aloe	✓	✓		2	2	✓			ok						Sun along coast, afternoon shade inland
Arctostaphylos hookeri Monterey manzanita	✓	✓		1	4	✓	✓		ok		✓		✓	✓	Better in part shade in hot sites
Arctostaphylos uva-ursi kinnick-kinnick	✓	✓		1	15	✓	✓		ok		✓		✓	✓	Full sun at coast, part shade inland. Cultivars to try include 'emerald carpet,' 'Point Reyes,' 'San Bruno Mountain' depending on site
Ceratostigma plumbaginoides dwarf plumbago		✓		0.75	5	✓	✓		✓	✓					
Epilobium canum California fuchsia	✓	✓		1	4	✓			ok					✓	
Eriogonum fasciculatum flattop buckwheat	✓			3	4	✓				✓				✓	
Eschscholzia californica California poppy	✓			1	1	✓			ok	✓	✓	✓	✓	✓	
Fragaria chiloensis beach strawberries	✓	✓	✓	0.3	2	✓			ok		✓			✓	
Gazania spp. treasure flower	✓			0.5	2	✓	✓		✓	✓			✓		
Iris douglasiana Douglas iris	✓	✓		1.5	2	✓	✓		ok	✓			✓	✓	Also, Iris hybrids

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name	Light Preference			Size (feet)		Watering				Tolerates				CA	
Common name	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind	Native	Other Notes
Lotus scoparius deerweed	✓			4	3	✓				✓		✓		✓	
Lupinus bicolor miniature lupine	✓			1	1	✓					✓	✓		✓	Adds nitrogen
Mimulus aurantiacus common monkeyflower	✓	✓		3	3	✓			ok			✓		✓	
Mimulus cardinalis scarlet monkeyflower	✓	✓	✓	3	3	☐	✓	✓	✓			✓		✓	Aggressive seeder
Polygonum capitatum pink knotweed	✓	✓		0.5	4	✓			✓	✓	✓		✓		
Prunella vulgaris self heal	✓	✓				✓	✓		ok		✓	✓	✓	✓	
Rudebeckia californica California coneflower	✓			3	2	✓	✓		ok	✓		✓		✓	
Salvia clevelandii Cleveland sage						✓									
Scaevola 'mauve clusters' fan flower	✓	✓		1	4	✓				✓			✓		
Sedum spathulifolium stone crop	✓					✓			ok	✓			✓	varies	For above the high water line
Sisyrinchium bellum blue eyed grass				1	1	✓			ok	✓	✓	✓	✓	✓	
Sisyrinchium californicum yellow eyed grass	✓	✓		1	1		✓		✓	✓	✓	✓	✓	✓	
Solidago californica California goldenrod		✓		3	2	✓	✓		ok	✓		✓		✓	
Stachys byzantine lamb's ears	✓	✓		1	3	✓			ok	✓	✓		✓		
Verbena tenuisecta moss verbena	✓			0.5	5	✓			ok	✓	✓		✓		

Plant Recommendations for Bioretention Facilities and Planter Boxes

Small Shrubs

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Artemisia californica California sagebrush	✓			2-5	4-5	✓				✓	✓		✓	✓	Will not tolerate sprinklers
Baccharis pilularis 'Twin Peaks' or Pigeon Point' dwarf coyote brush	✓			2	6	✓	✓		ok	✓	✓	✓	✓	c	
Cistus skanbergii hybrid rockrose	✓			3	5	✓	✓		✓	✓	✓	✓	✓		Best with annual shearing
Correa 'Carmine Bells' or 'ivory bells' Australian fuchsia	✓	✓		3	6	✓	✓		✓	✓			✓		Ivory bells does not tolerate wind. Attracts hummingbirds. Sunset Zones 16-17 (not recommended for E. Contra Costa)
Erigeron glaucus seaside daisy	✓			1	1.5				ok		✓			✓	
Eriogonum crocatum saffron buckwheat	✓			1.5	1.5	✓				✓	✓		✓	✓	
Eriogonum umbellatum sulfur buckwheat	✓			0.7	3	✓			ok	✓			✓	✓	
Grevillea lanigera woolly grevillea	✓			4	6	✓				✓			✓		Sunset Zones 15-24 (not recommended for E. Contra Costa)
Lavendula spp. lavender	✓			1.5	1.5	✓			ok	✓	✓				
Mahonia pinnata California holly grape	✓	✓	✓	4	4	✓	✓			✓		✓	✓	✓	
Mahonia repens creeping Oregon grape	✓	✓		2	3	✓	✓		ok		✓	✓		✓	
Rosmarinus officinalis rosemary	✓			2.5	5	✓			✓	✓	✓		✓		
Rubus ursinus California blackberry		✓	✓	3	5		✓	✓	ok	✓	✓	✓	✓	✓	Thorns. Harbors beneficial insects

Plant Recommendations for Bioretention Facilities and Planter Boxes

Symphorocarpos albus common snowberry	✓	✓	✓	4	4	✓	✓	✓	ok	✓				✓	Adaptable to many conditions
Westringia fruticosa coast rosemary	✓			4	8	✓				✓	✓		✓		
Whipplea modesta whipplevine		✓	✓	0.5	3		✓	✓	✓		✓	✓		✓	Sunset zones 16-17, 19-24 only (not recommended E. Contra Costa), best for moist shady spots

Large Shrubs

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Alyogyne huegelil blue hibiscus	✓			6	5	✓				✓					Very low water after second year, Sunset zones 15-17 & 20-24 (not recommended E. Contra Costa)
Arctostaphylos densiflora 'Howard Mcminn' McMinn manzanita	✓	✓		3	7	✓				✓			✓	c	
Baccharis pilularis coyote brush	✓			6	7	✓	✓		ok	✓	✓	✓	✓		Fast-growing, short-lived
Berberis darwinii Darwin's barberry	✓	✓		6	6	✓				✓		✓	✓		Sprinklers will kill foliage
Carpenteria californica Bush anemone	✓	✓		6	4	✓	✓		✓	✓				✓	Interior climate with occasional water otherwise low water needs
Ceanothus spp. Various ceanothus	✓	✓		varies	varies	✓			☐	✓			✓	✓	fast-growing but short-lived
Cercis occidentalis western redbud	✓			12	8	✓			☐	✓		✓	✓	✓	Prune low branches for small tree form, susceptible to disease if overwatered
Cotinus coggygia smoke bush	✓			15	15	✓			☐			✓	✓		No water after second year
Eriogonum arborescens Santa Cruz Island buckwheat	✓			3	5	✓			✓	✓	✓	✓	✓	✓	Low water after second year

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Eriogonum giganteum St. Catherines lace	✓			5	6	✓			☐		✓	✓	✓	✓	best at coast, tolerant of unwatered inland garden
Fremontodendron californicum flannel bush	✓			20	14	✓			☐	✓		✓		✓	Fast-growing, short-lived
Garrya elliptica Coast silktassel	✓	✓		8	8	✓	✓		✓	✓		✓	✓	✓	'Evie' is compact variety
Heteromeles arbutifolia toyon	✓	✓	✓	7	5	✓	✓		✓	✓	✓	✓		✓	Doesn't respond well to pruning low branches
Juniperus chinensis 'Mint Julep" mint julep juniper	✓	✓		3	6	✓	✓		✓	✓	✓	✓	✓		
Lonicera hispidula California honeysuckle	✓	✓	✓	4	2		✓	✓	✓		✓	✓		✓	Climbing vine-like. Best in part shade. Attracts birds
Lonicera involucrate twinberry honeysuckle	✓	✓	✓	6	3		✓	✓	✓		✓	✓		✓	Best in part shade. Attracts birds
Nandina domestica heavenly bamboo	✓	✓		4	3	✓	✓		✓	✓		✓			
Philadelphus coronaries sweet mock orange	✓	✓		10	10		✓		✓				✓		Best with annual pruning
Physocarpus capitatus Pacific ninebark	✓	✓		5	5	✓	✓	✓	ok		✓	✓		✓	Part shade and summer water required in hot locations
Pittosporum eugeniodes Pittosporum	✓	✓		40	15	✓	✓		✓	✓		✓	✓		shear to control height
Pittosporum tenuifolium Pittosporum	✓	✓		40	15	✓	✓		✓	✓		✓	✓		shear to control height
Prunus illicifolia holly leaf cherry	✓	✓		15	15	✓	✓			✓	✓	✓	✓	✓	
Prunus lyonii Catalina cherry	✓	✓		15	15	✓	✓			✓	✓	✓	✓	✓	
Rhamnus californica California coffeeberry	✓	✓		3-15	6	✓			✓	✓		✓	✓	✓	'Eve Case' is compact with broad foliage
Rhus integrifolia	✓	✓		8	6	✓			✓	✓			✓	✓	Shear to hedge if desired

lemonade berry															
Ribes malvaceum chaparral currant	✓	✓		5	5	✓	✓		ok	✓				✓	
Ribes sanguineum flowering currant		✓	✓	5-12	5-12	✓	✓		✓	✓	✓	✓		✓	Needs good air movement to avoid white fly
Ribes speciosum fuchsia-flowered gooseberry	✓	✓	✓	3-6	3-6	✓	✓		✓	✓	✓	✓		✓	
Rosa californica California wild rose	✓	✓		3	3-6		✓	✓	ok	✓	✓	✓	✓	✓	hooked thorns not compatible with foot traffic
Rosa gymnocarpa wood rose	✓	✓		2	3		✓		ok	✓	✓	✓		✓	
Vitis californica California grape	✓	✓		10	2-10	✓	✓		✓	✓	✓	✓	✓	✓	Climbing vine. Best in full sun. Can be aggressive in moist area.
Vitis girdiana desert grape	✓			8	2-11	✓	✓		✓	✓		✓	✓	✓	Climbing vine. May be more suited to biofilter soils than californica.

Small Trees

Scientific name Common name	Light Preference			Size (feet)		Watering				Tolerates				CA Native	Other Notes
	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind		
Acer Negundo box elder	✓	✓	✓	30	30	✓	✓		ok	✓	✓	✓	✓	✓	Tough shade tree, deciduous
Arbetus unedo strawberry tree	✓	✓				✓	✓		✓	✓	✓	✓			'Elfin King' is dwarf from 6' tall
Arctostaphylos manzanita common manzanita	✓			6-15	8-12	✓				✓			✓	✓	Prune to be small tree. "Dr. Hurd" is more tolerant of summer water.
Cercis occidentalis western redbud	✓	✓		12	8	✓				✓			✓	✓	Prune low branches for small tree form; susceptible to disease if overwatered.
Eriobotrya deflexa bronze loquat	✓	✓		18	25	✓	✓		✓	✓		✓			Monthly deep watering
Eriobotrya japonica Japanese loquat	✓	✓		25	20	✓	✓		✓	✓		✓			Susceptible to blight under stress
Fraxinus angustfolia Raywood ash	✓			30	30		✓		✓	✓					Fall color
Fraxinus dipetala California ash	✓	✓		20	20				ok	✓		✓		✓	

Plant Recommendations for Bioretention Facilities and Planter Boxes

Scientific name	Light Preference			Size (feet)		Watering				Tolerates				CA	
Common name	Sun	Part	Shade	Ht.	Width	L	M	H	Summer	Heat	Coast	Flood	Wind	Native	Other Notes
Fraxinus latifolia Oregon ash	✓	✓	✓	30	25	✓			✓	✓	✓	✓		✓	
Fraxinus velutina velvet ash	✓			25	15	✓	✓		ok	✓		✓	✓		
Garrya elleptica coast silk tassel	✓	✓		20	20	✓	✓		ok		✓				Afternoon shade inland, responds well to pruning
Laurus 'Saratoga' hybrid laurel	✓	✓		12-40	12-40	✓				✓		✓	✓		prune for tree form
Myrica californica Pacific wax myrtle	✓	✓	✓	10-30	10-30	✓	✓				✓				best at coast
Pinus thumbergiana Japanese black pine	✓	✓		25	20	✓			✓	✓	✓			✓	Asymmetrical, often leaning habit
Pittosporum undulatum victorian box	✓	✓		15	15	✓	✓		✓	✓					Sunset zones 16-17, 21-24 only (not recommended E. Contra Costa. Prune low branches for tree form.
Prunus ilicifolia holly leaf cherry	✓	✓		15	15	✓	✓			✓	✓		✓	✓	
Prunus lyonii Catalina cherry	✓	✓		15	15	✓	✓			✓	✓		✓	✓	
Prunus serrulata "shirofugen' cherry	✓			25	25		✓				✓	✓	✓		Additional cultivars

Plant Recommendations for Bioretention Facilities and Planter Boxes

Key

Water Preference-Low/Moderate/High	We have provided recommendations for irrigation. All plants should be watered with more frequency during the first two years after planting. After this establishment period, Low water use plants will only need supplemental irrigation at the hottest and driest sites. Plants with Moderate irrigation needs will be best with occasional supplemental water (once per week to once per month) and plants with High irrigation needs will be best with more frequent watering especially during periods of drought in the cooler seasons.
Water Preference-Summer Irrigation	Plants with a check in this column will not withstand a long period of summer drought without irrigation. Plants with an 'ok' in this column are tolerant of, but do not require, frequent summer irrigation. Plants with nothing in this column may not tolerate summer irrigation.
Tolerates Heat	A check in the heat column indicates that the plant will tolerate hot sites. It should not be confused with a plants preference for sun. Absence of the check indicates it should only be used in areas close to the Bay or other cool sites.
Tolerates Coast	The coast column indicates plants that perform well within 1,000 feet of the ocean or bay. Most of these plants tolerate some amount of salt air, fog, and wind.
Tolerates Flooding	
Tolerates Wind	A check in the wind column means that the plant will tolerate winds of ten miles per hour or more.
CA Native - c	Cultivar of California native. Cultivars offer habitat benefits to native wildlife and are adapted to the local climate but have reduced genetic diversity.
Other Notes - Sunset Climate Zones	Under the Other Notes category, we have indicated appropriate Sunset Climate Zones only for plants that will not do well across all of Contra Costa County. Please refer to the *Sunset Western Garden Book* which defines climate zones in the Bay Area based on elevation, influence of the Pacific Ocean, presence of hills and other factors.

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Appendix

C

Flow Control

Instructions and tools for meeting flow-control (hydrograph modification management) requirements.

Provision C.3.g in the MRP states:

> Stormwater discharges from [applicable] projects shall not cause an increase in the erosion potential of the receiving stream over the pre-projct (existing) condition. Increases in runoff flow and volume shall be managed so that post-proejct runoff shall not exceed pre-project rates and durations, where such increased flow and/or volume is likely to cause increased potential for erosion of creek beds and banks, silt pollutant generation, or other adverse impacts on beneficial uses due to increased erosive force.

As required by a 2003 amendment to the previous NPDES permit, the CCCWP submitted a Hydrograph Modification Management Plan (HMP), including a proposed flow-control standard, in July 2005. The flow-control standard was retained in the MRP issued in October 2009. See Attachment C-1.

The flow-control standard applies to projects which create or replace one acre or more of impervious area and for which applications for development approvals are deemed complete after October 14, 2006. See Chapter 1, including Table 1-1.

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The flow-control standard is preventative: project proponents are encouraged to design their projects so there will be no increase in runoff as compared to the pre-project condition of the development site. The CCCWP has created designs and design aids for Low Impact Development Integrated Management Practices (IMPs) which may be used to achieve this criterion.

However, increased runoff is allowed if it can be demonstrated the increases are unlikely to cause downstream erosion or other impacts on beneficial uses of streams. This may be the case either because the drainage downstream between the project site and the Bay/Delta is in pipes or in channels that are tidally influenced or aggrading. Or the applicant may propose a stream restoration project or projects which fully mitigate the erosion risk.

ICON KEY
☞ Helpful Tip
Submittal Requirement
Terms to Look Up
🕮 References & Resources

Comparison of post-project to pre-project flows is based on continuous simulation of runoff over a period of 30 years or more, using local hourly rainfall data, and statistical analysis of peak flow recurrence and of the cumulative duration of flows. See the discussion in Chapter 2.

To demonstrate compliance with the standard, select one of the following four options:

Option 1. Demonstrate the project produces no net increase in impervious area. A simple inventory and accounting of existing and proposed impervious area is required. You will also need to show, qualitatively, that changes to drainage facilities will not increase the efficiency of drainage collection and conveyance.

Option 2. Implement IMPs such as planters, swales, and bioretention areas using the Program's low-impact development site design procedure and facility sizing tool. Applicable criteria, including runoff factors and IMP sizing ratios, have been selected to meet the flow-control standard and are incorporated into the tool.

Option 3. Use a continuous-simulation hydrologic computer model such as USEPA's Hydrologic Simulation Program—Fortran (HSPF) to simulate pre-project and post-project runoff, including the effect of proposed IMPs, detention basins, or other storwmater management facilities. An hourly rainfall record of at least 30 years must be used. Compile flow statistics and produce summary peak flow and flow duration graphics to demonstrate the following criteria are met:

> For flow rates from 10% of the pre-project 2-year runoff event (0.1Q2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve.

For flow rates from 0.5Q2 to Q2, the post project peak flows shall not exceed pre-project peak flows. For flow rates from Q2 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.

Option 4. Show that, because of the specific characteristics of the stream receiving runoff from the project site, or because of proposed channel restoration projects, or both, there is little likelihood the cumulative impacts from new development could increase the net rate of stream erosion significantly.

Option 4a. Low Risk. Show all downstream reaches, from the project site to the Bay/Delta, are enclosed pipes, hardened channels, subject to tidal action, or aggrading.

Option 4b. Medium Risk. Use the methods and criteria in this Appendix to confirm each reach downstream from the project to the Bay/Delta meets criteria for the "medium risk" (or "low-risk") classification. Implement an in-stream mitigation project to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values. The expected environmental benefits of the mitigation project must substantially outweigh the potential impacts of an increase in runoff from the development project.

Option 4c. High Risk. Implement a comprehensive program of in-stream measures to improve stream channel hydrological and ecological functions while accommodating increased flows.

Whichever option is used to demonstrate flow control compliance, projects must also meet the C.3 treatment requirements. Under Option 2, projects can meet both the treatment and flow control requirements by using the low-impact development site design procedure and facility sizing tool. The following sections contain instructions and references to assist you.

Option 1: No increase in impervious area

This option applies to sites which have been previously developed. To use Option 1, simply compare existing to proposed impervious area. You will also need to show, qualitatively, that changes to drainage facilities will not increase the efficiency of drainage collection and conveyance.

► RATIONALE

In many cases, redevelopment of a previously built site will result in decreases in total impervious area—because of setback and landscaping requirements and use of IMPs to treat runoff. Even when sized for stormwater treatment only, IMPs also reduce runoff peaks and durations considerably. The combination of decreased impervious area and IMPs practically assures that post-project runoff will not exceed pre-project peaks and durations.

► MEETING THE REQUIREMENTS

Use a base map or aerial photo.

- Identify existing roofs, paved areas, and other impervious surfaces.
- Delineate the impervious areas, dividing them to facilitate identification of each area and estimation of its square footage.
- Mark each delineated area with a unique identifier and calculated square footage.
- Prepare a table listing each delineated area and its square footage and show a total for the project site.

Refer to the table of areas you prepared for the design of treatment facilities (Chapter 3, Step 3). Sum the impervious areas. Do not include pervious pavements or other pervious surfaces in this sum.

► PREPARING YOUR SUBMITTAL

See the instructions in Chapter 3, Step 2, regarding assessment of site opportunities and constraints to reduce imperviousness and retain or detain site drainage and in Chapter 3, Step 3, regarding design features and surface treatments used to minimize imperviousness. Make sure this information is included in your Stormwater Control Plan.

Include in your Stormwater Control Plan, as an attachment, figure, or exhibit, the marked-up base map or aerial photo showing existing impervious surfaces.

Include in your Stormwater Control Plan the tabulation and sum of existing impervious areas and a comparison to the total proposed impervious area.

If you used the recommended Low Impact Development design procedure (Chapter 4), including sizing IMPs for stormwater treatment only, no further documentation of reduced drainage efficiency is required. If you used a different design procedure to design stormwater treatment facilities, describe the existing and proposed drainage systems and explain, qualitatively or quantitatively:

- Why the time of concentration is increased as a result of the proposed development, and
- Why the total volume of runoff is reduced as a result of the proposed development.

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Option 2: Integrated Management Practices

Most applicants will find it easiest and most cost-effective to use this option. Use the Program's Design and Documentation Procedure for Low Impact Development (Chapter 4) to select and size swales, planter boxes, bioretention areas, or other IMPs to meet both treatment and flow-control requirements for your project.

► RATIONALE

The Program developed designs and sizing factors for a variety of IMPs. The sizing factor applicable to a particular IMP is dependent on the soil type and rainfall pattern at the development site. The sizing factors were calculated to ensure runoff discharged from the IMP does not exceed the pre-project peaks and durations of runoff from the area tributary to the IMP. See Chapter Two, Chapter Four, and the Program's Hydrograph Modification Management Plan for more background on calculation of the IMP sizing factors.

► MEETING THE REQUIREMENTS

Follow the instructions in Chapter Four to size IMPs. The Program's IMP sizing tool, which is available on the Program's C.3 web page, may be used to facilitate calculations. Select the "Treatment and Flow Control" option to size IMPs to provide both treatment and flow control for site runoff.

► PREPARING YOUR SUBMITTAL

Show calculations as described in Chapter 4. Or incorporate the output from the Program's IMP sizing tool into your Stormwater Control Plan.

Option 3: Model Pre- and Post-Project Runoff

This option is for applicants who wish to design their own flow-control facilities customized to the needs and character of their development projects. It requires the development of a continuous simulation hydrologic model of the project under pre-project and post-project conditions, including the effect of proposed IMPs, detention basins, or other storwmater management facilities

Building a continuous-simulation hydrologic model for a project, and analyzing its output to compare post-project to pre-project hydrology, may be a better option than the Program's IMP designs and sizing factors:

- When it is proposed to use facilities such as detention basins, constructed wetlands, or other facilities for which the Program has not developed sizing factors.
- For large drainage areas with complex drainage, steep slopes, dense vegetation, thin top soil, or other hydrological conditions where a site-

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specific model can provide a better representation of post-project and pre-project hydrology.

Because of the time and resources required to implement this option, it is typically applicable to larger developments (sites greater than 20 acres).

Projects that select Option 3 to meet the flow control requirements (Table 1-1) must also meet stormwater treatment requirements and LID requirements. Treatment requirements and flow-control requirements can be met via separate facilities in series, or a single facility may be designed for both treatment and flow-control. For example, a pond or wetland can serve as a treatment facility if it detains the required water quality volume for 48 hours and contains suitable design elements. To show the same pond or wetland also meets flow-control requirements, the applicant would need to construct a computer model to compare post-project to pre-project hydrology on the development site, including the hydrologic effects of the proposed pond or wetland.

Development of continuous simulation hydrologic model for a specific development site requires specialized expertise and substantial resources. Municipal staff may require the applicant to establish a force account or similar financial mechanism to provide for independent, third-party review of model documentation and output. Engineering and other design considerations related to flow-control may need to be coordinated with considerations related to flood protection and controlling other potential environmental impacts of the development.

Consult with municipal staff before beginning work on a computer model, and coordinate implementation with environmental agencies from which project approvals must be obtained.

► RATIONALE

Conventionally, drainage facilities have been designed to accommodate peak flows or volumes generated by a specific hypothetical rainfall event (design storm). The design storm is typically characterized by its recurrence interval (e.g., a 10-year or 100-year storm). Conventional drainage facilities, including flood-control basins, are designed for protection from flooding, not to protect streams from erosion.

As regulatory agencies began to develop criteria to protect streams from accelerated erosion caused by urbanization and increased imperviousness, many agencies limited the allowable increase in peak discharge associated with a specific design storm. The science of fluvial geomorphology showed that, for stable streams in undeveloped watersheds, the "channel forming flow"—the event with the most capability to move sediment—recurred approximately every 1-2 years. Initial criteria for stream protection focused on designing facilities to control peak flows from runoff events at and near this magnitude.

Further analysis of urbanizing streams indicated increases in the frequency and duration of lower flows can also contribute to accelerated stream erosion. Rainfall events which would produce little or no runoff in a pre-development watershed produce significant runoff from impervious surfaces—and that runoff is typically piped directly to streams. To fully protect streams in urbanizing watersheds from accelerated erosion, it may be necessary to control the entire regime of large and small flows.

Continuous simulation models, which typically use as input hourly rainfall data over 30 years or more, can simulate the entire runoff flow regime under existing and post-project conditions. Two sets of criteria are generally used to compare modeled pre-project and post-project flows over the long term: peak flows for each event contained in the simulation, and duration of flows at the full range of simulated flow rates.

Regardless of the hydrologic calculation method used, estimation of runoff from a particular development site requires selection of appropriate parameters to represent the quantity of rainfall that runs off versus that which puddles, infiltrates into the ground, or is absorbed by vegetation. The rational method uses "C" factors and the SCS methodology uses curve numbers to represent these relationships. Continuous simulation models, such as USEPA's Hydrologic Simulation Program—Fortran (HSPF), use a more complex suite of parameters to characterize soils and vegetation. Values for these parameters can be calibrated to stream flow data for whole watersheds. For individual development sites, or where stream flow data is not available, appropriate values for each parameter must be estimated.

► MEETING THE REQUIREMENTS

After discussing the process for technical review with municipal staff, build and run a continuous-simulation hydrologic model of the existing site and the proposed development including detention/retention facilities. Procedures and parameters must be consistent with the instructions in the Attachment 3 to the CCCWP's HMP. Prepare a statistical analysis of the results as described in that guidance.

► PREPARING YOUR SUBMITTAL

Provide a detailed report on the hydrologic modeling that includes, at a minimum:

- An **introduction** that provides a description of existing site conditions, land uses and land cover and a description of the proposed project.

- Separate **site maps** for pre-project and post-project conditions. The site maps should delineate the sub-basins used to characterize the site within the model under pre-project and post-project conditions and show a basin number or other identifier for each sub-basin. Show on your maps: hydraulic structures, roadways, drainageways, stormwater management facilities, and topography; the post-project map should also include proposed grading and site layout.

- An estimate of the Mean Seasonal Precipitation at the project site and identification of the long-term rainfall data set used in the simulation. The data should be from the Contra Costa gauge site with the most similar mean seasonal precipitation to the project site, as indicated by the Contra Costa County Public Works Department Mean Seasonal Isohyets Map (rainfall data and Isohyetal map available on the Program's web site).

- A table of model parameters used to characterize each sub-basin shown on the pre-project and post-project site maps. The table should include the sub-basin identifier, total basin area, pervious area, impervious area, NRCS soil type, and other model parameters used to define infiltration and runoff characteristics of the sub-basin. Applicants submitting an HSPF hydrologic analysis should include PWATER parameter values for each pervious land segment. (Common HSPF parameter values are provided in Appendix A of the CCCWP modeling guidance.)

- A detailed description of proposed facilities for stormwater treatment and flow control. Describe the type of facility, design dimensions, overflow capacity, underdrain sizing parameters (control device), emergency overflow route, and any other hydraulic controls. Describe how the facilities were characterized in the model and methods used for facility sizing; if IMPs are modeled, include a detailed discussion of the assumed water movement hydraulics describing infiltration, soil water storage, and soil water movement. Provide a sketch of each facility showing key hydraulic design elements such as orifice sizing and placement.

- A table of model parameters used to characterize proposed stormwater management facilities, such as FTABLEs (HSPF), rating curves etc.

- A description of runoff routing that explains how runoff from each sub-basin is routed through the project site. For sub-basins which drain to a single stormwater management facility, a discussion of the basin routing is sufficient. For more complex sub-basins or series of sub-basins, with explicit routing, provide a table describing the reach parameters and transform methods in addition to the detailed routing description. (Routing parameters will vary depending on hydrologic model and routing method selected.)

- Modeling results, summarized as partial duration statistics and flow duration tables. To compute partial duration statistics and separate the long-term HSPF output time series into discrete storm events, use a 24 hour period with flows less than 0.02 cfs per acre to signify the end of an event. The partial duration statistics table should list for each flow event: start date, event duration, peak flow, flow volume and recurrence interval. Show peak flow frequency and flow duration curves that illustrate the proposed project meets the peak flow control and flow duration control standard (as outlined in HMP Attachment 3).

Option 4a: Low Risk of Accelerated Erosion

This option may be applicable if your project is in low-elevation areas near the Bay/Delta or an adjacent urbanized area drained by underground pipes or hardened channels. It is the responsibility of the applicant to demonstrate all downstream channels between the project site and the Bay/Delta meet the "low risk" criteria.

► RATIONALE

Flow control is not necessary if it can be demonstrated that increased flow peaks and durations would have no effect on downstream channels. "No effect" can be stipulated if it is demonstrated that the entire drainage route from the site to the Bay/Delta is in pipes, engineered hardened channels, channels subject to tidal action, or channels subject to accumulation of sediments.

For some projects, this demonstration can be a simple reference to municipal storm drain maps (for example). However, drainage channels, particularly small channels, are not always well documented. Even where drainage is documented, the boundaries of areas tributary to the drainage may be difficult to discern. For this reason, Contra Costa has not prepared a comprehensive map showing where Option 4a applies. Where necessary, applicants may need to provide field notes, photographs, or other documentation to verify the characteristics of specific reaches along the route between their project site and the Bay/Delta.

Many reaches of Contra Costa's major creeks are natural or unhardened; Option 4a cannot be used to establish compliance with flow-control requirements for projects upstream of these reaches.

► MEETING THE REQUIREMENTS

Trace the drainage route from the project site down to the Bay/Delta. Divide the route into reaches based on the type and characteristics of drainage structures (pipe, engineered channel, natural channel). Assemble documentation and confirm each reach is in one of the following categories:

1. Enclosed pipe.

2. Channel with continuous hardened beds and banks engineered to withstand erosive forces and composed of concrete, engineered riprap, sackcrete, gabions, mats, etc. (Channel hardening must be an engineered continuous installation and not piecemealed in response to localized bank failure and erosion.)

3. Channel subject to tidal action.

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4.

TABLE C-1. Suggested format for presentation of reach-by-reach information for "low risk" (Option 4a).

Reach ID	*Description*	*"Low Risk" Category*	*Reference or documentation*

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i
ch is aggrading, i.e. consistently subject to accumulation over decades and with no indicators on erosion on the channel banks.

► PREPARING YOUR SUBMITTAL

Your report, signed by an engineer or qualified environmental professional, should include as necessary a map or diagram showing each reach, a narrative briefly describing the reaches in order from site to Bay/Delta, and a tabulated presentation of the documentation used to confirm the status of each reach. The format illustrated in Table C-1 can be used.

You can facilitate review of your submittal by attaching photocopies of, or providing links to, the key source materials used to establish each "low risk" classification. Examples of sources are in Table C-2.

TABLE C-2. Examples of source materials which could document "low risk" (Option 4a).

	"Low Risk" Category	*Examples of Source Materials*
1	Enclosed pipes	Municipal storm drain map or personal communication with municipal staff
2	Channel with continuous hardened beds and banks	Project name or number for original construction of the channel, or personal communication with staff of the agency responsible for channel maintenance, or field reconnaissance.
3	Tidally influenced channel	Elevation of outfall to channel (from construction drawings or field reconnaissance), or personal communication with Flood Control District staff.
4	Aggrading channel	Visual survey by a qualified geomorphologist or personal communication with Flood Control District staff confirming the history of sediment accumulation and removal.

Option 4b: Medium Risk of Accelerated Erosion

This option allows an applicant, in certain cases, to mitigate potential effects of increased runoff on a stream reach by sponsoring a bed or bank restoration project of limited scope.

The option is only available to projects smaller than 20 acres total area.

The applicant must first confirm downstream reaches have characteristics indicating channel beds and banks are, in the main, relatively resistant to accelerated erosion from increased runoff.

The applicant must then have a qualified geomorphologist confirm this finding and develop a proposal for a mitigation project, the benefits of which must substantially outweigh potential impacts of an increase in runoff from the proposed development project.

The applicant must also obtain concurrence from staff of regulatory agencies having jurisdiction—including Regional Water Board staff—that the mitigation project is feasible and desirable.

► RATIONALE

In a "medium risk" stream reach, the channel is stable under current conditions and may be able to absorb a slight increase in watershed imperviousness, but accelerated erosion cannot be ruled out. For some development projects upstream of these reaches, flow-control facilities may be costly or difficult to build, and the resulting benefit may be uncertain and small.

Detailed studies of the potential effects of a development on a stream can be costly, time consuming, and (in the case of a "medium risk" stream reach) could simply reiterate that increased erosion is not likely, but is possible.

As an alternative to extensive study of the stream, applicants have the option of proposing a mitigation project. Contra Costa streams have a substantial backlog of needed (but unfunded) maintenance to prevent or repair localized bank failures. Properly designed and executed, localized restoration projects can have substantial environmental benefits. Mitigation projects should seek to attenuate or reduce excessive erosive stresses (for example, by increasing channel cross section or reducing gradient), rather than just increasing shear resistance by stabilizing banks.

The benefits of the mitigation project must substantially outweigh the incremental increase in the risk of erosion due to the increased runoff represented by the project. This balance is established by the opinion of a qualified geomorphologist and then confirmed by consensus among staff of the agencies having jurisdiction.

Program consultants outlined a process and created technical tools applicants may use to implement this option. To begin the process, an engineer or qualified environmental professional can use the Program's Basic Geomorphic Assessment procedure to evaluate downstream reaches and show each reach is either "low risk" (see Option 4a) or "medium risk."

► MEETING THE REQUIREMENTS

Implementation of Option 4b proceeds in two phases. In the first phase, an engineer or qualified environmental professional makes a preliminary determination whether all reaches of drainage downstream from the project site to the Bay/Delta are either "low risk" or "medium risk" according to the Program's criteria. If this determination is affirmative, the applicant may proceed to the second phase, in which a qualified stream geomorphologist confirms the preliminary determination and proposes an appropriate mitigation project.

Applicants are strongly encourage to coordinate with municipal staff, staff of the Contra Costa Flood Control and Water Conservation District, property owners of stream reaches and adjacent parcels, and regulatory agencies having jurisdiction (including the Regional Water Board and the California Department of Fish and Game) during the first phase and/or before proceeding the second phase.

First phase (conducted by an engineer, stream geomorphologist, or other qualified environmental professional): As in Option 4a, trace the drainage route from the project site down to the Bay/Delta. Divide the route into reaches based on the type and characteristics of drainage structures. Identify and assemble documentation for any "low risk" reaches as in Option 4a.

Conduct the field site review and collect the field data described in the Basic Geomorphic Assessment procedure to each of the remaining reaches downstream to the point where:

- all further downstream reaches are "low risk," or
- the channel enters a publicly managed reservoir.

For each of these reaches, complete a Geomorphic Assessment Form, including field notes and photographs, to calculate the channel vulnerability indicators and evaluate the appropriate risk class. Write a narrative risk justification to accompany each assessment form.

Second phase (conducted by a qualified stream geomorphologist): Confirm the findings of the preliminary report using the information in the assessment forms, additional field data, and other available information.

Identify and describe a suitable mitigation project to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values. If a suitable project exists in the same stream reach or watershed, that project should be proposed; otherwise, a project in another watershed may be acceptable.

► PREPARING YOUR SUBMITTAL

Prepare a preliminary plan and proposal for the mitigation project including milestones, schedule, cost estimates, and funding. Include a written commitment from the developer or project proponent to implement the mitigation project timely in connection with the proposed development project.

Provide an opinion and supporting analysis by one or more qualified environmental professionals that the expected environmental benefits of the mitigation project substantially outweigh the potential impacts of an increase in runoff from the development project.

To complete documentation of compliance with flow-control requirements under Option 4b, obtain letters or meeting notes in which staff representatives of regulatory agencies having jurisdiction state the project is feasible and desirable. This must include a letter signed by the Regional Water Board Executive Officer or designee referencing this requirement.

Option 4c: High Risk of Accelerated Erosion

As noted at the beginning of this appendix, the Program's flow-control standard is preventative: project proponents are encouraged to design their projects so that there will be no increase in runoff as compared to the pre-project condition of the development site. This policy aims to ensure watershed-wide increases in runoff and the attendant impacts are minimized, while obviating the need for extensive analysis to characterize the complex and unpredictable relationship between increased runoff and accelerated stream erosion in a particular watershed.

However, where it is very difficult or infeasible to achieve no increase in runoff—or in cases where a stream channel is to be restored as mitigation for other environmental impacts—an applicant may propose to alter the receiving stream channel to accommodate the predicted post-project flow regime.

The analysis required to determine design objectives for in-stream measures will typically involve watershed-scale continuous hydrologic modeling of pre-project and post-project runoff flows, sediment transport modeling, collection and/or analysis of field data to characterize channel morphology including analysis of bed and bank materials and bank vegetation, selection and design of in-stream structures, and project environmental permitting.

► RATIONALE

Stream channels which do not meet the criteria for "low-risk" (Option 4a) or "medium-risk" (Option 4b) are considered at "high-risk" of accelerated erosion due to increased watershed imperviousness. High risk channels are geomorphically unstable under existing conditions, and therefore vulnerable to any increase in impervious area.. It is presumed that increases in runoff flows to these channels will accelerate bed and bank erosion.

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If downstream drainage includes high-risk channels, the applicant must either control runoff flows to pre-project peaks and durations or propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows.

► MEETING THE REQUIREMENTS

To obtain approval for a project which discharges increased runoff peaks and durations to a high-risk channel, the project proponent must perform a comprehensive analysis to determine the design objectives for channel restoration and must propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows. Specific requirements are developed case-by-case in consultation with regulatory agencies having jurisdiction.

Different project types, channels, and locations will demand different investigative approaches; however, the following framework can be tailored to most situations:

- Evaluation of watershed historic conditions.
- Evaluation of channel geomorphic conditions.
- Evaluation of project impacts on hydrology and sediment yield.
- Prediction of impacts on receiving channels.
- Design of avoidance or mitigation.
- Monitoring and adaptive management.

HMP Attachment 4 includes additional detail regarding this framework and recommended evaluation method and design methods.

► PREPARING YOUR SUBMITTAL

The analysis for compliance with flow-control requirements may, and in many cases should be, integrated with analyses conducted pursuant to obtaining Clean Water Act Section 401 or Section 404 certification, CEQA, California Department of Fish and Game Stream Alteration Permits, and other regulatory approvals which may be required for the development project or implementation of in-stream measures, or both.

Discuss the contents of required submittals with the staff of agencies having jurisdiction prior to the start of the analytical work.

References and Resources

- Municipal Regional Permit Provision C.3.g. and Attachment C.
- *Contra Costa Clean Water Program Final Hydrograph Modification Management Plan*, revised April 19, 2006.

I. Demonstrating Compliance with the Standard

Contra Costa Permittees shall ensure project proponents shall demonstrate compliance with the HM standard by demonstrating that any one of the following four options is met:

1. **No increase in impervious area.** The project proponent may compare the project design to the pre-project condition and show the project will not increase impervious area and also will not facilitate the efficiency of drainage collection and conveyance.
2. **Implementation of hydrograph modification IMPs.** The project proponent may select and size IMPs to manage hydrograph modification impacts, using the design procedure, criteria, and sizing factors specified in the Contra Costa Clean Water Program's *Stormwater C.3 Guidebook*. The use of flow-through planters shall be limited to upper-story plazas, adjacent to building foundations, on slopes where infiltration could impair geotechnical stability, or in similar situations where geotechnical issues prevent use of IMPs that allow infiltration to native soils. Limited soil infiltration capacity in itself does not make use of other IMPs infeasible.
3. **Estimated post-project runoff durations and peak flows do not exceed pre-project durations and peak flows.** The project proponent may use a continuous simulation hydrologic computer model such as USEPA's Hydrograph Simulation Program—Fortran (HSPF) to simulate pre-project and post-project runoff, including the effect of proposed IMPs, detention basins, or other stormwater management facilities. To use this method, the project proponent shall compare the pre-project and post-project model output for a rainfall record of at least 30 years, using limitations and instructions provided in the Program's *Stormwater C.3 Guidebook*, and shall show the following criteria are met:
   a. For flow rates from 10% of the pre-project 2-year runoff event (0.1Q2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over more than 10% of the length of the flow duration curve.
   b. For flow rates from 0.5Q2 to Q2, the post-project *peak flows* shall not exceed pre-project peak flows. For flow rates from Q2 to Q10, post-project peak flows may exceed pre-project flows by up to 10% for a 1-year frequency interval. For example, post-project flows could exceed pre-project flows by up to 10% for the interval from Q9 to Q10 or from Q5.5 to Q6.5, but not from Q8 to Q10.
4. **Projected increases in runoff peaks and durations will not accelerate erosion of receiving stream reaches.** The project proponent may show that, because of the specific characteristics of the stream receiving runoff from the project site, or because of proposed stream restoration projects, or both, there is little likelihood that the cumulative impacts from new development could increase the net rate of stream erosion to the extent that beneficial uses would be significantly impacted. To use this option, the project proponent shall evaluate the receiving stream to determine the relative risk of erosion impacts and take the appropriate actions as described below and in Table A-1. Projects 20 acres or larger in total area shall not use the medium risk methodology in "b" below.
   a. **"Low Risk."** In a report or letter report, signed by an engineer or qualified environmental professional, the project proponent shall show that all downstream channels between the project site and the Bay/Delta fall into one of the following "low-risk" categories.

i. Enclosed pipes.

ii. Channels with continuous hardened beds and banks engineered to withstand erosive forces and composed of concrete, engineered riprap, sackcrete, gabions, mats, etc. This category excludes channels where hardened beds and banks are not engineered continuous installations (i.e., have been installed in response to localized bank failure or erosion).

iii. Channels subject to tidal action.

iv. Channels shown to be aggrading, i.e., consistently subject to accumulation of sediments over decades, and to have no indications of erosion on the channel banks.

b. **"Medium Risk."** Medium risk channels are those where the boundary shear stress could exceed critical shear stress as a result of hydrograph modification, but where either the sensitivity of the boundary shear stress to flow is low (e.g., an oversized channel with high width to depth ratios) or where the resistance of the channel materials is relatively high (e.g., cobble or boulder beds and vegetated banks). In "medium-risk" channels, accelerated erosion due to increased watershed imperviousness is not likely but is possible, and the uncertainties can be more easily and effectively addressed by mitigation than by additional study.

In a preliminary report, the project proponent's engineer or qualified environmental professional will apply the Program's "Basic Geomorphic Assessment"[1] methods and criteria to show each downstream reach between the project site and the Bay/Delta is either at "low-risk" or "medium-risk" of accelerated erosion due to watershed development. In a following, detailed report, a qualified stream geomorphologist[2] will use the Program's Basic Geomorphic Assessment methods and criteria, available information, and current field data to evaluate each "medium-risk" reach. For *each* "medium-risk" reach, the detailed report shall show one of the following:

i. A detailed analysis, using the Program's criteria, showing the particular reach may be reclassified as "low-risk."

ii. A detailed analysis, using the Program's criteria, confirming the "medium-risk" classification, and:

1. A preliminary plan for a mitigation project for that reach to stabilize stream beds or banks, improve natural stream functions, and/or improve habitat values, and

2. A commitment to implement the mitigation project timely in connection with the proposed development project (including milestones, schedule, cost estimates, and funding), and

3. An opinion and supporting analysis by one or more qualified environmental professionals that the expected environmental benefits of the mitigation project

[1] Contra Costa Clean Water Program *Hydrograph Modification Management Plan*, May 15, 2005, Attachment 4, pp. 6-13. This method must be made available in the Program's *Stormwater C.3 Guidebook*.

[2] Typically, detailed studies will be conducted by a stream geomorphologist retained by the lead agency (or, on the lead agency's request, another public agency such as the Contra Costa County Flood Control and Water Conservation District) and paid for by the project proponent.

substantially outweigh the potential impacts of an increase in runoff from the development project, and

4. Communication, in the form of letters or meeting notes, indicating consensus among staff representatives of regulatory agencies having jurisdiction that the mitigation project is feasible and desirable. In the case of the Regional Water Board, this must be a letter, signed by the Executive Officer or designee, specifically referencing this requirement. (This is a preliminary indication of feasibility required as part of the development project's Stormwater Control Plan. All applicable permits must be obtained before the mitigation project can be implemented.)

c. **"High Risk."** High-risk channels are those where the sensitivity of boundary shear stress to flow is high (e.g., incised or entrenched channels, channels with low width-to-depth ratios, and narrow channels with levees) or where channel resistance is low (e.g., channels with fine-grained, erodible beds and banks, or with little bed or bank vegetation). In a "high-risk" channel, it is presumed that increases in runoff flows will accelerate bed and bank erosion.

To implement this option (i.e., to allow increased runoff peaks and durations to a high-risk channel), the project proponent must perform a comprehensive analysis to determine the design objectives for channel restoration and must propose a comprehensive program of in-stream measures to improve channel functions while accommodating increased flows. Specific requirements are developed case-by-case in consultation with regulatory agencies having jurisdiction. The analysis will typically involve watershed-scale continuous hydrologic modeling (including calibration with stream gauge data where possible) of pre-project and post-project runoff flows, sediment transport modeling, collection and/or analysis of field data to characterize channel morphology including analysis of bed and bank materials and bank vegetation, selection and design of in-stream structures, and project environmental permitting.

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APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

How to use this worksheet (also see instructions on page 28 of the *Stormwater C.3 Guidebook*):

1. Review Column 1 and identify which of these potential sources of stormwater pollutants apply to your site. Check each box that applies.
2. Review Column 2 and incorporate all of the corresponding applicable BMPs in your Stormwater Control Plan drawings.
3. Review Columns 3 and 4 and incorporate all of the corresponding applicable permanent controls and operational BMPs in a table in your Stormwater Control Plan. Use the format shown in Table 3-1 on page 27 of the *Guidebook*. Describe your specific BMPs in an accompanying narrative, and explain any special conditions or situations that required omitting BMPs or substituting alternative BMPs for those shown here.

IF THESE SOURCES WILL BE ON THE PROJECT SITE …	… THEN YOUR STORMWATER CONTROL PLAN SHOULD INCLUDE THESE SOURCE CONTROL BMPs		
1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ A. **On-site storm drain inlets**	❑ **Locations of inlets.**	❑ **Mark all inlets with the words "No Dumping! Flows to Bay" or similar.**	❑ **Maintain and periodically repaint or replace inlet markings.** ❑ **Provide stormwater pollution prevention information to new site owners, lessees, or operators.** ❑ **See applicable operational BMPs in Fact Sheet SC-44, "Drainage System Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com** ❑ **Include the following in lease agreements: "Tenant shall not allow anyone to discharge anything to storm drains or to store or deposit materials so as to create a potential discharge to storm drains."**
❑ B. **Interior floor drains and elevator shaft sump pumps**		❑ **State that interior floor drains and elevator shaft sump pumps will be plumbed to sanitary sewer.**	❑ **Inspect and maintain drains to prevent blockages and overflow.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ C. **Interior parking garages**		❑ **State that parking garage floor drains will be plumbed to the sanitary sewer.**	❑ **Inspect and maintain drains to prevent blockages and overflow.**
❑ D1. **Need for future indoor & structural pest control**		❑ **Note building design features that discourage entry of pests.**	❑ **Provide Integrated Pest Management information to owners, lessees, and operators.**
❑ D2. **Landscape/ Outdoor Pesticide Use**	❑ **Show locations of native trees or areas of shrubs and ground cover to be undisturbed and retained.** ❑ **Show self-retaining landscape areas, if any.** ❑ **Show stormwater treatment and hydrograph modification management BMPs. (See instructions in Chapter 3, Step 5 and guidance in Chapter 5.)**	**State that final landscape plans will accomplish all of the following.** ❑ **Preserve existing native trees, shrubs, and ground cover to the maximum extent possible.** ❑ **Design landscaping to minimize irrigation and runoff, to promote surface infiltration where appropriate, and to minimize the use of fertilizers and pesticides that can contribute to stormwater pollution.** ❑ **Where landscaped areas are used to retain or detain stormwater, specify plants that are tolerant of saturated soil conditions.** ❑ **Consider using pest-resistant plants, especially adjacent to hardscape.** ❑ **To insure successful establishment, select plants appropriate to site soils, slopes, climate, sun, wind, rain, land use, air movement, ecological consistency, and plant interactions.**	❑ **Maintain landscaping using minimum or no pesticides.** ❑ **See applicable operational BMPs in Fact Sheet SC-41, "Building and Grounds Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com** ❑ **Provide IPM information to new owners, lessees and operators.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ E. **Pools, spas, ponds, decorative fountains, and other water features.**	❑ **Show location of water feature and a sanitary sewer cleanout in an accessible area within 10 feet. (Exception: Public pools must be plumbed according to County Department of Environmental Health Guidelines.)**	**If the local municipality requires pools to be plumbed to the sanitary sewer, place a note on the plans and state in the narrative that this connection will be made according to local requirements.**	❑ **See applicable operational BMPs in Fact Sheet SC-72, "Fountain and Pool Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ F. **Food service**	❑ **For restaurants, grocery stores, and other food service operations, show location (indoors or in a covered area outdoors) of a floor sink or other area for cleaning floor mats, containers, and equipment.** ❑ **On the drawing, show a note that this drain will be connected to a grease interceptor before discharging to the sanitary sewer.**	❑ **Describe the location and features of the designated cleaning area.** ❑ **Describe the items to be cleaned in this facility and how it has been sized to insure that the largest items can be accommodated.**	❑ **See the brochure, "Water Pollution Prevention Tips to Protect Water Quality and Keep Your Food Service Facility Clean." Provide this brochure to new site owners, lessees, and operators.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ G. **Refuse areas**	❑ **Show where site refuse and recycled materials will be handled and stored for pickup. See local municipal requirements for sizes and other details of refuse areas.** ❑ **If dumpsters or other receptacles are outdoors, show how the designated area will be covered, graded, and paved to prevent run-on and show locations of berms to prevent runoff from the area.** ❑ **Any drains from dumpsters, compactors, and tallow bin areas shall be connected to a grease removal device before discharge to sanitary sewer.**	❑ **State how site refuse will be handled and provide supporting detail to what is shown on plans.** ❑ **State that signs will be posted on or near dumpsters with the words "Do not dump hazardous materials here" or similar.**	❑ **State how the following will be implemented:** **Provide adequate number of receptacles. Inspect receptacles regularly; repair or replace leaky receptacles. Keep receptacles covered. Prohibit/prevent dumping of liquid or hazardous wastes. Post "no hazardous materials" signs. Inspect and pick up litter daily and clean up spills immediately. Keep spill control materials available on-site. See Fact Sheet SC-34, "Waste Handling and Disposal" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ H. **Industrial processes.**	❑ **Show process area.**	❑ **If industrial processes are to be located on site, state: "All process activities to be performed indoors. No processes to drain to exterior or to storm drain system."**	❑ **See Fact Sheet SC-10, "Non-Stormwater Discharges" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ I. **Outdoor storage of equipment or materials. (See rows J and K for source control measures for vehicle cleaning, repair, and maintenance.)**	❑ **Show any outdoor storage areas, including how materials will be covered. Show how areas will be graded and bermed to prevent run-on or run-off from area.** ❑ **Storage of non-hazardous liquids shall be covered by a roof and/or drain to the sanitary sewer system, and be contained by berms, dikes, liners, or vaults.** ❑ **Storage of hazardous materials and wastes must be in compliance with the local hazardous materials ordinance and a Hazardous Materials Management Plan for the site.**	**Include a detailed description of materials to be stored, storage areas, and structural features to prevent pollutants from entering storm drains.** **Where appropriate, reference documentation of compliance with the requirements of Contra Costa Hazardous Materials Programs for:** ▪ **Hazardous Waste Generation** ▪ **Hazardous Materials Release Response and Inventory** ▪ **California Accidental Release (CalARP)** ▪ **Aboveground Storage Tank** ▪ **Uniform Fire Code Article 80 Section 103(b) & (c) 1991** ▪ **Underground Storage Tank** **www.cchealth.org/groups/hazmat/**	❑ **See the Fact Sheets SC-31, "Outdoor Liquid Container Storage" and SC-33, "Outdoor Storage of Raw Materials " in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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❑ J. Vehicle and Equipment Cleaning	❑ Show on drawings as appropriate: (1) Commercial/industrial facilities having vehicle/equipment cleaning needs shall either provide a covered, bermed area for washing activities or discourage vehicle/equipment washing by removing hose bibs and installing signs prohibiting such uses. (2) Multi-dwelling complexes shall have a paved, bermed, and covered car wash area (unless car washing is prohibited on-site and hoses are provided with an automatic shut-off to discourage such use). (3) Washing areas for cars, vehicles, and equipment shall be paved, designed to prevent run-on to or runoff from the area, and plumbed to drain to the sanitary sewer. (4) Commercial car wash facilities shall be designed such that no runoff from the facility is discharged to the storm drain system. Wastewater from the facility shall discharge to the sanitary sewer, or a wastewater reclamation system shall be installed.	❑ If a car wash area is not provided, describe measures taken to discourage on-site car washing and explain how these will be enforced.	Describe operational measures to implement the following (if applicable): ❑ Washwater from vehicle and equipment washing operations shall not be discharged to the storm drain system. ❑ Car dealerships and similar may rinse cars with water only. See Fact Sheet SC-21, "Vehicle and Equipment Cleaning," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com

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❑ K. **Vehicle/Equipment Repair and Maintenance**	❑ Accommodate all vehicle equipment repair and maintenance indoors. Or designate an outdoor work area and design the area to prevent run-on and runoff of stormwater. ❑ Show secondary containment for exterior work areas where motor oil, brake fluid, gasoline, diesel fuel, radiator fluid, acid-containing batteries or other hazardous materials or hazardous wastes are used or stored. Drains shall not be installed within the secondary containment areas. ❑ Add a note on the plans that states either (1) there are no floor drains, or (2) floor drains are connected to wastewater pretreatment systems prior to discharge to the sanitary sewer and an industrial waste discharge permit will be obtained.	❑ State that no vehicle repair or maintenance will be done outdoors, or else describe the required features of the outdoor work area. ❑ State that there are no floor drains or if there are floor drains, note the agency from which an industrial waste discharge permit will be obtained and that the design meets that agency's requirements. ❑ State that there are no tanks, containers or sinks to be used for parts cleaning or rinsing or, if there are, note the agency from which an industrial waste discharge permit will be obtained and that the design meets that agency's requirements.	In the Stormwater Control Plan, note that all of the following restrictions apply to use the site: ❑ No person shall dispose of, nor permit the disposal, directly or indirectly of vehicle fluids, hazardous materials, or rinsewater from parts cleaning into storm drains. ❑ No vehicle fluid removal shall be performed outside a building, nor on asphalt or ground surfaces, whether inside or outside a building, except in such a manner as to ensure that any spilled fluid will be in an area of secondary containment. Leaking vehicle fluids shall be contained or drained from the vehicle immediately. ❑ No person shall leave unattended drip parts or other open containers containing vehicle fluid, unless such containers are in use or in an area of secondary containment.

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❑ L. **Fuel Dispensing Areas**	❑ **Fueling areas[1] shall have impermeable floors (i.e., portland cement concrete or equivalent smooth impervious surface) that are: a) graded at the minimum slope necessary to prevent ponding; and b) separated from the rest of the site by a grade break that prevents run-on of stormwater to the maximum extent practicable.** ❑ **Fueling areas shall be covered by a canopy that extends a minimum of ten feet in each direction from each pump. [Alternative: The fueling area must be covered and the cover's minimum dimensions must be equal to or greater than the area within the grade break or fuel dispensing area[1].] The canopy [or cover] shall not drain onto the fueling area.**		❑ **The property owner shall dry sweep the fueling area routinely.** ❑ **See the Business Guide Sheet, "Automotive Service—Service Stations" in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

[1] **The fueling area shall be defined as the area extending a minimum of 6.5 feet from the corner of each fuel dispenser or the length at which the hose and nozzle assembly may be operated plus a minimum of one foot, whichever is greater.**

APPENDIX D—STORMWATER POLLUTANT SOURCES/SOURCE CONTROL CHECKLIST

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1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
❑ M. **Loading Docks**	❑ **Show a preliminary design for the loading dock area, including roofing and drainage. Loading docks shall be covered and/or graded to minimize run-on to and runoff from the loading area. Roof downspouts shall be positioned to direct stormwater away from the loading area. Water from loading dock areas shall be drained to the sanitary sewer, or diverted and collected for ultimate discharge to the sanitary sewer.** ❑ **Loading dock areas draining directly to the sanitary sewer shall be equipped with a spill control valve or equivalent device, which shall be kept closed during periods of operation.** ❑ **Provide a roof overhang over the loading area or install door skirts (cowling) at each bay that enclose the end of the trailer.**		❑ **Move loaded and unloaded items indoors as soon as possible.** ❑ **See Fact Sheet SC-30, "Outdoor Loading and Unloading," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**
❑ N. **Fire Sprinkler Test Water**		❑ **Provide a means to drain fire sprinkler test water to the sanitary sewer.**	❑ **See the note in Fact Sheet SC-41, "Building and Grounds Maintenance," in the CASQA Stormwater Quality Handbooks at www.cabmphandbooks.com**

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1 Potential Sources of Runoff Pollutants	2 Permanent Controls—Show on Stormwater Control Plan Drawings	3 Permanent Controls—List in Stormwater Control Plan Table and Narrative	4 Operational BMPs—Include in Stormwater Control Plan Table and Narrative
O. **Miscellaneous Drain or Wash Water or Other Sources** ❑ **Boiler drain lines** ❑ **Condensate drain lines** ❑ **Rooftop equipment** ❑ **Drainage sumps** ❑ **Roofing, gutters, and trim.** ❑ **Other sources**		❑ **Boiler drain lines shall be directly or indirectly connected to the sanitary sewer system and may not discharge to the storm drain system.** ❑ **Condensate drain lines may discharge to landscaped areas if the flow is small enough that runoff will not occur. Condensate drain lines may not discharge to the storm drain system.** ❑ **Rooftop equipment with potential to produce pollutants shall be roofed and/or have secondary containment.** ❑ **Any drainage sumps on-site shall feature a sediment sump to reduce the quantity of sediment in pumped water.** ❑ **Avoid roofing, gutters, and trim made of copper or other unprotected metals that may leach into runoff.** ❑ **Include controls for other sources as specified by local reviewer.**	
❑ P. **Plazas, sidewalks, and parking lots.**			❑ **Sweep plazas, sidewalks, and parking lots regularly to prevent accumulation of litter and debris. Collect debris from pressure washing to prevent entry into the storm drain system. Collect washwater containing any cleaning agent or degreaser and discharge to the sanitary sewer not to a storm drain.**

RB-AR34430

Stream fish occurrence in response to impervious cover, historic land use, and hydrogeomorphic factors

Seth J. Wenger, James T. Peterson, Mary C. Freeman, Byron J. Freeman, and D. David Homans

Abstract: We evaluated competing models explaining the occurrence of five stream fishes in an urbanizing watershed to determine the relative importance of (*a*) impervious surface and other indicators of current land use, (*b*) historic land use (e.g., agriculture, impoundments), and (*c*) hydrogeomorphic characteristics (e.g., stream size, elevation, geology). For four of five species, the best-supported models were those that included both current effective impervious cover and historic land use predictor variables, although models with only effective impervious cover were equally well supported for two of those species. For the best-supported models for three species, occurrence probability was predicted to approach zero at levels of development equivalent to about 2%–4% effective impervious cover in the surrounding region. Data were drawn from 357 fish collections made in the Etowah River basin, Georgia, USA, between 1998 and 2003 and analyzed using hierarchical logistic regression accounting for imperfect species detection. This is the first study we know of to examine the response of individual fish species to both increasing impervious cover and historic land use. Such individual species assessments will be increasingly necessary to guide policies for managing urban effects and preventing extirpations of sensitive species.

Résumé : Nous évaluons plusieurs modèles concurrents explicatifs de la présence de cinq poissons d'eau courante dans un bassin versant urbanisé afin de déterminer l'importance relative (*a*) de la surface imperméable et des autres indicateurs de l'utilisation actuelle des terres, (*b*) de l'utilisation des terres dans le passé (par ex., agriculture, barrages) et (*c*) des caractéristiques hydrogéomorphiques (par ex., taille des cours d'eau, altitude, géologie). Pour quatre des cinq espèces, les modèles les plus solides sont ceux qui incluent à la fois la couverture imperméable effective actuelle et les variables prédictives de l'utilisation des terres du passé; par ailleurs, les modèles qui tiennent compte seulement de la couverture imperméable efficace fonctionnent aussi solidement avec deux de ces espèces. Dans le cas du modèle le plus solide pour trois espèces, il prédit que la probabilité d'occurrence s'approche de zéro à des niveaux de développement équivalents à environ une couverture imperméable effective de 2 % – 4 % dans la région avoisinante. Les données proviennent de 357 récoltes de poissons faites dans le bassin de l'Etowah, Géorgie, É.-U., entre 1998 et 2003 et elles ont été analysées à l'aide d'une régression logistique hiérarchique qui tient compte de la détection imparfaite des espèces. Il s'agit de la première étude, à notre connaissance, qui examine les réactions d'espèces individuelles de poissons à la fois à la croissance de la couverture imperméable et à l'utilisation des terres dans le passé. De telles évaluations d'espèces individuelles deviendront de plus en plus nécessaires afin de guider les politiques de la gestion des effets de l'urbanisation et de prévenir l'extirpation des espèces sensibles.

[Traduit par la Rédaction]

Introduction

Many studies have demonstrated that fish assemblages respond to a gradient of urbanization (e.g., Wang et al. 2001; Meador et al. 2005; Roy et al. 2005). Most such studies have used characteristics of the fish assemblage — such as an index of biotic integrity, species diversity, or a ratio of homogenization — as response variables (but see Olden 2003 and Walsh et al. 2004*b*, the latter of which is for an amphipod). The limitation of assemblage-level analyses is that they do not provide information about the response of individual species, especially rare ones. Species-level responses can be a matter of significant interest in the management of imperiled fish species. As urban land cover

Received 21 March 2007. Accepted 14 October 2007. Published on the NRC Research Press Web site at cjfas.nrc.ca on 15 May 2008. J19899

S.J. Wenger.[1] University of Georgia River Basin Center, Athens, GA 30602, USA.
J.T. Peterson. US Geological Survey Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia, Athens, GA 30602, USA.
M.C. Freeman. US Geological Survey Patuxent Wildlife Research Center, University of Georgia, Athens, GA 30602, USA.
B.J. Freeman. Georgia Museum of Natural History, University of Georgia, Athens, GA 30602, USA.
D.D. Homans. University of Georgia, Institute of Ecology, Athens, GA 30602, USA.

[1]Corresponding author (e-mail: swenger@uga.edu).

 doi:10.1139/F08-046 © 2008 NRC Canada

RB-AR34431

increases globally, a growing number of species will be impacted by urbanization, and knowledge of species-specific relationships between indicators of urban cover and fish occurrence or abundance will be essential to develop effective conservation strategies.

In the absence of sufficient long-term data sets relating changes in fish occurrence to land use, most studies employ a space-for-time substitution. That is, variation in species occurrence over space is related to variation in land use patterns at a fixed point in time. The space-for-time substitution requires the assumption that observed species distribution patterns are due to the effects of contemporary land use patterns. However, this assumption may not be supported. Contemporary fish distributions are likely the result of (1) complex interactions between hydrogeomorphic characteristics of streams, the landscape, and other biota (Allan 2004), and (2) past human land use activities (Harding et al. 1998), and the two are often strongly related. For example, cities tend to be built on low-slope, formerly agricultural land, rather than high-slope, formerly forested land. If we fail to account for the influence of hydrogeomorphic influences and historic land use, we risk misinterpreting the role of current land use.

This study involves fish species of the Etowah River basin, Georgia, USA. The Etowah River is a major tributary of the Coosa River system in the Mobile River basin (Fig. 1). The Etowah basin supports a diverse aquatic fauna, with 76 extant native species of fish (Burkhead et al. 1997), including three that are listed under the Endangered Species Act and six others that are considered imperiled but are not currently listed. A significant threat facing these organisms is rapid urbanization from the metropolitan Atlanta region (Wenger 2006). To head off a potential conflict between development and species protection, in 2003 the local governments of the Etowah basin began a process to develop the Etowah Aquatic Habitat Conservation Plan (HCP; Etowah HCP Advisory Committee 2006). The purpose of the plan is to implement a set of growth management policies and ordinances that minimize the impact of future development on the aquatic fauna, thus permitting additional growth without threatening the persistence of federally protected organisms.

This study was designed to evaluate whether there was sufficient evidence of an urban effect on listed fish species to justify controls on stormwater runoff as part of the HCP. Although the occurrence patterns of many Etowah fish species appear to suggest a negative relationship with urbanization, these patterns may also reflect natural landscape characteristics or past land use activities. Historic land use appears especially likely to have influenced distributions because much of the Etowah basin experienced intense row-crop agriculture from the 1800s to the early 1900s. The agricultural practices caused massive erosion and the sedimentation of stream valleys (Trimble 1974), which could have led to extirpation of sensitive fish species from many tributaries. Subsequently, many impoundments were constructed across the basin, which may have prevented recolonization and otherwise influenced (and may continue to influence) fish distributions.

In this study we examine five species native to the Etowah system (Table 1) whose distribution patterns suggest possible negative correlations to urban cover. Two of the species (*Etheostoma etowahae* and *Etheostoma scotti*) are listed under the Endangered Species Act and are targets of the Etowah HCP. Our objective is to determine the relative importance of hydrogeomorphic characteristics, historic land use, and current urbanization in explaining the distribution of the species. Our focal metric of current land use is effective impervious area (EIA), which other studies have found to be a key indicator of urban effects on aquatic biota (Walsh et al. 2005*a*). A secondary objective is to identify response thresholds of fish occurrence to increasing EIA.

Materials and methods

Data preparation

Fish collections

We selected 357 records of fish collections from a database maintained by the Georgia Museum of Natural History (Athens, Georgia). We used collections made in the Etowah basin between 1 January 1999 and 31 December 2003, which we considered approximately contemporaneous with the available "current" land cover data (see below). We selected only collections intended to characterize the full assemblage of sampled habitats using electroshocking, kick-seining, and seine hauling. Some of the data were used in previously published studies (Walters et al. 2003*a*; Roy et al. 2005). We excluded collections from streams draining less than 0.5 km^2 and those of uncertain reliability, which included collections targeting only certain species, collections that appeared to be missing information, and collections where notes indicated that an incomplete or low-effort sample had been taken. Sample reaches at sites were 50 m to 200 m in length. Collections from localities that were very close together (less than 0.5 km apart within the same stream, without large intervening tributaries) were assumed to be from the same site. However, collections from the same locality but more than 2 years apart were treated as if they were from independent sites with regard to estimating detection probability, under the assumption that populations could not be considered "closed" across this time period (see below). With these adjustments, the primary data set included 252 distinct sites, each sampled from one to five times.

We selected an additional set of 65 records for collections made at 31 sites to provide supplementary data for estimating species-specific probability of detection (following MacKenzie et al. 2002). We used sites where collections were made twice within 2 consecutive years (28 sites) or three times in 3 years (3 sites; temporal replicates) between 1 January 1990 and 31 December 1998; we also selected pairs of sites that were immediately adjacent and were sampled within a day of one another (spatial replicates) within this time period. We assumed that a species was either present or absent during samplings for each set of replicates, i.e., that the populations were closed.

Hydrogeomorphic predictor variables

For each collection site, we delineated the watershed that drained to the site and assigned it to one of 21 tributary systems (Fig. 1). We derived seven hydrogeomorphic predictor variables: watershed area, downstream link magnitude

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Fig. 1. The Etowah River basin (Georgia, USA), showing collection sites and tributary system boundaries.

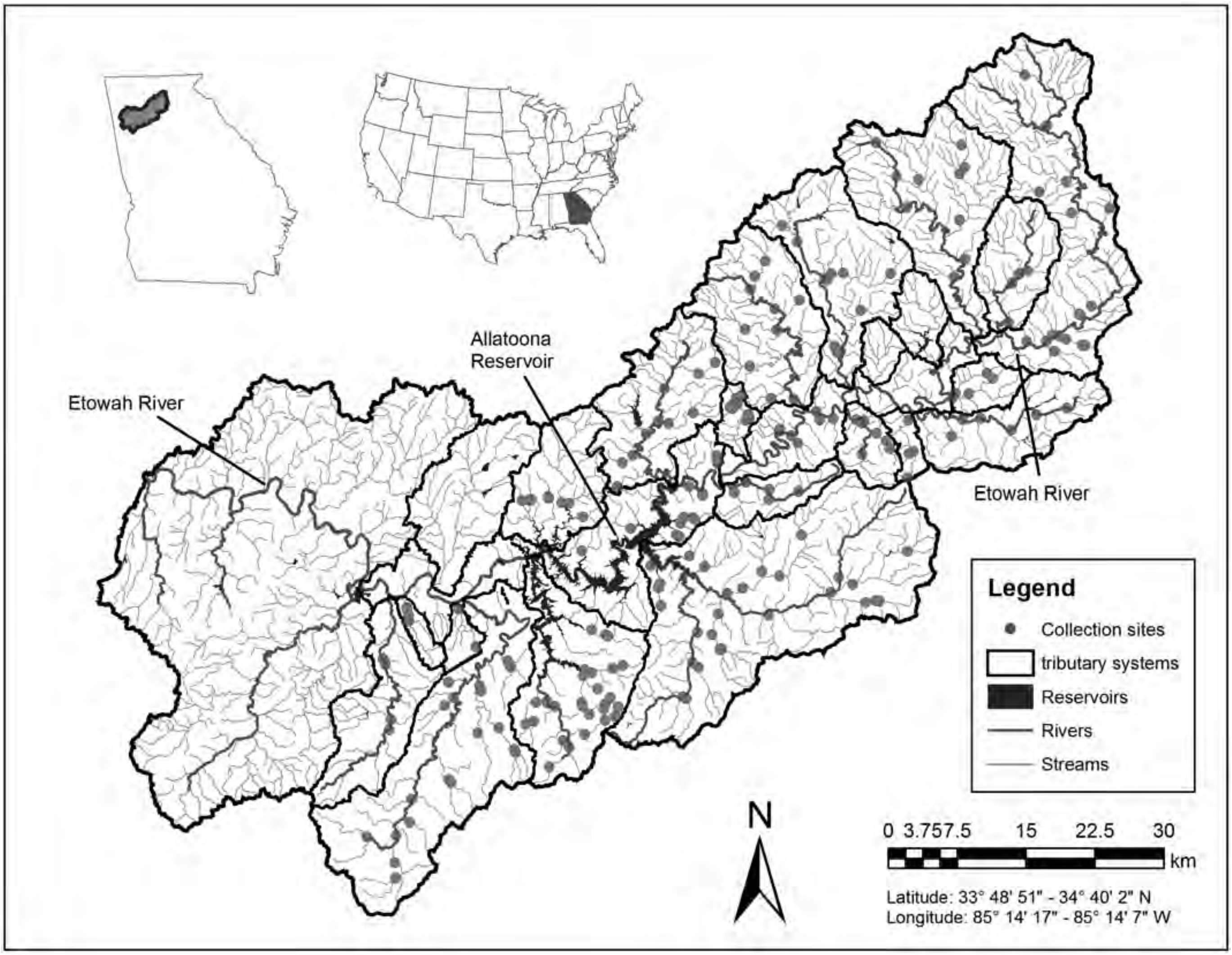

Table 1. Species analyzed for occurrence in relation to hydrogeomorphic variables, historic land use, and current land use.

Species	Family	Distribution	Status
Cyprinella trichroistia Jordan and Gilbert, tricolor shiner	Cyprinidae	Mobile River basin, AL, GA, TN	CS; sensitive to increasing turbidity (Burkhead and Jelks 2001); representative of other sensitive minnows
Noturus leptacanthus Jordan, speckled madtom	Ictaluridae	Atlantic and Gulf Slope drainages, SC to LA	CS; potential surrogate for *N.* sp. cf. *munitus*, coosa madtom (T)
Etheostoma etowahae Wood and Mayden, Etowah darter	Percidae	Etowah River system, GA	E; federally listed
Etheostoma scotti Bauer, Etnier and Burkhead, Cherokee darter	Percidae	Etowah River system, GA	T; federally listed
Percina palmaris Bailey, bronze darter	Percidae	Coosa and Tallapoosa river systems, AL, GA	CS; potential surrogate for *P. antesella* Williams and Etnier, amber darter (E)

Note: Status follows Warren et al. 2000: currently stable (CS), threatened (T), and endangered (E).

(d-link), elevation, physiographic province, bedrock geology, surficial geology, and stream slope (Table 2). All were calculated in ArcView 3.3 or ArcGIS 9.0 software (ESRI, Redlands, California). Watershed area was calculated as the total area draining to the collection site and served as an indicator of stream size at the fish sampling location. D-link was used as a way of describing a stream reach's position in a watershed — whether it was a headwater stream or directly connected to larger main-stem streams, for example. D-link was calculated as the number of unbranched streams draining to the next confluence downstream of the site, using 1:24 000 scale maps (Osborne and Wiley 1992). Elevation was calculated at the collection site from 30 m resolution digital elevation models (DEMs) (US Geological Survey 1988). Physiographic province (Georgia Geologic Survey 1999), bedrock geology summarized by group

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RB-AR34433

Table 2. Summary statistics on continuous predictor variables measured for 252 collection sites used in models of species occurrence.

Variable	Abbrev.	Group	Mean	SD	Min.	Max.
Watershed area (km^2)	area	Hydrogeo	9.3	28.3	0.5	1591
Elevation (m above sea level)	elev	Hydrogeo	305.01	53.06	207.43	536.52
Downstream link magnitude	d-link	Hydrogeo	56.5	118.4	0.00	415
Density of dams in watershed ($no.\cdot km^{-2}$)	damw	Historic	0.98	0.87	0.00	5.95
% of watershed in impoundments	waterw	Historic	0.70	0.64	0.00	3.73
% watershed in intense historic land use	histw	Historic	33.39	22.48	0.00	90.69
% watershed urban cover	urbanw	Current	16.11	17.60	0.00	73.12
% watershed forest cover	forestw	Current	65.12	17.74	0.00	99.15
% watershed TIA	tiaw	Current	3.83	5.55	0.01	28.37
% TIA in 500 m radius	tia500	Current	3.32	5.39	0.00	29.78
% TIA in 1 km radius	tia1	Current	3.47	5.41	0.00	28.89
% TIA in 1.5 km radius	tia15	Current	3.57	5.23	0.00	26.37
% TIA in 2 km radius	tia2	Current	3.71	5.26	0.02	24.71
% watershed EIA	eiaw	Current	2.49	4.44	0.00	23.67
% EIA in 500 m radius	eia500	Current	2.07	4.33	0.00	26.23
% EIA in 1 km radius	eia1	Current	2.23	4.34	0.00	24.56
% EIA in 1.5 km radius	eia1.5	Current	2.32	4.14	0.00	22.07
% EIA in 2 km radius	eia2	Current	2.44	4.19	0.00	20.41
Mean slope of large streams in tributary system (Δ elev./watershed area)	slope	Hydrogeo	83.75	73.03	14.62	289.64
Density of dams in tributary system ($no.\cdot km^{-2}$)	damswden	Hydrogeo	0.83	0.41	0.29	1.90
% of tributary system in impoundments	watertr	Hydrogeo	0.58	0.37	0.12	1.35
% tributary system in intense historic land use	histtr	Hydrogeo	32.37	18.60	4.84	61.47
Presence of metamorphic mafic bedrock geology group (binary)	meta. mafic	Hydrogeo	—	—	—	—
Clayey sand / sandy clay quaternary geology (binary)	rck	Hydrogeo	—	—	—	—
Micaceous saprolite quaternary geology (binary)	ssb	Hydrogeo	—	—	—	—
Multiple binary bedrock geology groups	geology	Hydrogeo	—	—	—	—

Note: TIA, total impervious area; EIA, effective impervious area. "Abbrev." indicates the abbreviation used for the variable in other tables. "Group" refers to whether the variable is classed as hydrogeomorphic ("Hydrogeo"), historic land use, or current land use. SD, standard deviation; "Min." and "Max." indicate the minimum and maximum values, respectively.

(Georgia Geologic Survey 1999), and surficial (quaternary) geology (Richmond et al. 1987) were included as candidate measures of the influence of geology on physicochemical properties of streams. Local stream slope data were not available for most collection sites, so we estimated the mean slope of all streams draining at least 10 km^2 at the scale of each system using 30 m DEMs (US Geological Survey 1988), and assigned the mean to each site in that system.

Impervious area and other measures of current land cover

We focused on impervious area as an indicator of urbanization, as stormwater runoff from impervious surfaces has been identified as the primary source of stressors to urban streams (Walsh et al. 2005*b*). Previous researchers have suggested that the most problematic impervious surfaces are those that are directly connected to streams via drainage and conveyance systems (Alley and Veenhuis 1983; Booth and Jackson 1997; Walsh et al. 2005*a*). Studies have demonstrated that this effective impervious area (EIA) is a better predictor of stream biological and chemical response than total impervious area (TIA) (e.g., Wang et al. 2001; Hatt et al. 2004; Walsh et al. 2004*a*). The 2001 National Land Cover Database Zone 54 Imperviousness Layer (US Geological Survey 2003) was used as the source for TIA. This is a raster coverage with a resolution of 30 m derived from supervised classification of LandSat satellite imagery. To calculate EIA, we followed Alley and Veenhuis (1983) in developing our own empirical relationship between TIA and EIA, which we applied to the TIA coverage. We hand-delineated both impervious and directly connected impervious surfaces (which we considered EIA) from high-resolution aerial photographs for 15 sites of 25–70 ha in size. Impervious areas included roofs, roads, parking lots, sidewalks, and any other artificial impervious surfaces distinguishable on the aerial photos. Directly connected impervious surfaces were a subset of impervious surfaces that were visually noted to drain to the stormwater conveyance network. Such connections were generally obvious from the high-resolution aerial photographs, although there was occasional ambiguity; uncertain cases were considered directly connected. We then determined the relationship between TIA and EIA by fitting the data to different candidate models. The best model, selected on the basis of the coefficient of determination, was linear with a threshold:

$$\text{(1)} \quad \text{EIA} = (1.046 \times \text{TIA}) - 6.23\%$$

where EIA = 0 for TIA values less than 6.23% ($R^2 = 0.98$).

We applied this formula cell-by-cell to the TIA layer to create a raster EIA layer. For each fish collection site, we then calculated TIA and EIA at five scales: impervious area in the watershed upstream of the site, and impervious area

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within 0.5 km, 1 km, 1.5 km, and 2 km radiuses of the site (Table 2). Note that summarizing these values across many cells reduced the differences between EIA and TIA below that expected from the above relationship. The reason was that (especially at low development levels) impervious cover was not distributed evenly across the landscape but tended to occur in patches of cells of moderate TIA surrounded by cells of zero TIA. The transformation calculation of TIA to EIA was applied only to cells with TIA values greater than zero. Therefore, in practice, a watershed of 4% TIA equated to about 2.0%–2.5% EIA. In addition to impervious cover, we also considered urban land cover and forested land cover as indicators of current land use. These variables were calculated for the upstream watershed for each site using 2001 land cover data (Kramer 2004) (Table 2).

Historic land cover

We investigated three candidate indicators of historic land cover, each measured at two scales. The first was historic modified land cover in the basin, which was quantified from 1938 aerial photographs. These were the oldest aerial photographs available for the entire region, and the best representation we could find of land use from the era of cotton production. We georectified scans of 1938 Agricultural Stabilization and Conservation Service (ASCS) 1:100 000 scale aerial photograph index sheets from the Georgia Aerial Photographs database (http://dbs.galib.uga.edu/gaph/html/). We classified the resulting images into forested areas and agricultural or developed land based on cell brightness.

The other candidate indicators of historic land use were the number and area of reservoirs, which we expected to correlate with historic land cover. Many reservoirs were built in the 1950s through the 1970s on agricultural lands, and these can be viewed both as indicators of agricultural influences and as potential stressors. All indicators of historic land use (percentage of drainage area in agricultural land cover in 1938, number of reservoirs, and area of reservoirs) were measured at two scales: (1) the watershed above each collection site and (2) the tributary system within which the collection site was nested (Table 2).

Data analysis

One of our goals in the modeling was to obtain covariate parameter estimates with minimal bias by accounting for spatial dependencies in the data and incomplete detectability of species. Failure to account for spatial correlations can lead to underestimates of the variance of parameter estimates (Snijders and Bosker 1999), while failure to correct for incomplete detection can lead to bias in the means of parameter estimates (Gu and Swihart 2004). We constructed logistic regression models using two-level hierarchical modeling to manage spatial correlations (Snijders and Bosker 1999), following the general approach for modeling species distributions outlined by Latimer et al. (2006). We adapted this to account for incomplete detectability using a species occupancy model (MacKenzie et al. 2002). While incorporating both hierarchy and incomplete detectability into a logistic regression model presents significant challenges for conventional maximum likelihood estimation, Monte Carlo Markov Chain (MCMC) model-fitting techniques are able to accommodate such complexity (Conroy et al. 2005; Peterson et al. 2005). The disadvantage of MCMC techniques is that model fitting is computer-intensive and time-consuming. Therefore, we used a two-stage modeling approach: (1) We screened potential predictor variables representing hydrogeomorphic characteristics, historic land use, and current land use with ordinary logistic regression that assumed complete detectability. (2) We evaluated the relative fit of the best-supported models from the initial screening using hierarchical species occupancy models.

Screening of candidate predictor variables

For the candidate predictor variable selection, we ignored spatial dependencies and assumed complete detectability. For sites with multiple collections, we assumed a species was present if it was encountered in any of the collections. To increase linearity in the predictor variables, watershed area was square root transformed and d-link was natural log transformed. All continuous predictors were normalized with a mean of 0 and standard deviation of 1 and we included quadratic terms for area, d-link, and elevation as possible predictors.

We evaluated a series of logistic regression models for each of the five species, with species occurrence as the dependent variable. All models were run with the statistical package R 2.0.1 (R Development Core Team 2004). There were four model categories: (1) models with only hydrogeomorphic predictors, or "hydrogeomorphic", (2) models with hydrogeomorphic predictors plus a historic land use predictor, or "historic", (3) models with hydrogeomorphic predictors plus a current land use predictor, or "current", and (4) models with hydrogeomorphic predictors plus a historic and a current land use predictor, or "global". Our goal was to identify the best-approximating model in each category (1 through 4) for each species, using Akaike's information criterion modified for small sample size (AIC_c) as the basis for selection (Burnham and Anderson 2002). To identify the most plausible model that included only hydrogeomorphic predictor variables, we fitted a model with all hydrogeomorphic predictors and then performed a series of stepwise removals, selecting the three best-supported models based on AIC_c. Next, we compared 18 models, each of which was based on one of the three best-supported hydrogeomorphic predictor models and included one of the six candidate historic land cover predictor variables. We again performed a stepwise removal of variables to determine whether a reduced model was better supported. We then repeated the process for the 12 candidate predictor variables for current land use (comparing 36 models). Finally, we compared models with different combinations of both a historic land use predictor variable and a current land use predictor variable, to select the best global model. We compared the best-supported models in each category with one another to estimate which was best supported overall.

Hierarchical occupancy modeling

To account for incomplete detection, we jointly modeled species detectability and presence as

$$P(\mathrm{d}) = P(\mathrm{d}|\psi)P(\psi) \qquad (2)$$

where $P(\mathrm{d})$ is the probability that the species is present and detected at the site, $P(\psi)$ is the probability that the species

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is present, and $P(\mathrm{d}|\psi)$ is the probability that the species is detected given that it is present, i.e., detectability. Detection probability was calculated using a site occupancy model (MacKenzie et al. 2002) based on the encounter history of the species at sites sampled multiple times. Briefly, this method simultaneously estimates species presence and detectability by assuming that the occupancy state (presence or absence) of a site sampled multiple times does not change between samples; thus, if a species is found three out of four times when a site is sampled in rapid succession, its detectability is 75%. In our data set, 63 sites were sampled a second time, 21 of those were sampled a third time, 13 of those were sampled a fourth time, and 8 of those were sampled a fifth time (the remaining 189 sites were sampled only once each). The assumption that populations remain unchanged ("closed") between samples was likely violated in many cases, which adds slightly to the uncertainty of the detectability estimates. To improve our estimate of detectability, we added a second data set of an additional 31 sites sampled at least twice during the period 1990–1998. We assumed that because collection methods remained relatively consistent through the 1990s and early 2000s, species detectability was also consistent. The MCMC methods we employed permitted us to construct models in which these auxiliary data informed the estimate of $P(\mathrm{d}|\psi)$ but not any of the other model parameters. That is, the detectability parameter for each species was estimated across both data sets, but parameters for explaining presence–absence were estimated using only the main data set. It is possible to include covariates of detectability to account for differences in sample effort and methods, but we did not do so because we lacked relevant collection-level data across all samples.

Prior to running the hierarchical occupancy models, we tested for spatial autocorrelation at the level of the tributary systems by performing an analysis of variance on the residuals of each of the best-supported screening models, using the tributary systems as treatments. We detected significant dependence within the tributary systems ($P < 0.001$), indicating that samples within the same tributary system tended to be similar to one another and could not be considered fully independent samples. If ignored, this problem would tend to produce overly narrow credible intervals for model parameters (Snijders and Bosker 1999). We addressed the issue by defining a two-level hierarchical structure with sites nested within the 21 tributary systems, implemented in the model by adding a normally distributed random effect at level two (Snijders and Bosker 1999). Level one of the model can be represented as

$$(3)\qquad \mathrm{logit}(P(\psi_{i,j})) = \beta_{0j} + \sum_{s=1}^{m} \beta_s x_{s,i,j}$$

where $x_{s,i,j}$ are $s = 1, 2, \ldots m$ predictors for site i within tributary system j. The intercept is then modeled as a function of tributary system characteristics (level two):

$$(4)\qquad \beta_{0j} = \gamma_0 + \sum_{r=1}^{n} \gamma_r w_{r,j} + \delta_j$$

where $w_{r,j}$ are the $r = 1, 2, \ldots n$ predictors corresponding to tributary system j, and δ_j is a random effect that varies normally among reaches with a mean of zero and variance σ_j^2.

For each of the five species, we fit the best-supported screening model in each of the four categories (hydrogeomorphic, historic, current, and global) to the hierarchical occupancy models. If the screening analyses showed that the second- or third-best models in a category also had considerable support, we also fit these to the hierarchical occupancy models. We used MCMC methods as implemented in WinBUGS 1.4 (Spiegelhalter et al. 2003) for all hierarchical occupancy modeling. We ran six parallel chains and tested each model for convergence using the Gelman–Rubin diagnostic (Gelman and Rubin 1992). Models converged within 8000 iterations, and the values from this "burn in" period were discarded. Models were then run for a further 60 000 iterations to estimate parameters and deviance. We used diffuse priors for all parameters. To reduce MCMC autocorrelation, models were thinned by a factor of 10, which means that only every tenth sample was used in calculating statistics. The use of this technique greatly reduced autocorrelation but did not eliminate it in all cases. We tested increased iterations with even greater thinning, up to 600 000 iterations with 100× thinning, but parameter estimates, deviance, and convergence diagnostics remained stable throughout the range of iterations evaluated. Therefore, we considered 10× thinning adequate.

We used threefold cross-validation to select models and estimate their out-of-sample predictive performance. For test sites we assumed that tributary system membership was unknown. We ranked models by their predictive performance using the area under the curve (AUC) of the receiver-operating characteristic (ROC) plot as a summary statistic. The ROC curve is the ratio of true positives to false positives when the species occurrence decision threshold is varied between zero and one; the AUC of the ROC curve is considered a robust measure that is invariant to species prevalence (Manel et al. 2001; Olden et al. 2002; Latimer et al. 2006).

We found that for models with large variances on the random effect, fixed-effect parameter estimates were proportionately large. These large values are a result of the fixed level one variance of logistic regression models, which leads to inflation of parameter estimates to maintain proportionality between levels one (e.g., stream site) and two (e.g., tributary) when random effects are added (Snijders and Bosker 1999). We corrected for this phenomenon by standardizing the parameter estimates of each model by the sum of level one and level two variances. These standardized values were used to calculate odds ratios for the mean and 90% credible intervals for the fixed-effect parameter estimates for all variables of the best-supported current, historic, and global models.

Results

Impervious cover, historic land cover, and reservoir density varied considerably across the basin and among tributary systems (Figs. 2 and 3), resulting in high variances of most variables across the collection sites or watersheds (Table 2). As expected, there were correlations between historic land use predictor variables and current land use pre-

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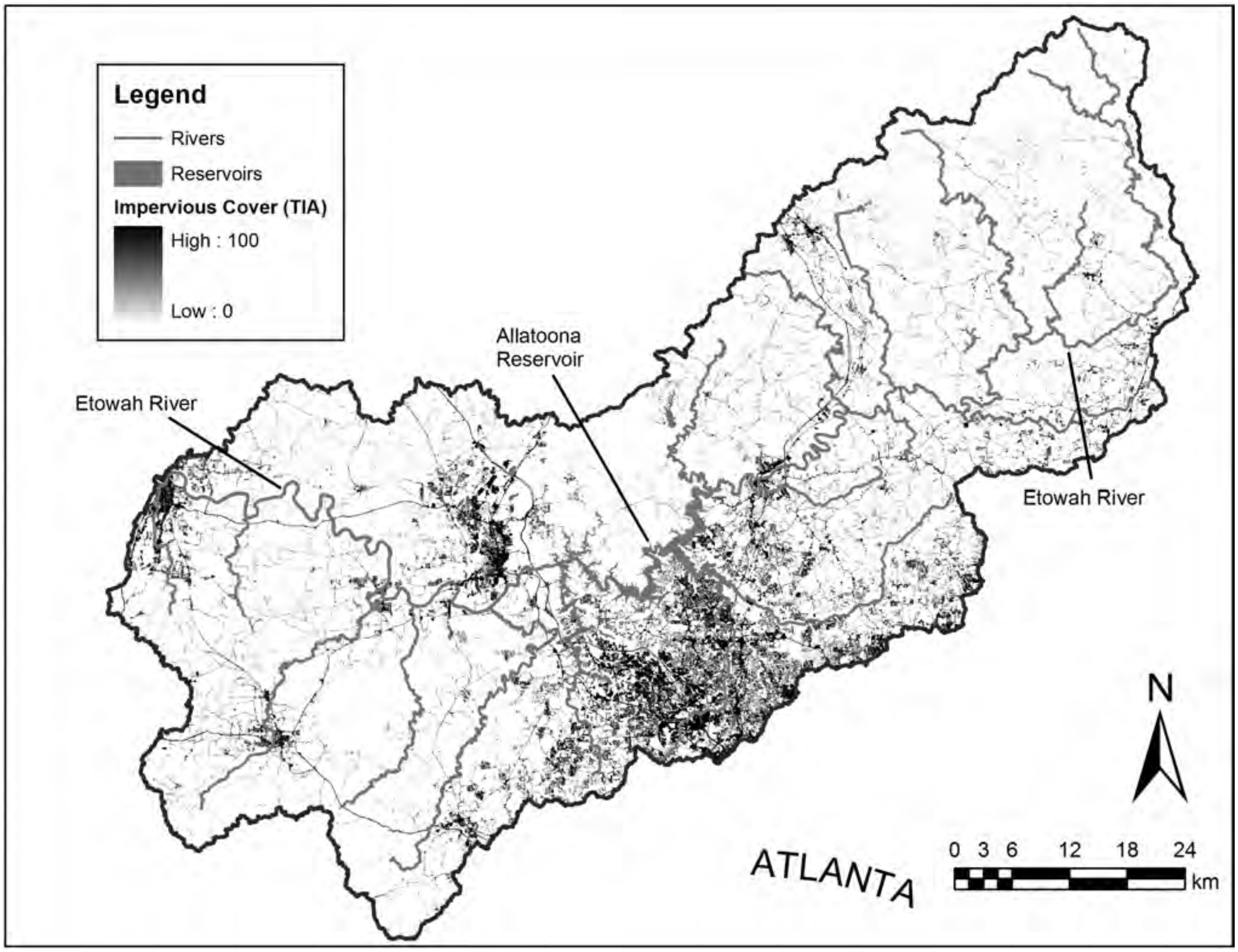
RB-AR34436

Fig. 2. Total impervious area in the Etowah basin.



dictor variables, but pairwise Pearson correlations between historic and current land use predictors were less than 0.6 in all cases and we observed no evidence that multicollinearity affected parameter estimates.

Based on the screening model analysis, we selected 7–14 models to run for each species in the hierarchical occupancy modeling (Table 3). Among the hydrogeomorphic predictor variables evaluated, watershed area, downstream link magnitude, tributary system slope, and elevation were the most commonly included in the best-fitting models. Among historic land use predictors, area inundated by impoundments was the most commonly included, but historic land cover was included for at least some models for two species. Effective impervious area (EIA) within 500 m to 1.5 km of the collection site was the most common measure of current land use selected for inclusion in models, based on the screening analysis. The only exception was *E. scotti*, for which forest cover in the watershed was the best current land use predictor.

Gelman–Rubin convergence diagnostics showed that all of the hierarchical occupancy models converged. Based on the AUC values, the best model for each species was a global model, with the exception of *E. scotti*, for which a historic model (i.e., one without a predictor variable for current land use) was best supported (Table 3). However, for *N. leptacanthus* and *E. etowahae* the best current land use model (i.e., one without a predictor variable for historic land use) was equally or nearly equally well supported. The best historic land use model was less well supported than the best current land use model for all species except *E. scotti*. For all species, the best hydrogeomorphic model was a poorer predictor than the best global, historic, and current models. The differences among the AUC scores for the best models for each species were small. According to a rule of thumb (Swets 1988), models with AUC values > 0.9 have high accuracy. The best models for three of the species met this threshold, while those for *N. leptacanthus* had slightly lower AUC values and those for *E. scotti* had substantially lower AUC values (Table 3).

Cross-validation inherently penalizes model overfitting, and this was evidenced in our analyses by the higher AUC scores of some models that were subsets of others. For example, *N. leptacanthus* model 8 was a subset of models 1–7, but was ranked equal to or higher than these more complex models, indicating that it was the more parsimonious model. Nevertheless, some highly ranked models included parameters whose credible intervals overlapped 1 (Table 4), indicating uncertainty in whether the direction of

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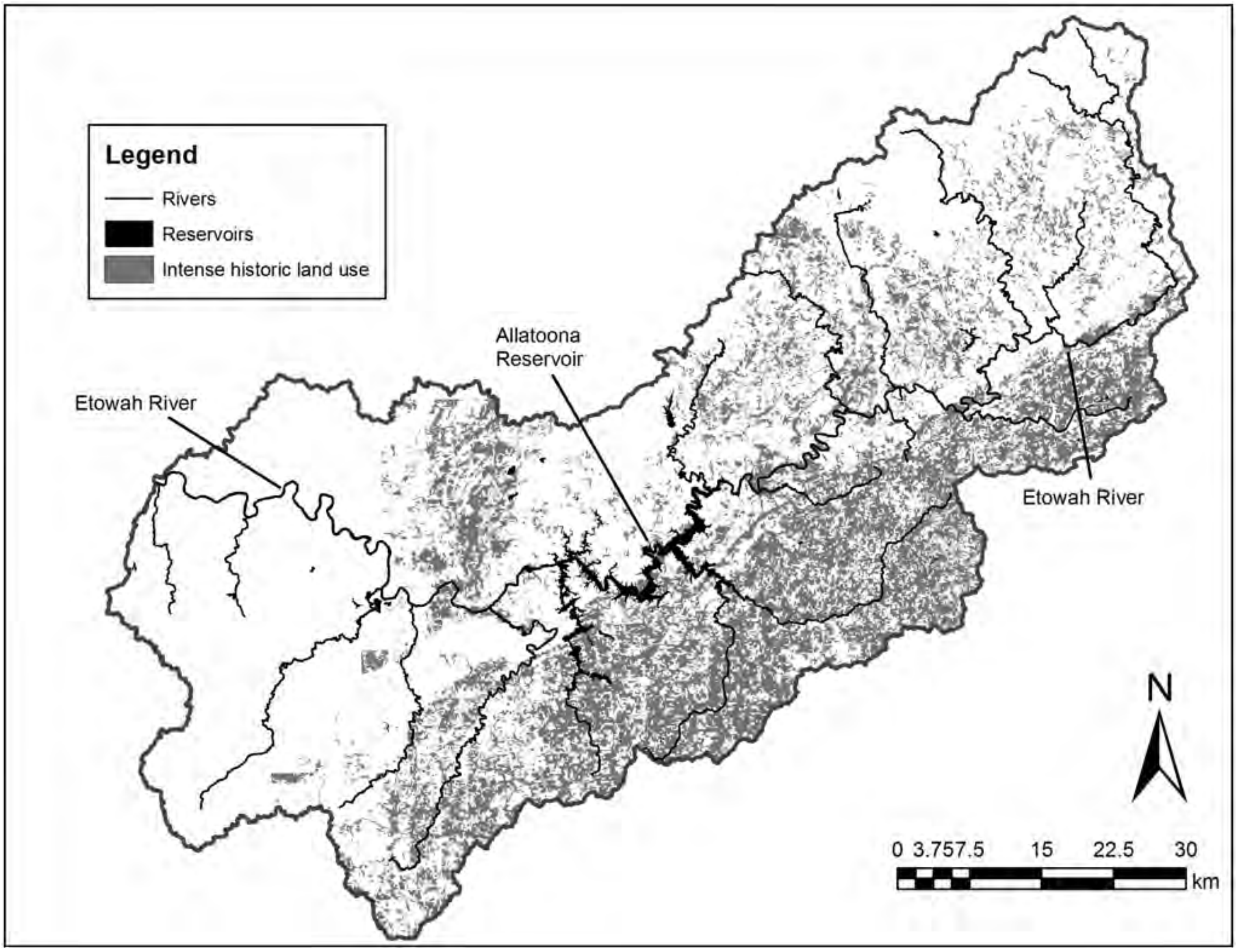
Fig. 3. Historic modified land cover in the Etowah basin.



the correlation was positive (values greater than 1) or negative (values less than 1). For example, for *N. leptacanthus* model 5, the credible interval for historic land use ranged from 0.08 (a strong negative effect) to 1.80 (a moderate positive effect). The historic land use term was therefore of questionable predictive value, and indeed the simpler model 8, which lacked this parameter, had an AUC score equal to that of model 5.

The species with the strongest relationship with current land use was *C. trichroistia* (Table 4). Using the best predicting model, we estimated that the species was almost 20 times less likely to occur for each 1% increase in EIA within 1.5 km (note that this was not a relative increase in EIA, but an absolute increase; e.g., a change from 5% to 6% would be a 1% increase). Occurrence probability approached zero when EIA exceeded about 2% and other predictor variables were held to their mean values (Fig. 4). The presence of *P. palmaris* and the presence of *E. etowahae* also were strongly negatively related to EIA, although the 90% credible interval for *E. etowahae* was very broad (Table 4). For both species the models predicted that the occurrence probabilities approached zero at 4% EIA and above, using the mean estimates for the EIA parameter (Fig. 4). *Noturus leptacanthus* showed a weaker relationship with EIA, and *E. scotti* showed essentially no relationship, with the mean credible interval for the odds ratio centered near 1 and broadly overlapping on either side (Table 4, Fig. 4).

Under the highest-ranked models, the distributions of three species showed a strong relationship with historic land use (Table 4). Using the mean parameter estimates of the best-supported models for *C. trichroistia*, *E. etowahae*, and *P. palmaris*, species were 1.7 to 2.5 times less likely to occur for each increase of 0.25% in the area of upstream watershed or tributary system that was impounded. *Noturus leptacanthus* was 2.3 times less likely to occur for each 10% increase in the area of the upstream watershed in historic modified land cover, but the credible interval of the odds ratio was very wide and included 1, indicating large uncertainty around the species' response. The odds ratio credible interval for *E. scotti* was centered near 1, suggesting little relationship with historic land use.

The current distribution of four of the five species was positively related to watershed area and downstream link magnitude, usually with a second-order term indicating lower occurrence probability in the largest streams. The exception was *E. scotti* occurrence, which was negatively related to watershed area (Table 4). The best-supported model

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Table 3. Hierarchical occupancy models for each species with model selection statistics.

Model No.	Category	Predictor variables	AUC
Cyprinella trichroistia			
2	**Global**	**area, area^2, d-link, d-link^2, slope, waterw, eia1.5**	**0.933**
1	Global	area, area^2, d-link, d-link^2, waterw, eia1.5	0.931
4	Global	area, area^2, d-link, d-link^2, histtr, eia1.5	0.929
3	Global	area, area^2, d-link, d-link^2, slope, histtr, eia1.5	0.926
5	**Current**	**area, area^2, d-link, d-link^2, eia1.5**	**0.922**
6	Current	area, area^2, d-link, d-link^2, slope, eia1.5	0.922
8	**Historic**	**area, area^2, d-link, d-link^2, histtr**	**0.915**
7	Historic	area, area^2, d-link, d-link^2, slope, histtr	0.904
9	Historic	area, area^2, d-link, d-link^2, waterw	0.875
10	**Hydrogeomorphic**	**area, area^2, d-link, d-link^2, slope**	**0.788**
Noturus leptacanthus			
5	**Global**	**area, slope, histw, eia1**	**0.892**
8	**Current**	**area, slope, eia1**	**0.892**
7	Current	area, elev, slope, eia1	0.887
4	Global	area, d-link^2, elev^2, slope, histw, eia1	0.885
6	Current	area, d-link^2, elev^2, slope, eia1	0.878
3	Global	area, elev, slope, histtr, eia1	0.875
2	Global	area, slope, histtr, eia1	0.874
1	Global	area, d-link^2, elev^2, slope, histtr, eia1	0.873
12	**Historic**	**area, slope, histtr**	**0.858**
14	**Hydrogeomorphic**	**area, slope**	**0.855**
11	Historic	area, elev, slope, histtr	0.851
9	Historic	area, d-link^2, elev^2, slope, histw	0.843
10	Historic	area, d-link^2, elev^2, slope, histtr	0.834
13	Hydrogeomorphic	area, d-link^2, elev^2, slope	0.814
Etheostoma etowahae			
3	**Global**	**area, d-link, d-link^2, slope, watertr, eia1.5**	**0.946**
1	**Current**	**area, d-link, d-link^2, slope, eia1.5**	**0.945**
6	Global	area, d-link, d-link^2, slope, damswden, eia1.5	0.945
4	Global	area, area^2, d-link, d-link^2, slope, watertr, eia1.5	0.943
7	**Historic**	**area, area^2, d-link, d-link^2, slope, damswden**	**0.936**
5	Global	area, d-link, d-link^2, watertr, eia1.5	0.932
9	Historic	area, area^2, d-link, d-link^2, watertr, slope	0.931
2	Current	area, d-link, d-link^2, eia1.5	0.927
11	**Hydrogeomorphic**	**area, area^2, d-link, d-link^2, slope**	**0.912**
8	Historic	area, d-link, d-link^2, damswden	0.903
10	Hydrogeomorphic	area, area^2, d-link, d-link^2, elev, elev^2, slope	0.896
Etheostoma scotti			
4	**Historic**	**area, elev^2, meta. mafic, rck, ssb, watertr**	**0.737**
5	**Global**	**area, elev^2, meta. mafic, rck, ssb, watertr, forestw**	**0.727**
2	**Current**	**area, elev^2, meta. mafic, rck, ssb, forestw**	**0.724**
7	**Hydrogeomorphic**	**area, elev^2, meta. mafic, rck, ssb**	**0.711**
3	Historic	area, elev, meta. mafic, rck, ssb, watertr	0.700
6	Hydrogeomorphic	area, d-link^2, elev^2, geology	0.675
1	Current	area, d-link^2, elev^2, forestw	0.624
Percina palmaris			
1	**Global**	**area, area^2, d-link, d-link^2, elev, slope, watertr, eia500**	**0.921**
2	Global	area, d-link, d-link^2, elev, watertr, eia500	0.918
6	**Current**	**area, d-link, d-link^2, elev, eia500**	**0.908**
5	Current	area, area^2, d-link, d-link^2, elev, slope, eia500	0.905
3	**Historic**	**area, area^2, d-link, d-link^2, elev, slope, watertr**	**0.895**
4	Historic	area, d-link, d-link^2, elev, watertr	0.891
7	**Hydrogeomorphic**	**area, area^2, d-link, d-link^2, elev, slope**	**0.870**
8	Hydrogeomorphic	area, d-link, d-link^2, elev	0.853

Note: The best model in each category for each species is shown in bold. Models are shown sorted from best to worst fitting based on area under the curve (AUC) of the receiver-operating characteristic plot. Variable abbreviations are defined in Table 2.

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Table 4. Parameter estimates for detection probability, intercepts, and fixed effects of best-supported hierarchical occupancy models for each species.

Parameter	Estimate	5% CI	95% CI	Unit of increase
Cyprinella trichroistia				
Detection probability	82%	75%	88%	
Intercept	1%	0%	15%	
area	37.83	5.46	340.22	Standard deviation
$area^2$	0.48	0.23	0.86	Standard deviation
d-link	1.79	0.59	5.64	Standard deviation
$d\text{-}link^2$	0.22	0.04	0.69	Standard deviation
slope	1.97	0.89	4.31	Standard deviation
waterw	0.57	0.37	0.80	0.25%
eia1.5	0.05	0.01	0.29	1%
Level 2 random effect variance	3.28	0.43	8.08	
Noturus leptacanthus				
Detection probability	55%	44%	67%	
Intercept	24%	10%	46%	
area	9.14	2.85	44.41	Standard deviation
slope	0.11	0.02	0.43	Standard deviation
histw	0.44	0.08	1.80	10%
eia1	0.70	0.50	0.88	
Level 2 random effect variance	27.94	6.46	60.82	
Etheostoma etowahae				
Detection probability	55%	44%	65%	
Intercept	1%	0%	22%	
area	17.13	2.95	372.81	Standard deviation
d-link	80.02	6.39	6664.24	Standard deviation
$d\text{-}link^2$	0.01	0.00	0.16	Standard deviation
slope	4.36	0.93	32.95	Standard deviation
watertr	0.41	0.14	0.95	0.25%
eia1.5	0.19	0.01	0.85	1%
Level 2 random effect variance	15.62	4.64	34.64	
Etheostoma scotti				
Detection probability	81%	75%	86%	
Intercept	73%	55%	86%	
area	0.74	0.50	0.93	Standard deviation
$elev^2$	0.84	0.66	0.98	Standard deviation
watertr	0.95	0.53	1.67	0.25%
meta. mafic	0.48	0.19	0.88	Present (binary)
rck	121.58	0.12	4.40×10^7	Present (binary)
ssb	0.47	0.19	0.85	Present (binary)
Level 2 random effect variance	7.78	3.02	16.86	
Percina palmaris				
Detection probability	86%	79%	92%	
Intercept	6%	0%	41%	
area	47.09	5.67	782.68	Standard deviation
$area^2$	0.88	0.40	2.20	Standard deviation
d-link	3.23	1.27	9.79	Standard deviation
$d\text{-}link^2$	0.23	0.05	0.77	Standard deviation
elev	1.47	0.79	3.28	Standard deviation
slope	1.55	0.60	3.80	Standard deviation
watertr	0.44	0.23	0.85	0.25%
eia500	0.19	0.04	0.57	1%
Level 2 random effect variance	5.26	1.16	17.39	

Note: CI, credible interval. Detection probability estimates are given as percentages. For the intercept term, estimates correspond to site occupancy (occurrence probability) when other parameters are zero. For fixed effects, values are given as odds ratios per specified unit of increase. A value greater than 1 indicates a positive correlation, and a value less than 1 indicates a negative correlation. For example, *Cyprinella trichroistia* is 95% less likely to occur for each 1% increase in EIA within 1.5 km. A credible interval that overlaps 1 indicates a variable of uncertain effect. For the level 2 random effect, values are variance estimates.

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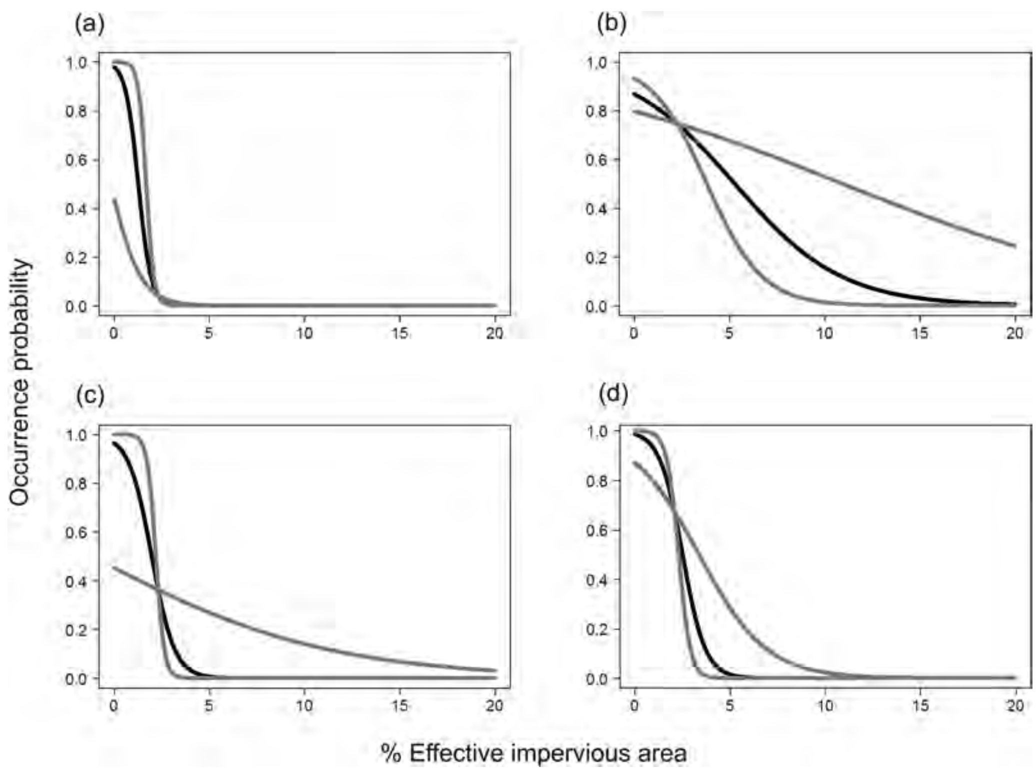

Fig. 4. Occurrence probability of each species under the best-supported model in response to increasing impervious cover. The black line represents the response curve based on the mean parameter estimate for effective impervious area (EIA); gray lines represent the response curves based on the 5% and 95% values for the parameter estimate for EIA. Predictor values for watershed area and d-link are set to one standard deviation larger than the mean, while other predictors are set to mean values. (*a*) *Cyprinella trichroistia*; (*b*) *Noturus leptacanthus*; (*c*) *Etheostoma etowahae*; (*d*) *Percina palmaris*. *Etheostoma scotti* is not plotted because the best-supported model did not include a current land use predictor variable.

for *P. palmaris* indicated that species occurrence was positively related to elevation, whereas *E. scotti* occurrence was negatively related to elevation. Slope was positively related with the occurrence of *C. trichroistia*, *E. etowahae*, and *P. palmaris*, although in all cases the 90% credible interval overlapped 1. The occurrence of *N. leptacanthus* was negatively related to slope (Table 4).

There was unexplained variation at the tributary system level, as indicated by the level 2 random effect variance estimates (Table 4). Variation was greatest for *N. leptacanthus* and lowest for *C. trichroistia*. The variability among tributary systems is reflected in shifted intercepts, which affect the relationship of fixed effects (such as EIA) by shifting the curve to the left or right of the overall mean (Fig. 5, using *E. etowahae* as an example).

Discussion

We found that for four of the five species evaluated, both historic and current land use variables were included in the best-supported hierarchical occupancy models. For *N. leptacanthus* and *E. etowahae*, the best model was a toss-up between one including current land use (and not historic land use) and one with both current and historic land use, suggesting that historic land use added relatively little explanatory power. The results provide good evidence that both current and historic land use are potentially important determinants of occupancy patterns for these species. However, the similarity in AUC scores among the best models for each species suggests that caution is warranted in determining which model is best. Although we know of no standard criteria for identifying a candidate set of well-supported models based on AUC scores, we considered it prudent to consider any model with a score within 0.010–0.015 of the top model to be an alternative hypothesis with good support from the data. By this criterion, both the current land use and global models are well-supported alternatives for *C. trichroistia*, *N. leptacanthus*, and *P. palmaris*, while the global, current, and historic models are supported for *E. etowahae* and *E. scotti*.

Based on the top models, the occurrence of several species was strongly related to low levels of EIA. Many previous studies have reported declines in aquatic fauna in watersheds draining more than 10%–12% impervious cover (Klein 1979; Schueler 1994; Wang et al. 2000). Our results indicate that some species become rare at impervious cover levels as low as 2% EIA. For some species there is considerable uncertainty around this value, but for *C. trichroistia* this threshold is consistent across all credible intervals of all well-supported models. We caution that the accuracy of these values is somewhat uncertain because the accuracy and bias of the impervious cover layer (US Geological Survey 2003) on which EIA is based are unreported in the metadata and apparently unmeasured. We anecdotally

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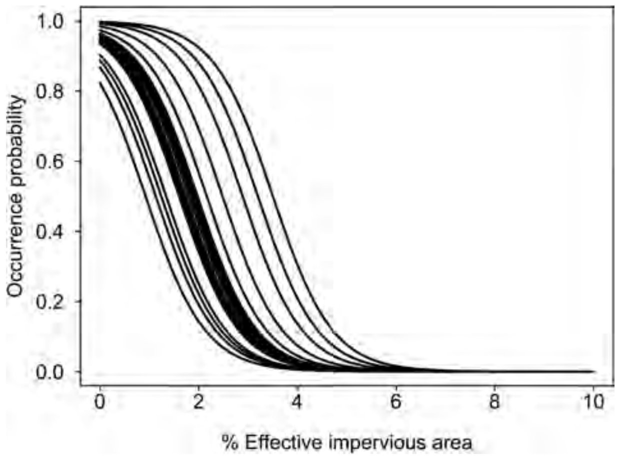
Fig. 5. Occurrence probability for *Etheostoma etowahae* in each of 21 tributary systems as a function of increasing EIA under the best-supported model. Coefficients for fixed and random effects are held to their mean estimates. Predictor values for watershed area and d-link are set to one standard deviation larger than the mean, while other predictors are set to mean values.



observed that impervious cover appeared to be underestimated in the data layer in some geographic regions; we suspect this may be a common problem with impervious layers derived from satellite imagery. Nevertheless, our observed 2% EIA threshold value for the most sensitive species is consistent with a recent study that suggested EIA must remain below 2% to maintain natural ecological conditions (Ladson et al. 2006).

We found that for four of five species, models with current land use (and not historic land use) provided slightly more accurate predictions than models with historic land use (and not current land use). Our finding is in contrast to the results of Harding et al. (1998), who found that 1950s land use was a better predictor of fish and invertebrate diversity than current land use. However, Harding et al. (1998) examined only forested and agricultural watersheds, whereas we considered urban watersheds as well. We found that models including both current and historic land use predictors were among the best supported for most species, providing evidence that current fish distributions are the product of past land use legacies and recent activities, especially urban development. We hypothesize that in the Etowah basin, historic agricultural activities caused extirpations of some species from large sections of the basin. The decline in agriculture and subsequent reforestation then allowed a slow recovery of these species, but current urbanization and suburbanization activities are now causing new extirpations. Such a pattern is probably evident in much of North America, owing to the widespread conversion of current and former agricultural land to urban and suburban uses.

Of the historic land use variables, density of and area inundated by impoundments were generally better predictors than historic modified land cover as mapped from aerial photos. Historic land cover may have performed less well because it was only a snapshot at one point in time (1938) and perhaps not an accurate predictor of the locations that suffered the greatest impacts. Cotton agriculture in Georgia crashed in the early 20th century with the arrival of the boll weevil (Haney et al. 1996), and by 1938 some agricultural areas may already have been abandoned and reforested. Reservoirs (many constructed for sediment control on agricultural lands) may be a better long-term signal of past land use because they are pervasive and because they may prevent recolonization of areas of extirpation. In this sense, reservoirs are both indicators of past land use and current stressors in their own right. In addition to blocking fish movement, reservoirs also eliminate fluvial habitat; alter flows, temperature, and chemistry; and have been shown to affect downstream fish assemblages (Collier et al. 1996; Freeman and Marcinek 2006). In our data set, the number of dams in the tributary system was highly correlated with the historic modified land cover in the tributary system (r = 0.88). However, the area inundated by impoundments in the collection watershed, which was a good predictor for some species, was relatively uncorrelated with historic modified land cover (r = 0.34).

The appearance of slope in the best-supported models for most species is consistent with the findings of previous studies in the Etowah basin, which identified slope (i.e., stream channel gradient) as a critical variable influencing the distribution of many species (Walters et al. 2003*a*, 2003*b*). The strengths of the relationships are somewhat remarkable considering that we were able to use only map slope and not field-measured reach slope, which was unavailable for many sites. We measured slope at the tributary system scale under the assumption that tributary systems with lower average slope had less riffle habitat, which made these systems less suited to riffle-dwelling species such as the five modeled here. Thus, at the tributary system scale mean slope is a potential filtering mechanism (Poff 1997), limiting whether fish species are likely to be present or absent from the system as a whole (we also hypothesized that low slope could indicate high suitability for agriculture, but we found no relationship between slope and historic land cover at the tributary system scale; r = 0.2). Reach-scale slope may serve as a second filter, limiting whether a species is locally present, given its presence in the tributary system.

Our study did not evaluate mechanisms by which urbanization affects fishes. Urbanization is a complex phenomenon that can impact fish populations through multiple potentially interacting pathways, including modification of the hydrologic regime, introduction of toxins, physical alteration of habitat, and reduction and shifts in the food base (see Paul and Meyer 2001; Walsh et al. 2005*b*; Wenger 2006). Past studies in the Etowah basin have related shifts in fish communities across an urban gradient to geomorphic change (Walters et al. 2003*a*) and to hydrologic alteration associated with imperviousness (Roy et al. 2005). It is possible that the mechanism by which urbanization causes extirpation varies from species to species. Indeed, considering the variability in natural-history characteristics among different fish species, we believe this is quite likely to be the case: some fishes will be sensitive to alteration of spawning habitat and others to toxins in their larval stage, while still others are feeding specialists that will respond to shifts in their food resources. If these responses were better understood, management strategies could be better targeted to the needs of individual species. However, there is consid-

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erable value in understanding the overall thresholds of responses of individual species, even without a mechanistic understanding, because these thresholds can be used to inform policies that broadly manage the impacts of urbanization. For example, most of the potential mechanisms are driven by stormwater runoff from impervious surfaces, which can be controlled by stormwater management programs designed to mimic natural hydrology (e.g., Ladson et al. 2006).

In previous studies in the Etowah basin, urban effects were found to be strongest on fish species classified as regional endemics or fluvial specialists (Walters et al. 2003*a*; Roy et al. 2005). Of the species examined here, *C. trichroistia*, *P. palmaris*, and *E. scotti* were included in both of these categories. Our results provide strong evidence that *C. trichroistia* and *P. palmaris* are indeed sensitive to urban stressors, but that occurrence of *E. scotti* is not strongly related to current land use. We also found that *N. leptacanthus* appears to be influenced by impervious cover, despite the fact that this species had previously been included among cosmopolitan species (i.e., species which as a group responded neutrally or positively to urban impacts; Walters et al. 2003*a*). These exceptions serve as a reminder that species groupings based on traits and classifications — such as endemics and cosmopolitans, or any of various index of biotic integrity metrics — may contain considerable noise in the form of species that respond in a manner opposite to what is expected. While such groupings may provide some utility in assessing the degree of impact experienced at the level of the fish assemblage, the response of a group as a whole cannot be used as a surrogate for the response of an individual species. However, it is realistic to use groups as a preliminary screen to identify species that are potentially sensitive to urbanization.

Similarly, general ecological correlates of imperilment such as benthic habit and small body size (Burkhead et al. 1997; Reynolds et al. 2005) may also be indicators of potential urban sensitivity. While such characteristics may provide an initial group of candidate species to test for sensitivity, they do not provide much insight into the degree of sensitivity. For example, the life-history traits of the highly sensitive *C. trichroistia* as a small fluvial specialist do not differentiate it from many other minnow species that are robust to urbanization effects.

Ultimately, effective management of the impacts of urbanization requires an understanding of the thresholds of response of individual species. For the two federally protected species we evaluated, we found good evidence for a strong response of *E. etowahae* to impervious cover but little evidence to indicate a relationship between presence of *E. scotti* and urbanization. These findings are consistent with field observations: *E. etowahae* is unknown from urban or suburban streams, while *E. scotti* has been collected in a number of suburban and moderately urban watersheds, albeit at lower abundances than in streams in forested or agricultural catchments. These results have important management implications, as they suggest that aggressive stormwater management policies are justified by the presence of *E. etowahae* but not by the presence of *E. scotti*.

We assert that in evaluating the sensitivity of individual species to urbanization or other hypothesized stressors, it is important to consider alternative hypotheses. Specifically, historic land use is likely to be of considerable importance in explaining present distribution patterns of many fish species. The extent to which this is true will depend on the magnitude of the historic effect and subsequent recolonization. Recolonization will depend on (1) persistence of effects or degree of habitat recovery, (2) movement potential and propensity of the species, and (3) presence of movement barriers. These factors may be difficult to assess. However, we suggest that in many cases it will be possible to use the type of approach presented here, or a simplified version, to compare the relative support for historic land use, current land use, hydrogeomorphic factors, or a combination of the three in explaining present fish distribution patterns.

This is the first study we know of to quantify the response of individual fish species to both historic and current land use. We found that both factors were important in explaining the distribution of fishes in an urbanizing watershed, and that some species exhibited a strong relationship to impervious cover, with occurrence probability approaching zero at levels above 2% EIA. Assessment of the response of individual species is a necessary step if we are to advance from merely cataloguing urban effects on fish assemblages to developing management policies that prevent extirpation of sensitive fish species.

Acknowledgements

This study was funded by Habitat Conservation Planning grants from the US Fish and Wildlife Service. The data used in this study were originally collected by numerous researchers. In addition to the authors, these included Noel Burkhead, Bill Ensign, David Etnier, Megan Hagler, Howard Jelks, Brady Porter, Allison Roy, Mark Scott, Chris Skelton, Steven Walsh, David Walters, and Paul Yokley, Jr. Carrie Straight created some of the data layers used in these analyses, Tim Carter delineated total and effective impervious surfaces from aerial photography, and Jess Melgey digitized dam locations. We thank Jordan Rosenfeld and an anonymous reviewer for extremely helpful comments on an earlier draft. The Georgia Cooperative Fish and Wildlife Research Unit is jointly sponsored by USGS, US Fish and Wildlife Service, University of Georgia, Georgia Department of Natural Resources, and the Wildlife Management Institute.

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RB-AR34445

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act

December 2009

RB-AR34446

Foreword

Stormwater runoff in urban and developing areas is one of the leading sources of water pollution in the United States. In recognition of this issue, Congress enacted Section 438 of the Energy Independence and Security Act of 2007 (EISA) to require federal agencies to reduce stormwater runoff from federal development projects to protect water resources. More recently, the President signed Executive Order 13514 on "Federal Leadership in Environmental, Energy, and Economic Performance" calling upon all federal agencies to "lead by example" to address a wide range of environmental issues, including stormwater runoff. The Executive Order required the U.S. Environmental Protection Agency (EPA), in coordination with other federal agencies, to publish this Technical Guidance.

EPA worked closely with many federal agencies to develop this Technical Guidance to help federal agencies in implementing EISA Section 438. The guidance provides a step-by-step framework that will help federal agencies maintain pre-development site hydrology by retaining rainfall on-site through infiltration, evaporation/transpiration, and re-use to the same extent as occurred prior to development. The Technical Guidance provides background information, key definitions, case studies, and guidance on meeting the new requirements.

Federal agencies can comply with Section 438 by using a variety of stormwater management practices often referred to as "green infrastructure" or "low impact development" practices, including, for example, reducing impervious surfaces, using vegetative practices, porous pavements, cisterns and green roofs.

One of the most exciting new trends in water quality management today is the movement by many cities, counties, states, and private sector developers toward the increased use of this next generation stormwater management practices to help protect and restore water quality. Many federal agencies, including EPA, are already using a full spectrum of stormwater management practices to reduce the impact of federal facilities on local watersheds. These projects have produced results such as reductions in site runoff volumes and increased stormwater quality, which ultimately lead to more sustainable facilities.

EPA enjoyed the opportunity to work with a number of federal agencies to develop this state-of-the art, technical guidance and appreciate all their input. We look forward to continuing the dialogue as we all work to implement this guidance.

Peter S. Silva
Assistant Administrator
Office of Water
U.S. Environmental Protection Agency

RB-AR34447

Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act

INTRODUCTION

In December 2007, Congress enacted the Energy Independence and Security Act of 2007. Section 438 of that legislation establishes strict stormwater runoff requirements for federal development and redevelopment projects. The provision reads as follows:

> **"Storm water runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow."

The intent of Section 438 of the Energy Independence and Security Act of 2007 (EISA) is to require federal agencies to develop and redevelop applicable facilities in a manner that maintains or restores stormwater runoff to the maximum extent technically feasible. Until recently, stormwater programs established to address water quality objectives have been designed to control traditional pollutants that are commonly associated with municipal and industrial discharges, e.g., nutrients, sediment, and metals. Increases in runoff volume and peak discharge rates have been regulated through state and local flood control programs. Although these programs have merit, knowledge accumulated during the past 20 years has led stormwater experts to the conclusion that conventional approaches to control runoff are not fully adequate to protect the nation's water resources (National Research Council, 2008).

Implementation of Section 438 of the EISA can be achieved through the use of the green infrastructure/low impact development (GI/LID) infrastructure tools described in this guidance. The intention of the statute is to maintain or restore the pre-development site hydrology during the development or redevelopment process. To be more specific, this requirement is intended to ensure that receiving waters are not negatively impacted by changes in runoff temperature, volumes, durations and rates resulting from federal projects. It should also be noted that a performance-based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site.

Section 14 of the Executive Order 13514, Federal Leadership in Environmental, Energy, and Economic Performance

On October 5, 2009, President Barack Obama signed Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance." Section 14 of the Executive Order provides:

> Stormwater Guidance for Federal Facilities. Within 60 days of the date of this order, the Environmental Protection Agency, in coordination with other Federal agencies as

> appropriate, shall issue guidance on the implementation of section 438 of the Energy Independence and Security Act of 2007 (42 U.S.C. 17094).

This provision contains two significant elements. First, for the first time, EPA is formally assigned the responsibility to write and issue the Section 438 guidance, in coordination with other federal agencies. Second, it establishes a deadline for EPA to do so by December 5, 2009.

Purpose and Organization of this Guidance

The purpose of this document is to provide technical guidance and background information to assist federal agencies in implementing EISA Section 438. Each agency or department is responsible for ensuring compliance with EISA Section 438. The document contains guidance on how compliance with Section 438 can be achieved, measured and evaluated. In addition, information detailing the rationale for the stormwater management approach contained herein has been included.

This document is intended solely as guidance. This document is not a regulation nor does it substitute for statutory provisions or regulations. This guidance does not impose any legally binding requirements on federal agencies and does not confer any legal rights or impose legal obligations upon any member of the public. This document does not create a cause of action against the EPA, other federal agencies, or the United States.

The following information is presented within this document:

Part I: Implementation Framework

A. Background
B. Benefits and outcomes of the new stormwater performance requirements
C. Applicability and definitions
D. Tools to implement the requirements of Section 438
E. Calculating the 95^{th} percentile rainfall event

Part II: Case Studies on Capturing the 95^{th} Percentile Storm Using Onsite Management Practices

Case studies representing typical federal installations have been included. The case studies were selected to demonstrate the feasibility of providing adequate stormwater control for a range of site conditions and building designs. To the maximum extent technically feasible, each case study includes a description of a method that can be used to determine the design objectives of the project based on retaining the 95^{th} percentile storm. Examples of onsite technologies and practices have also been provided. The case studies are intended to provide examples of modeling procedures that can be used to quantify treatment system performance and processes for assessing sites and determining appropriate control techniques to the maximum extent technically feasible.

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Part I: Implementation Framework

A. BACKGROUND

This section contains background on the causes and consequences of stormwater discharges, solutions that can be used to address the causes and consequences of stormwater discharges and how to implement those solutions to comply with Section 438 of EISA.

Alterations to Natural Hydrology and the Impact on Stormwater Runoff
In the natural, undisturbed environment rain that falls is quickly absorbed by trees, other vegetation, and the ground. Most rainfall that is not intercepted by leaves infiltrates into the ground or is returned to the atmosphere by the process of evapotranspiration. Very little rainfall becomes stormwater runoff in permeable soil, and runoff generally only occurs with larger precipitation events. Traditional development practices cover large areas of the ground with impervious surfaces such as roads, driveways, sidewalks, and buildings. Under developed conditions runoff occurs even during small precipitation events that would normally be absorbed by the soil and vegetation. The collective force of the increased runoff scours streambeds, erodes stream banks, and causes large quantities of sediment and other entrained pollutants to enter the water body each time it rains (Shaver, et al., 2007; Booth testimony, 2008).

As watersheds are developed and impervious surfaces increase in area, the hydrology of the watersheds fundamentally changes over time which results in degraded aquatic ecosystems. In recognition of these problems, stormwater managers employed extended detention approaches to mitigate the impacts of increased peak runoff rates. However, wet ponds and similar practices are not fully adequate to protect downstream hydrology because of the following inherent limitations of these conventional practices (National Research Council, 2008; Shaver, et al., 2007):

- Poor peak control for small, frequently-occurring storms;
- Negligible volume reduction; and
- Increased duration of peak flow.

Detention storage targets relatively large, infrequent storms, such as the two and 10-year/24-hour storms for peak flow rate control. As a result of this design limitation, flow rates from smaller, frequently-occurring storms typically exceed those that existed onsite before land development occurred and these increases in runoff volumes and velocities typically result in flows erosive to stream channel stability (Shaver, et al., 2007). Section 438 is intended to address the inadequacies of the historical detention approach to managing stormwater and promote more sustainable practices that have been selected to maintain or restore predevelopment site hydrology.

A 2008 National Research Council report on urban stormwater confirmed that current stormwater control efforts are not fully adequate. Three of the report's findings on stormwater management approaches are particularly relevant (National Research Council, 2008).

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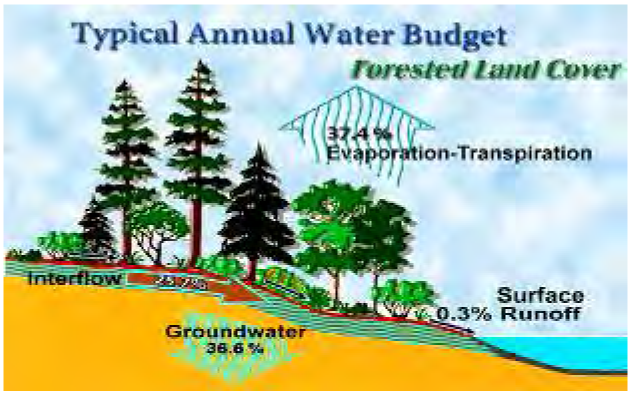
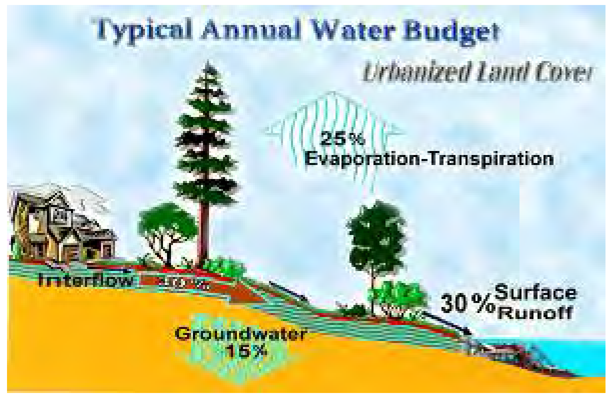
1. Individual controls on stormwater discharges are inadequate as the sole solution to stormwater in urban watersheds;
2. Stormwater control measures such as product substitution, better site design, downspout disconnection, conservation of natural areas, and watershed and land-use planning can dramatically reduce the volume of runoff and pollutant load from new development; and
3. Stormwater control measures that harvest, infiltrate, and evapotranspire stormwater are critical to reducing the volume and pollutant loading of small storms.



Pre-development Hydrology. *Courtesy of C. May, University of Washington.*



Post-Development Hydrology. *Courtesy of C. May, University of Washington.*

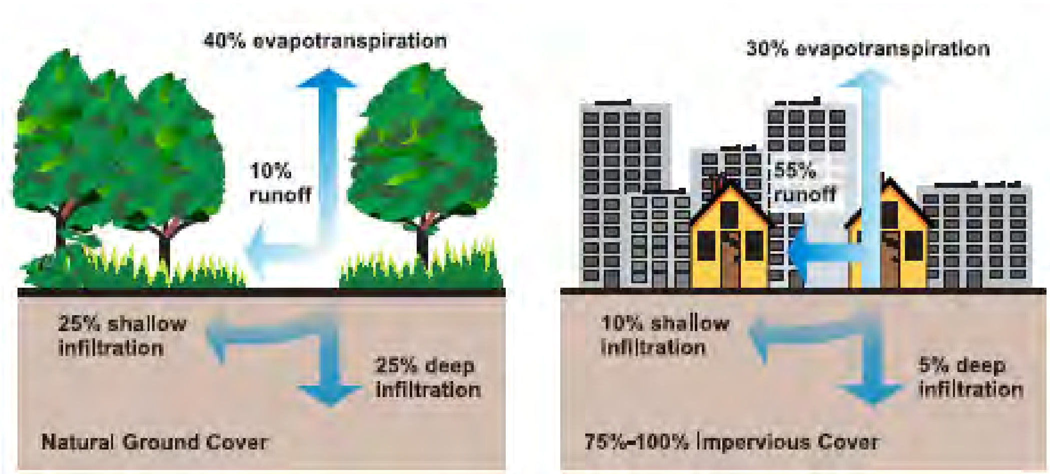


Figure 1. Pre-Development and Post-Development Hydrology. (USDA).

Figure 1 contains two sets of diagrams depicting the water balances at undeveloped and developed sites. Runoff patterns will vary based on factors such as geographic location, local meteorological conditions, vegetative cover and soils. The first set of figures represents conditions in the Pacific Northwest where storms have a long duration and low intensity, i.e., the volume of rain in an individual storm is small. The second set of figures from the U.S. Department of Agriculture represents a more generalized set of conditions, but was included to illustrate that heavily urbanized areas typically cause large increases in runoff.

Land cover changes that result from site development include increased imperviousness, soil compaction, loss of vegetation, and loss of natural drainage patterns, which result in increased runoff volumes and peak runoff rates. The cumulative impacts of the land cover changes result in alterations of the natural hydrology of a site, which disrupts the natural water balance and changes water flow paths. The consequences of these impacts include:

1. *Increased volume of runoff*. With decreased area for infiltration and evapotranspiration due to development, a greater amount of rainfall is converted to overland runoff which results in larger stormwater discharges.
2. *Increased peak flow of runoff*. Increased impervious surface area and higher connectivity of impervious surfaces and stormwater conveyance systems increase the flow rate of stormwater discharges and increase the energy and velocity of discharges into the stream channel.
3. *Increased duration of discharge*. Detention systems generate greater flow volumes and rates. These prolonged higher discharge rates can undermine the stability of the stream channel and induce erosion, channel incision and bank cutting.
4. *Increased pollutant loadings*. Impervious areas are a collection site for pollutants. When rainfall occurs these pollutants are mobilized and transported directly to stormwater conveyances and receiving streams via these impervious surfaces.
5. *Increased temperature of runoff*. Impervious surfaces absorb and store heat and transfer it to stormwater runoff. Higher runoff temperatures may have deleterious effects on receiving streams. Detention basins magnify this problem by trapping and discharging runoff that is heated by solar radiation (Galli, 1991; Schueler and Helfrich, 1988).

The resulting increases in volume, peak flow, and duration are illustrated in the hydrograph in Figure 2, which is a representation of a site's stormwater discharge with respect to time. The hydrograph illustrates the impacts of development on runoff volume and timing of the runoff. Individual points on the curve represent the rate of stormwater discharge at a given time. The graph illustrates that development and corresponding changes in land cover result in greater discharge rates, greater volumes, and shorter discharge periods. In a natural condition, runoff rates are slower than those on developed sites and the discharges occur over a longer time period. The predevelopment peak discharge rate is also much lower than the post-development peak discharge rate due to attenuation and absorption by soils and vegetation. In the post-development condition there is generally a much shorter time before runoff begins because of increased impervious surface area, a higher degree of connectivity of these areas and the loss of soils and vegetative cover that slow or reduce runoff.

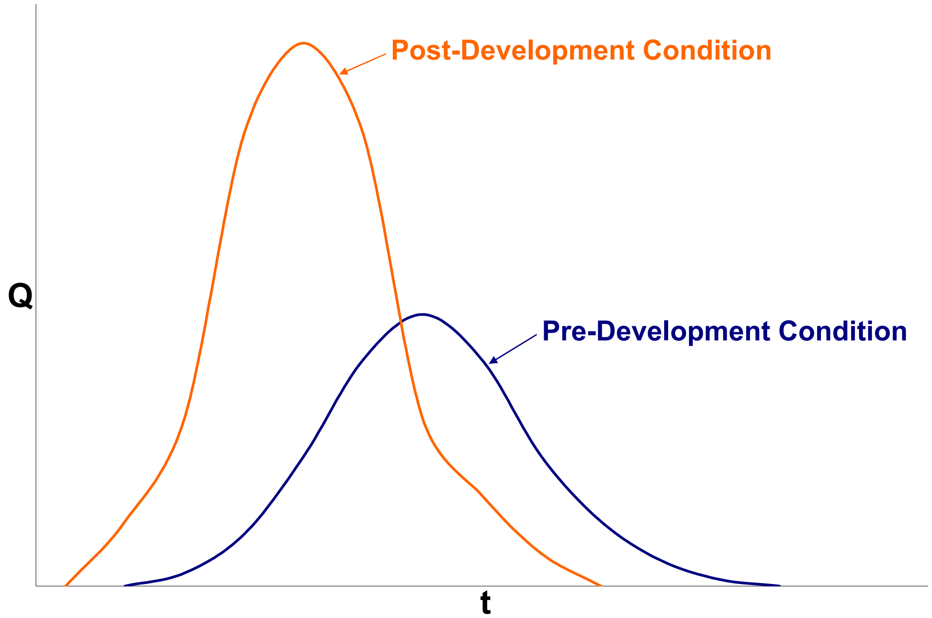


Figure 2. Post-Development Hydrograph.
(Q = volumetric flow rate; t = time)

Figure 3. Stream Displaying the Effects of Stormwater Runoff and Channel Downcutting.

The Solution: Preserving and Restoring Hydrology
A new approach has evolved in recent years to eliminate or reduce the amount of water and pollutants that run off a site and ultimately are discharged into adjacent water bodies.

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The fundamental principle is to employ systems and practices that use or mimic natural processes to: 1) infiltrate and recharge, 2) evapotranspire, and/or 3) harvest and use precipitation near to where it falls to earth.

GI/LID practices include a wide variety of practices that utilize these mechanisms. These practices can be used at the site, neighborhood and watershed/regional scales. In this document the focus is on site-level practices, which is most consistent with the terms used in Section 438: "project," "facility," and "property." Although these performance requirements apply at the project site-level, flexibility exists to utilize nearby areas or areas directly adjacent to the facility to manage the runoff, i.e., evapotranspirate, infiltrate or harvest and use. Where justifiable, it also may be appropriate to evapotranspirate, infiltrate or harvest and use an equivalent or greater amount of runoff offsite as long as the runoff is discharged or used in the same receiving subwatershed or watershed.

The purpose of EISA Section 438 is to replicate the pre-development hydrology to protect and preserve both the water resources onsite and those downstream. For example, if prior to development, twenty five (25) percent of the annual rainfall runs directly into the stream and the remainder infiltrates into the ground or is evapotranspired into the air, then the post-development goal should be to limit runoff to twenty five (25) percent of the annual precipitation while maintaining the correct aquifer recharge rate. This has the benefit, in most cases, of delivering water to the stream at approximately the same rate, volume, duration and temperature as the stream had naturally evolved to receive prior to development. The result will be to eliminate or minimize the erosion of streambeds and streambanks, significantly reduce the delivery of many pollutants to water bodies, and retain historical instream temperatures.

Figure 4. Parking lot bioswale and permeable pavers in Chicago.

Restoring or maintaining pre-development hydrology has emerged as a control approach for several reasons. Most importantly, this approach is intended to directly address the root cause of impairment. Current control approaches have been selected in an attempt to control the symptoms (peak flow, and excess pollutants), but this strategy is not fully adequate because of the scale of the problem, the cumulative impacts of multiple developments and the need to manage both site and watershed level impacts. With current approaches, it is also difficult to adequately protect and improve water quality because the measures employed are not addressing the main problem which is a hydrologic imbalance.

Designing facilities based on the goal of maintaining or restoring pre-development hydrology provides a site specific basis and an objective methodology with which to determine appropriate practices to protect the receiving environment.

Using pre-development hydrology as the guiding control principal also allows the designer to consider climatic and geologic variability and tailor the solutions to the project location. Thus the need for a one size fits all approach is rendered unnecessary since the design objective is dictated by the pre-development site conditions and other technicalities of the project site and facility. Instead of prescribed approaches dictating discharge volumes or flow rates, site assessments of historical infiltration and runoff rates will inform the designer and provide the basis for a suitable design. The use of this approach will minimize compliance complications that may arise from prescriptive design approaches which do not account for the variability of precipitation frequencies, rainfall intensities and pre-development land cover and soil conditions that influence infiltration and runoff.

B. Benefits and Outcomes of the New Stormwater Performance Requirements

Implementation of these new stormwater performance requirements in EISA Section 438 provides numerous environmental and economic benefits in addition to reducing the volume of stormwater runoff:

Benefits to Water Resources:

- *Cleaner Water.* The use of plants, soils and water harvesting and use practices can reduce stormwater runoff volumes and pollutant loadings and the frequency and magnitude of combined sewer overflows (volume and pollutant loading reductions). These practices are part of a larger set of practices called green infrastructure/low impact development.
- *Clean and Adequate Water Supplies.* GI/LID approaches using soil based vegetated infiltration systems can be used to recharge ground water and maintain stream base flow. By recharging ground water aquifers, aquatic ecosystem health is maintained and base flows are increased which helps ensure more constant flows for drinking water withdrawals. Harvesting and reusing rainwater also reduces the need to use potable water for all uses and can reduce both the infrastructure and energy needed to treat and transport both drinking water and stormwater.
- *Source Water Protection.* GI/LID practices provide pollutant removal benefits, thereby providing some protection for both ground water and surface water sources of drinking water. In addition, GI/LID provides ground water recharge benefits.

GI/LID approaches are a set of management approaches and technologies that utilize and/or mimic the natural hydrologic cycle processes of infiltration, evapotranspiration and use. GI/LID practices include green roofs, trees and tree boxes, rain gardens, vegetated swales, pocket wetlands, infiltration planters, porous and permeable pavements, vegetated median strips, reforestation and revegetation and protection of riparian buffers and floodplains. These practices can be used almost anywhere soil and vegetation can be worked into the urban or suburban landscape. They include decentralized harvesting approaches such as rain barrels and cisterns that can be used to capture and re-use rainfall for watering plants or flushing toilets.

Other Social and Environmental Benefits:

- *Cleaner Air.* Trees and vegetation improve air quality by filtering many airborne pollutants and can help reduce the amount of respiratory illness (Vingarzan and Taylor, 2003).
- *Reduced Urban Temperatures.* Summer city temperatures can average 10ºF higher than nearby suburban temperatures (Casey Trees, 2007). High temperatures are also linked to higher ground level ozone concentrations. Vegetation creates shade, reduces the amount of heat absorbing materials and emits water vapor – all of which cool hot air (Grant, et al., 2003). Reductions in impervious surface and the use of light colored pervious surfaces (e.g., permeable concrete) also can mitigate urban temperatures.
- *Moderate the Impacts of Climate Change.* Climate change impacts and effects vary regionally, but GI/LID techniques can provide adaptation benefits for a wide array of circumstances. They can be used to conserve, harvest and use water, to recharge ground waters and to reduce surface water discharges that could contribute to flooding. In addition, there are mitigation benefits such as reduced energy demand and carbon sequestration by vegetation.
- *Increased Energy Efficiency.* Green space helps lower ambient temperatures and, when incorporated on and around buildings, helps shade and insulate buildings from wide temperature swings, decreasing the energy needed for heating and cooling. Diverting stormwater from wastewater collection, conveyance and treatment systems can reduce the amount of energy needed to pump and treat the water. Energy efficiency not only reduces costs, but also reduces generation of greenhouse gases.
- *Community Benefits.* Trees and plants improve urban aesthetics and community livability by providing recreational and wildlife areas. Studies show that property values are higher when trees and other vegetation are present. Increased green space also has public health benefits and has been shown to reduce crime and the associated stresses of urban living.

Figure 5. Rain water cistern.

C. APPLICABILITY AND DEFINITIONS

Applicability

1. Who is a "**Sponsor**" of a project?

Section 438 applies to the "**sponsor** of any development or redevelopment project involving a Federal facility . . ." Section 438 requires that the "sponsor . . . shall use . . . strategies for the property to maintain or restore . . . the predevelopment hydrology. . ." The "sponsor" should generally be regarded as the federal department or agency that owns, operates, occupies or is the primary user of the facility and has initiated the development or redevelopment project. If the federal agency hires another entity to perform activities such as site construction or maintenance, the agency should nonetheless be regarded as the sponsor and be responsible to assure compliance with the requirements of Section 438. The agency sponsor is free to contract out various duties and responsibilities that are associated with achieving compliance.

2. What is a "**Federal facility**"?

Section 438 provides that its requirements apply to the "sponsor of any development or redevelopment project involving a **Federal facility** . . ." Section 401(8) of EISA states: "The term `Federal facility' means any building that is constructed, renovated, leased, or purchased in part or in whole for use by the Federal Government."

3. What is a **"footprint**"?

Section 438 applies to a federal facility "with a **footprint** that exceeds 5,000 square feet." For the purposes of this guidance, any project involving a federal facility that disturbs 5,000 square feet or more of ground area is covered by this guidance. Existing facilities that have an overall **footprint** of 5,000 square feet or greater that disturb less than 5,000 square feet of land area as part of any single development or redevelopment project are not subject to Section 438 requirements. Consistent with the purpose of Section 438 to preserve or restore pre-development hydrology, the term "footprint" includes all land areas that are disturbed as part of the project.

4. What is "**the property**"?

Section 438 provides that the project sponsor "shall use site planning, design, construction, and maintenance strategies for the **property** to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the **property."** This clause has been interpreted to mean that the land surrounding the project site is available to implement the appropriate GI/LID practices where optimal.

Although the performance requirements of EISA Section 438 apply only to the project footprint, the flexibility exists to utilize the entire federal property in implementing the stormwater strategies for the project.

Definitions

95th percentile rainfall event. The 95th percentile rainfall event represents a precipitation amount which 95 percent of all rainfall events for the period of record do not exceed. In more technical terms, the 95th percentile rainfall event is defined as the measured precipitation depth accumulated over a 24-hour period for the period of record that ranks as the 95th percentile rainfall depth based on the range of all daily event occurrences during this period.

The 24-hour period is typically defined as 12:00:00 am to 11:59:59 pm. In general, at least a 20-30 year period of rainfall record is recommended for such an analysis. This raw data is readily available and collected by most airports across the county. Small rainfall events that are 0.1 of an inch or less are excluded from the percentile analysis because this rainfall generally does not result in any measureable runoff due to absorption, interception and evaporation by permeable, impermeable and vegetated surfaces. Many stormwater modelers and hydrologists typically exclude rainfall events that are 0.1 inch or less from calculations of rainfall events of any storm from their modeling analyses of rainfall event frequencies. See, for example, the Center for Watershed Protection's Urban Subwatershed Restoration Manual 3 (available at www.cwp.org).

Federal facility. The term "federal facility" means any buildings that are constructed, renovated, leased, or purchased in part or in whole for use by the federal government as defined in section 401(8) of the Energy Independence and Security Act.

Development or re-development. For the purposes of this provision this term applies to any action that results in the alteration of the landscape during construction of buildings or other infrastructure such as parking lots, roads, etc, (e.g., grading, removal of vegetation, soil compaction, etc.) such that the changes affect runoff volumes, rates, temperature, and duration of flow. Examples of projects that would fall under "re-development" include structures or other infrastructure that are being reconstructed or replaced and the landscape is altered. Typical patching or resurfacing of parking lots or other travel areas would not fall under this requirement.

D. TOOLS TO IMPLEMENT THE REQUIREMENTS OF SECTION 438

Section 438 of the Energy Independence and Security Act of 2007 reads as follows:

> **Section 438. Storm water runoff requirements for federal development projects.** The sponsor of any development or redevelopment project involving a Federal facility with a footprint that exceeds 5,000 square feet shall use site planning, design, construction, and maintenance strategies for the property to maintain or restore, to the maximum extent technically feasible, the predevelopment hydrology of the property with regard to the temperature, rate, volume, and duration of flow.

The intention of EISA Section 438 is to preserve or restore the hydrology of the site during the development or redevelopment process. To be more specific, this requirement is intended to ensure that aquatic biota, stream channel stability, and historical aquifer recharge rates of receiving waters are not negatively impacted by changes in runoff temperature, volumes, durations and rates resulting from federal projects. A performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site.

To meet these performance objectives, technically feasible stormwater control practices that are effective in reducing the volume of stormwater discharge should be used. To implement EISA Section 438, this guidance recommends that the federal facility use all known, available and reasonable methods of stormwater retention and/or use to the maximum extent technically feasible (METF). Tools to implement the requirements of Section 438 are described below and illustrated in Figure 8.

Establishing Section 438 Performance Design Objectives
Described below are options site designers can use to comply with Section 438. There may be situations where Option 1 (retaining the 95th percentile rainfall event) is not protective enough to maintain or restore the predevelopment hydrology of the project (for example, in some headwater streams). In these cases, Option 2 (site-specific hydrologic analysis) could be used to determine the types of stormwater practices necessary to preserve predevelopment runoff conditions. Option 2 could also be used if predevelopment runoff conditions can be maintained by retaining less than the 95th percentile rainfall event. Because a performance based approach was selected in lieu of a prescriptive requirement in order to provide site designers maximum flexibility in selecting control practices appropriate for the site, Option 2 was provided in recognition that there are established methodologies that can be utilized to estimate the volume of infiltration and evapotranspiration based on site-specific hydrology and thus establish the predevelopment hydrology performance design objectives.

Option 1: Retain the 95th Percentile Rainfall Event

One approach to establishing the performance design objectives is to design, construct, and maintain stormwater management practices that manage rainfall onsite, and prevent the off-site discharge of the precipitation from all rainfall events less than or equal to the 95th percentile rainfall event to the maximum extent technically feasible (METF). This objective should be accomplished by the use of practices that infiltrate, evapotranspire and/or harvest and use rainwater. The 95th percentile rainfall event is the event whose precipitation total is greater than or equal to 95 percent of all storm events over a given period of record. For example, to determine what the 95th percentile storm event is in a specific location, all 24 hour storms that have recorded values over a 30 year period would be tabulated and a 95th percentile storm would be determined from this record, i.e., 5% of the storms would be greater than the number determined to be the 95th percentile storm. Thus the 95th percentile storm would be represented by a number such as 1.5 inches, and this would be the design storm (example 95th percentile storm events for selected cities are presented in Table 1). The designer would then select a system of practices, to the METF, that infiltrate, evapotranspire or harvest and use this volume multiplied by the total area of the facility/project footprint. Methods and data used to estimate the 95th percentile event are discussed in Part II of this document.

For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites. This 95th percentile approach was identified and recommended because this storm size represents the volume that appears to best represent the volume that is fully infiltrated in a natural condition and thus should be managed onsite to restore and maintain this pre-development hydrology for duration, rate and volume of stormwater flows. In general, only large storms generate significant runoff. In addition, this approach was identified because it employs natural treatment and flow attenuation methods that are presumed to have existed on the site before construction of infrastructure (e.g., building, roads, parking lots, driveways,) and is intended to infiltrate or evapotranspirate the full volume of the 95th percentile storm. Because this approach necessitates the use of practices that generally preclude extended detention, it will also typically address the issue of maintaining predevelopment temperatures. However, in cases where there are discharges to cool water streams or other sensitive receiving waters, additional strategies may be needed to ensure that stormwater discharges do not result in greater thermal impacts than would occur in pre-development conditions (Schueler and Helfrich, 1988).

Where technically feasible, the goal of Option 1 is that one hundred percent (100%) of the volume of water from storms less than or equal to the 95th percentile event over the footprint of the project should not be discharged to surface waters. In some cases, runoff can be harvested and used and ultimately may be discharged to surface waters or a sanitary treatment system; such direct or indirect discharges must be authorized or allowed by the regulatory authority. For example, if runoff is captured for nonpotable uses such as toilet flushing or other uses that are not irrigation related, these waters potentially could be discharged into the sanitary sewer system. Preferred mechanisms for retaining discharges from storms greater than the 95th percentile event are through overflow or diversion for the volume that exceeds the 95th percentile amount. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume. For structures such as roofs and paved surfaces that can increase the temperature of stormwater runoff, materials that minimize temperature increases (e.g., concrete vs. asphalt; vegetated roofs) should be considered and used as appropriate.

Retaining 100 percent of all rainfall events equal to or less than the 95th percentile rainfall event was identified as Option 1 because small, frequently-occurring storms account for a large proportion of the annual precipitation volume, and the runoff from those storm events also significantly alters the discharge frequency, rate and temperature of the runoff.

Figure 6. Bioretention facility in Oregon.

The runoff produced by these small storms and the initial portion of larger storms has a strong negative cumulative impact on receiving water hydrology and water quality. In areas that have been developed, runoff is generated from almost all storms, both small and large, due to the impervious surfaces associated with development and the loss of soils and vegetation. In contrast, natural or undeveloped areas discharge little or no runoff from small storms because the rain is absorbed by the landscape and vegetation. Studies have shown that increases in runoff event frequency, volume and rate can be diminished or eliminated through the use of GI/LID designs and practices, which infiltrate, evapotranspire and capture and use stormwater.

Option 1 was identified because it is a simplified approach to meet the intent of Section 438 in contrast to Option 2 which requires the designer to conduct a hydrologic analysis of the site based on site-specific conditions.

Table 1. Example 95th Percentile Storm Events for Select U.S. Cities (adapted from Hirschman and Kosco, 2008).

City	95th Percentile Event Rainfall Total (in)	City	95th Percentile Event Rainfall Total (in)
Atlanta, GA	1.8	Kansas City, MO	1.7
Baltimore, MD	1.6	Knoxville, TN	1.5
Boston, MA	1.5	Louisville, KY	1.5
Buffalo, NY	1.1	Minneapolis, MN	1.4
Burlington, VT	1.1	New York, NY	1.7
Charleston, WV	1.2	Salt Lake City, UT	0.8
Coeur D'Alene, ID	0.7	Phoenix, AZ	1.0
Cincinnati, OH	1.5	Portland, OR	1.0
Columbus, OH	1.3	Seattle, WA	1.6
Concord, NH	1.3	Washington, DC	1.7
Denver, CO	1.1		

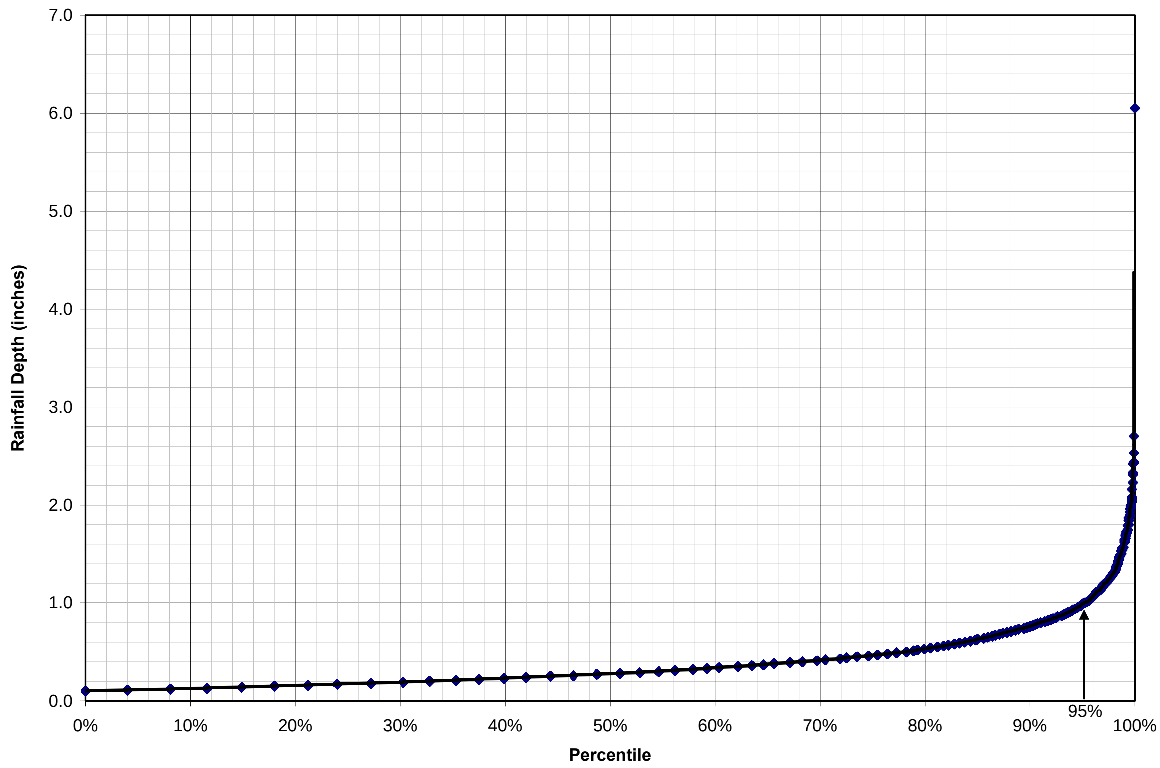

Figure 7. Rainfall Frequency Spectrum showing the 95th percentile rainfall event for Portland, OR (~1.0 inches)

Calculating the 95th Percentile Rainfall Event
Section E of this guidance contains information on how to calculate the 95th percentile rainfall event for a specific area. A long-term record of daily rainfall amounts (ideally, at least 30 years) is needed to calculate the 95th percentile rainfall.

Designers opting to use Option 1 need to do the following:

1) calculate or verify the precipitation amount from the 95th percentile storm event (this number would be typically expressed in inches, e.g., 1.5", and

2) employ onsite stormwater management controls to the METF that infiltrate, evapotranspire or harvest and use the appropriate design volume.

The 95th percentile event can be calculated by using the following procedures below (summarized from Hirschman and Kosco, 2008, *Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program*, Center for Watershed Protection):

- Obtain a long-term rainfall record from a nearby weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). Long-term rainfall records can be obtained from many sources, including NOAA at http://cdo.ncdc.noaa.gov/pls/plclimprod/poemain.accessrouter?datasetabbv=SOD&countryabbv=&georegionabbv=.
- Remove data for small rainfall events that are 0.1 inch or less and snowfall events that do not immediately melt from the data set. These events should be deleted since they do not typically cause runoff and could potentially cause the analyses of the 95th percentile storm runoff volume to be inaccurate.
- Using a spreadsheet or simple statistical package, sort the rainfall events from highest to lowest. In the next column, calculate the percentage of rainfall events that are less than each ranked event (event number/total number of events). For example, if there were 1,000 rainfall events and the highest rainfall event was a 4" event, then 999 events (or a percentile of 999/1000, or 99.9%) are less than the 4" rainfall event.
- Use the rainfall event at 95% as the 95th percentile storm event.

Option 2: Site-Specific Hydrologic Analysis

Another approach to establishing the performance design objective is to design, construct, and maintain stormwater management practices that preserve the pre-development runoff conditions following construction. Option 2 allows the designer to conduct a site-specific hydrologic analysis to determine the pre-development runoff conditions instead of using the estimated volume approach of Option 1. Under Option 2, the pre-development hydrology would be determined based on site-specific conditions and local meteorology by using continuous simulation modeling techniques, published data, studies, or other established tools. If the designer elects to use Option 2, the designer would then identify the pre-development condition of the site and quantify the post-development runoff volume and peak flow discharges that are equivalent to pre-development conditions. The post-construction rate, volume, duration and temperature of runoff should not exceed the pre-development rates and the predevelopment hydrology should be replicated through site design and other appropriate practices to the maximum extent technically feasible. These goals should be accomplished through the use of infiltration, evapotranspiration, and/or rainwater harvesting and use. Defensible and consistent hydrological assessment tools should be used and documented. Additional discussions of appropriate methodologies to use in assessing site hydrology have been included in the technical sections of this document. See, for example, the discussion of spreadsheet versions or curve numbers based on the Natural Resource Conservation Service Technical Release 55 (TR-55) Method in Appendix A of this document.

Development
The pre-development hydrologic condition of the site is the combination of runoff, infiltration and evapotranspiration rates and volumes that typically existed on the facility site before "development" on a greenfields site (meaning any construction of infrastructure on undeveloped land such as meadows or forests). In practice, determining the pre-development hydrology of a given site can be difficult if there is no suitable reference site. As a result, reference conditions for typical land cover types in the locality often are used to approximate what fraction of the precipitation ran off, soaked into the ground or was evaporated from the landscape. The use of reference conditions can be problematic if suitable data are not available or unique site conditions exist that do not fit within a typical land use cover type for the area, e.g., meadow or forest. In cases where suitable data from comparable conditions cannot be found or is otherwise inadequate to be used in conducting an Option 2 analysis for the specific area being considered for development or redevelopment, the project sponsor should use the Option 1 analytical framework.

Re-development
For re-development sites, existing site conditions and uses of the site can influence the amount of runoff that can be managed on site through infiltration, evapotransporation and harvest and use and thus the performance design objective. In these cases the design process in Figure 8 and Scenario 9 illustrate the decision processes that can be used.

In the context of some re-development projects, fully restoring predevelopment hydrology can be difficult to achieve and Congress recognized this potential difficulty by including the METF language in the statute. In these cases, Congressional intent can be best carried out by using a systematic METF analysis to determine what practices can be implemented at the site to maintain or store the hydrologic condition of the site. Scenarios 1-8 provide examples of METF analyses that demonstrate that pre-development hydrology can be achieved. Scenario 9 provides an example of an METF analysis that demonstrates that pre-development hydrology cannot be fully achieved and illustrates the extent to which pre-development hydrology can be restored.

Note: *It should also be emphasized that the performance based approach in Option 1 is intended to be a surrogate for determining the pre-development reference condition and this standard is intended to be used in cases where it is more practical, cost effective, and/or expeditious than Option 1, or where it is difficult or infeasible to identify the relevant reference conditions for the site.*

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Determination of Maximum Extent Technically Feasible

Compliance with Section 438 requires that stormwater management measures are implemented to the maximum extent technically feasible (METF) to maintain or restore the pre-development hydrology conditions specifically with respect to temperature, rate, volume, and duration of flow.

Performance or design goals based on the pre-development hydrology can be established by using options such as the following: Retention of the 95th percentile rainfall event (Option 1), or through a site-specific hydrologic analysis that estimates the volume of infiltration, evapotranspiration or onsite stormwater harvesting and use based on site-specific hydrologic conditions (Option 2).

Technical Infeasibility

For projects where technical infeasibility exists, the federal agency or department sponsoring the project should document and quantify that stormwater strategies, such as infiltration, evapotranspiration, and harvesting and use have been used to the METF, and that full employment of these types of controls are infeasible due to site constraints. Some western states place restrictions on harvesting and use due to water rights, however, these requirements do not necessarily preclude the sponsor of the project from implementing strategies such as infiltration and evapotranspiration. Documentation of technical infeasibility should include, but may not be limited to, engineering calculations, geologic reports, hydrologic analyses, and site maps. A determination that the performance design goals cannot be met on site should include analyses that rule out the use of an adequate combination of infiltration, evapotranspiration, and use measures. Examples of where site conditions may prevent the full employment of appropriate management techniques to the METF include a combination of:

- The conditions on the site preclude the use of infiltration practices due to the presence of shallow bedrock, contaminated soils, near surface ground water or other factors such as underground facilities or utilities.
- The design of the site precludes the use of soil amendments, plantings of vegetation or other designs that can be used to infiltrate and evapotranspirate runoff.
- Water harvesting and use are not practical or possible because the volume of water used for irrigation, toilet flushing, industrial make-up water, wash-waters, etc. is not significant enough to warrant the design and use of water harvesting and use systems.
- Modifications to an existing building to manage stormwater are not feasible due to structural or plumbing constraints or other factors as identified by the facility owner/operator.
- Small project sites where the lot is too small to accommodate infiltration practices adequately sized to infiltrate the volume of runoff from impervious surfaces,
- Soils that cannot be sufficiently amended to provide for the requisite infiltration rates,
- Situations where site use is inconsistent with the capture and use of stormwater or other physical conditions on site that preclude the use of plants for evapotranspiration or bioinfiltration.
- Retention and/or use of stormwater onsite or discharge of stormwater onsite via infiltration has a significant adverse effect on the site or the down gradient water balance of surface waters, ground waters or receiving watershed ecological processes.

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- State and local requirements or permit requirements that prohibit water collection or make it technically infeasible to use certain GI/LID techniques.
- Compliance with the Section 438 requirements would result in the retention and/or use of stormwater on the site such that an adverse water balance impact may occur to the receiving surface waterbody or ground water.

Please note that a single one of these characteristics is very unlikely to preclude meeting the performance standard, but a combination of factors may.

In cases where the facility has a defensible showing of technical infeasibility and can provide adequate documentation of site conditions or other factors that preclude full implementation of the performance design goal, the facility should still install stormwater practices to infiltrate, evapotranspire and/or harvest and use onsite the maximum amount of stormwater technically feasible. Note: Facilities must still comply with all other applicable federal, state and local requirements.

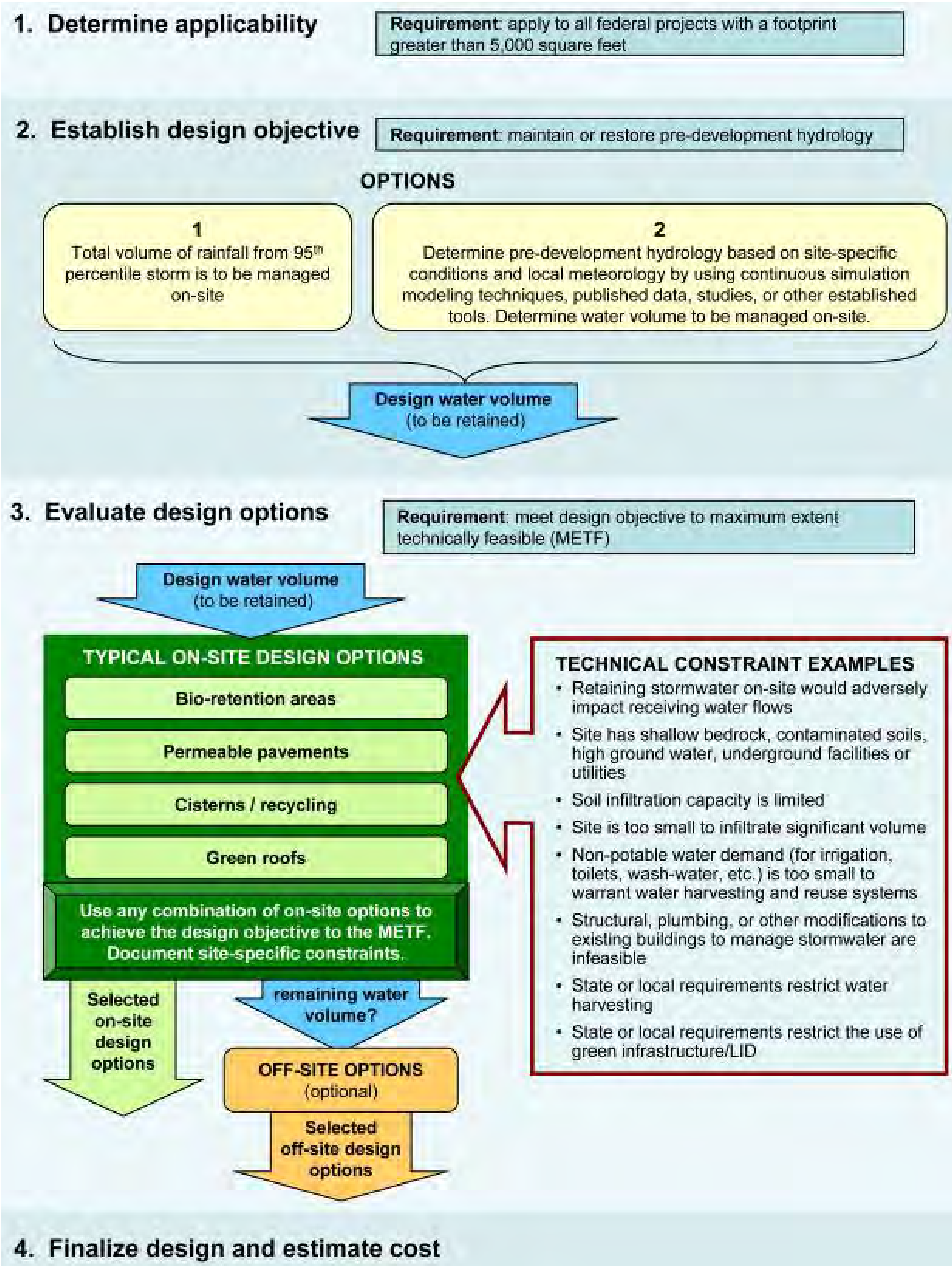

Figure 8. Section 438 Implementation Process

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Documenting EISA Section 438 Implementation
Each agency or department is responsible for ensuring compliance with Section 438. It is recommended that: 1) the final design and as-built drawings of each facility shall be reviewed by a registered professional engineer and 2) the agency or department develop and maintain documentation of the following design criteria for each project subject to Section 438:

- Site evaluation and soils analysis
- Calculations for the 95th percentile rainfall event or the pre-development runoff volumes and rates to identify the volume of stormwater requiring management
- Documentation of modifications to the performance design objective based on technical constraints (site-specific METF determination)
- The site design and stormwater management practices employed on the site
- Design calculations for each stormwater management practice employed
- The respective volume of stormwater managed by each practice and the system as a whole
- Operations and maintenance protocols for the stormwater management system

The information should provide the necessary documentation and detail to demonstrate compliance and operation of stormwater management practices for the entire site.

Common Green Infrastructure/Low Impact Development Tools to Implement Section 438
Although Congress did not prescribe specific practices to be used to implement Section 438 it can be inferred that one of the goals of the Act was to promote the use of innovative stormwater management approaches, designs and practices that better protect receiving water quality, flow regimes and provide other important environmental benefits. GI/LID are preferred practices, to be supplemented with or replaced with conventional controls when site specific conditions dictate.

The GI/LID management approaches and technologies that federal agencies would typically use enhance and/or mimic the natural hydrologic cycle processes of infiltration, evapotranspiration, and use. Federal agencies can also use footprint reduction practices (e.g., building up instead of out) to reduce their stormwater impact. GI/LID approaches include biological systems and engineered systems. These include but are not necessarily limited to:

- Rain gardens, bioretention, and infiltration planters
- Porous pavements
- Vegetated swales and bioswales
- Green roofs
- Trees and tree boxes
- Pocket wetlands
- Reforestation/revegetation using native plants
- Protection and enhancement of riparian buffers and floodplains
- Rainwater harvesting for use (e.g., irrigation, HVAC make-up, non-potable indoor uses).

GI/LID practices are recommended to implement EISA Section 438 for the following reasons:

- cost savings in many cases

- overall environmental performance
- pollutant loading reduction capability
- pollution prevention focus
- effectiveness in managing runoff volumes and rates
- energy efficient and energy conservative
- appropriate in a wide range of site condition and locations
- appropriate for new development and redevelopment projects
- appropriate at multiple scales of development, e.g., site, neighborhood, region

For more information on specific GI/LID practices and how they function, visit: www.epa.gov/greeninfrastructure and www.epa.gov/nps/lid.

Figure 9. Disconnected downspout discharging to planter box.

Cost of Compliance

The cost of complying with Section 438 may require the use of approaches and techniques that initially may be more costly to design and implement. It is anticipated that as the expertise of the implementing agency or department increases and the demand for GI/LID materials and equipment increases that the overall costs of the projects will be lower or equivalent to the costs of constructing conventional stormwater practices. Initial studies conducted by EPA and others suggest that the use of GI/LID practices can be cost competitive. Recent evaluations of GI/LID projects have identified opportunities for cost savings because of reduced infrastructure and site preparation demands. In addition, longer term studies have indicated that GI/LID practices are continuing to gain cost efficiency as they are adopted more widely and with greater frequency thus reducing overall implementation costs.

In *Reducing Stormwater Costs through LID Strategies and Practices* (EPA 841-F-07-006, December 2007 - available for download at www.epa.gov/nps/lid), EPA examined 17 case studies in which conventional development costs were compared to GI/LID costs. In the great majority of cases, the GI/LID approach was between 15 and 80 percent less expensive than conventional control measures because implementation of GI/LID practices can offset costs of conventional construction and stormwater management approaches. Significant cost savings that were identified in the report include:

- Elimination or reduction of detention ponds
- Elimination or reductions of stormwater and CSO treatment and conveyance systems such as pipes, storage structures, stormwater treatment devices, and other related stormwater infrastructure
- Narrower streets with reduced material demands

- Fewer square yards of sidewalks
- Reduced land purchases for stormwater control structures

In addition, other benefits were achieved through the use of GI/LID such as more beneficial uses of land previously dedicated to stormwater devices, increased livability and higher property values.

There are many different combinations of practices that can be employed at particular sites to achieve pre-development hydrology. In selecting the appropriate set of practices to be used at the site, project sponsors should consider a broad range of factors, including cost-effectiveness of particular combinations of practices as applied to the site, as well as the potential for ancillary cost savings or community benefits (e.g., elimination or reduction of infrastructure costs, or the creation of attractive green spaces). EPA encourages project sponsors to include these factors in the planning and design phases of their projects so as to maximize triple bottom-line (economic, environmental, and social) results.

E. Calculating the 95th Percentile Rainfall Event

A long period of precipitation records, i.e., a minimum of 10 years of data, is needed to determine the 95th percentile rainfall event for a location. Thirty years or more of monitoring data are desirable to conduct an unbiased statistical analysis. The National Climatic Data Center (NCDC) provides long-term precipitation data for many locations of the United States. You can download climate data from their Web site (www.ncdc.noaa.gov) or by ordering compact discs (NOTE: The NCDC charges a fee for access to their precipitation data). Local airports, universities, water treatment plants, or other facilities might also maintain long-term precipitation records. Data reporting formats can vary based on the data sources. In general, each record should include the following basic information:

- Location (monitoring station)
- Recording time (usually the starting time of a time-step)
- Total precipitation depth during the time-step

In addition to the above information, a status flag is sometimes included to indicate data monitoring errors or anomalies. Typical NCDC flags include A (end accumulation), M (missing data), D (deleted data), or I (incomplete data). If there are no flags, the record has passed the quality control as prescribed by the NCDC and has been determined to be a valid data point.

There are several data processing steps to determine the 95th percentile rainfall event using a spreadsheet. These steps are summarized below:

1. Obtain a long-term 24-hr precipitation data set for a location of interest (i.e., from the NCDC website).

2. Import the data into a spreadsheet. In MS Excel [Data / Import External Data / Import Data]

3. Rearrange all of the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.

	A	B	C	D
1	Date	Prcp		
2	1/2/1921	0.05		
3	1/3/1921	0		
4	1/4/1921	0		
5	1/5/1921	0.33		
6	1/6/1921	0.08		
7	1/7/1921	0.08		
8	1/8/1921	0.19		
9	1/9/1921	0		

4. Review the records to identify if there are early periods with a large number of flagged data points (e.g., erroneous data points). Select a long period of good recording data that represents, ideally, 30 years or more of data. Remove all of the extra data (if not using the entire dataset).

5. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.

6. Remove small rainfall events (typically less than 0.1 inches), which may not contribute to rainfall runoff. These small events are categorized as depressional storage, which, in general, does not produce runoff from most sites.

	A	B	C	D
1	Date	Prcp		
2	1/5/1921	0.33		
3	1/8/1921	0.19		
4	1/14/1921	1.04		
5	2/6/1921	0.12		
6	2/11/1921	0.63		
7	2/20/1921	1.33		
8	2/28/1921	0.43		
9	3/3/1921	0.13		

Note: Steps 4 through 6 can be processed by applying data sort, delete and re-sort spreadsheet functions. In MS Excel [Data / Sort]

7. Calculate the 95th percentile rainfall amount by applying the PERCENTILE spreadsheet function at a cell. In MS Excel [=PERCENTILE(precipitation data range,95%)]

	A	B	C	D	E	F
1	Date	Prcp				
2	1/5/1921	0.33		=PERCENTILE(B:B,95%)		
3	1/8/1921	0.19		1.52		
4	1/14/1921	1.04				
5	2/6/1921	0.12				
6	2/11/1921	0.63				
7	2/20/1921	1.33				
8	2/28/1921	0.43				

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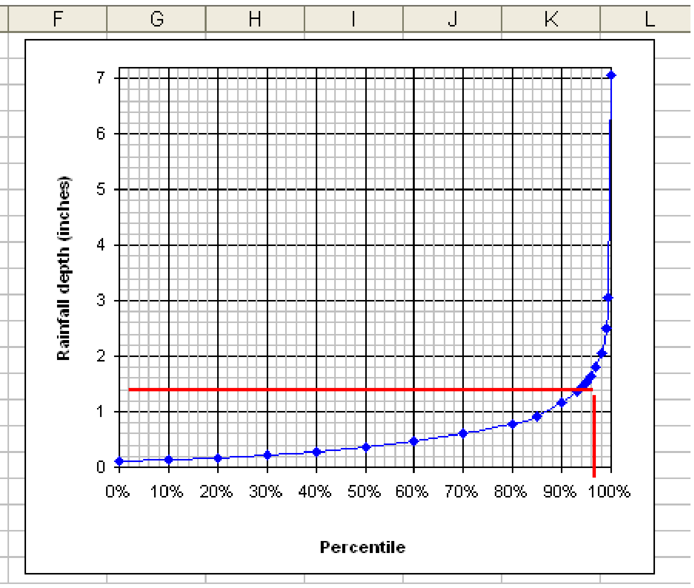
Note: The PERCENTILE function returns the nth percentile of value in the entire precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5% of storms.

8. The 95th percentile was calculated in the previous step. However, if the user would like to see this information represented graphically and get a relative sense of where individual storm percentiles fall in terms of rainfall depths, the following methodology can be used. Derive a table showing percentile versus rainfall depth to draw a curve as shown below. The PERCENTILE spreadsheet function can be used for each selected percent. It is recommended to include at least 6 points between 0% and 100% (several points should be between 80% and 100% to draw an accurate curve).

	A	B	C	D	E	F	G
1	Date	Prcp		Percentile	Rainfall		
2	1/5/1921	0.33		0%	=PERCENTILE(B:B,D2)		
3	1/8/1921	0.19		10%	=PERCENTILE(B:B,D3)		
4	1/14/1921	1.04		20%	=PERCENTILE(B:B,D4)		
5	2/6/1921	0.12		30%	=PERCENTILE(B:B,D5)		
6	2/11/1921	0.63		40%	=PERCENTILE(B:B,D6)		

	A	B	C	D	E
1	Date	Prcp		Percentile	Rainfall
2	1/5/1921	0.33		0%	0.1
3	1/8/1921	0.19		10%	0.13
4	1/14/1921	1.04		20%	0.17
5	2/6/1921	0.12		30%	0.22
6	2/11/1921	0.63		40%	0.28
7	2/20/1921	1.33		50%	0.36
8	2/28/1921	0.43		60%	0.46
9	3/3/1921	0.13		70%	0.6
10	3/9/1921	0.31		80%	0.79
11	3/13/1921	0.46		85%	0.93
12	3/25/1921	0.47		90%	1.16
13	3/28/1921	0.12		93%	1.35
14	4/1/1921	0.36		94%	1.44
15	4/9/1921	0.69		95%	1.52
16	4/15/1921	0.24		96%	1.65
17	4/17/1921	0.32		97%	1.82
18	4/18/1921	0.55		98%	2.068
19	4/23/1921	0.69		99%	2.508
20	4/24/1921	0.19		99.5%	3.049
21	4/30/1921	1.44		100%	7.06



Use the spreadsheet software to create of plot of rainfall depth versus percentile, as shown above. The 95th percentile storm event should correlate to the rainfall depth calculated in step 7, however the graph can be used to calculate rainfall depths at other percentiles (e.g., 50%, 90%).

Part II: Case Studies on Capturing the 95th Percentile Storm Using Onsite Management Practices

INTRODUCTION

This section contains nine case studies that are intended to be representative of the range of projects that are subject to the requirements legislated in Section 438 of the Energy Independence and Security Act. The facility examples in the case studies were selected to illustrate project scenarios for differing geographic locations, site conditions, and project sizes and types. As noted in Part I, all projects with a footprint greater than 5,000 square feet must comply with the provisions of Section 438. What this means is that both new development and redevelopment projects should be designed to infiltrate, evapotranspirate, and/or harvest and use runoff to the maximum extent technically feasible (METF) to maintain or restore the pre-development hydrology of the site. Scenarios 1-8 are examples of sites where it was technically feasible to design the stormwater management system to retain the 95th percentile storm onsite. Scenario 9, however, was provided as an example of an METF analysis where site constraints allowed the designers to retain only 75% of the 95th percentile storm.

Given the site-specific nature of individual projects, the case study scenarios described herein do not include site specific design features such as runoff routing, specific site infiltration rates, the structural loading capacity of buildings, etc. in terms of stormwater practice selection.

It should be noted that an example of Option 2, which requires a site-specific hydrologic analysis, has not been provided in this document because of the complexity of factors and the lack of general applicability such an analysis would have.

Background

Numerous approaches exist for determining the volume of runoff to be treated through stormwater management. Retaining stormwater runoff from all events up to and including the 95th percentile rainfall event was identified as Option 1 because small, frequently-occurring storms account for a large proportion of the annual precipitation volume. Using GI/LID practices to retain both the runoff produced by small storms and the first part of larger storms can reduce the cumulative impacts of altered flow regimes on receiving water hydrology, e.g., channel degradation and diminished baseflow. For the purposes of this guidance, retaining all storms up to and including the 95th percentile storm event is analogous to maintaining or restoring the pre-development hydrology with respect to the volume, flow rate, duration and temperature of the runoff for most sites.

Determination of the 95th Percentile Rainfall Event

The 95th percentile rainfall rainfall event was determined using the long-term daily precipitation records from the National Climate Data Center (NCDC, 2007). By analyzing the frequency and rainfall depths from daily rainfall records over 24-hour periods, the 95th percentile storm event can be determined. From a frequency analysis viewpoint, the 95th percentile event is the storm event that is greater than or equal to 95% of all storms that occur within a given period of time. Regional climate conditions and precipitation vary across the U.S. Because of local values, it is essential that the implementing agency or department establish the 95th percentile storm event for

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the project site since the control volume may vary depending on local weather patterns and conditions.

Onsite Stormwater Management Practice Determinations
For the purposes of the case study scenarios, the following four categories of practices were selected as the most appropriate practices for implementing Section 438 requirements: bioretention, permeable pavements and pavers, cisterns, and green roofs. These practices were selected based on known performance data and cost. For each case study, the same hierarchy of selection criteria was used, i.e., the most cost effective practices were considered before other practices were considered. Bioretention practices were considered first because these systems generally have the lowest cost per unit of stormwater treated (Hathaway and Hunt, 2007). Thus, if the bioretention system could not be designed to adequately capture the desired runoff volume, permeable pavement and pavers, cisterns, and green roofs were considered in that order based on relative cost. In most cases a combination of practices was selected as part of an integrated treatment system. It should be noted that all treatment systems were designed to accomplish the goal of capturing the 95th percentile rainfall event onsite. Examples of onsite stormwater management practices selected for each site are presented in the results section. For the Boston, MA site, it was assumed that bioretention was not feasible in order to simulate a situation where space was severely limited; as a result, interlocking modular pavers were selected as the most cost-effective stormwater management to capture the requisite design volume. To further illustrate the range of site conditions designers may encounter, and how site conditions impact the selection of appropriate control options, Scenario #3 (Cincinnati, OH) was re-analyzed as Scenario #8. In Scenario #8, it was assumed that the site had clay soils and low infiltrative capacity. Given these site conditions, the range of potential control options was more limited and a combination of modular paving blocks, a green roof, and cisterns was ultimately selected based on cost and site suitability factors.

For purposes of these modeling exercises, a number of assumptions were associated with each category of practice. These assumptions are not necessarily an endorsement of a particular design paradigm, but rather were used to keep a somewhat conservative cap on the scenarios in order to demonstrate the feasibility of the approach. For example, bioretention retrofits can and should often be located in prior impervious locations; however, in all modeled scenarios bioretention was restricted to currently landscaped areas. The assumptions were:

- **Bioretention areas**: On-lot retention of stormwater through the use of vegetation, soils, and microbes to capture, treat and infiltrate runoff.

  It is assumed bioretention practices would be installed within currently landscaped pervious areas or that pervious areas would be created for bioretention cells. While termed bioretention, these systems are designed to provide infiltration as well as temporary storage. Bioretention areas would be designed to accept up to a depth of 10 inches of water across the surface of the bioretention cell (see Appendix A). The conceptual design of this storage depth would occur within the media and/or could be included as ponded storage. Further design storage beyond the 10 inches would be acceptable (and encouraged) above the media on a site-by-site basis with ponded depth generally not to exceed 12 inches.

Uniform infiltration was assumed across the entire base of the bioretention cell. No additional media underneath the amended soils were included in the designs with infiltration rates in this layer governed by the *in situ* soils. Underdrains were not modeled directly but could be applied at the point of storage overflow such that no overflow occurs until the design depth of 10 inches is saturated. This approach was selected to maximize the storage and infiltration benefits of these systems. Designs utilizing underdrains at the base of the bioretention cell do not store the requisite volumes because the media is permeable and the underdrain conveys the runoff offsite through the underdrain before it can be infiltrated. Because standard underdrains typically discharge from smaller storms as well, underdrain designs, if employed, should ensure adequate retention capacity for the 95th percentile event volume.

The bioretention footprint for modeling purposes was calculated as one uniform area that did not include side slopes. There is an expectation that actual bioretention cell construction would be distributed throughout the site with targeted locations based on hydrology (natural flow paths) and soils with greater infiltrative capacity. Side slopes may increase the surface excavation area required to accommodate the footprint and freeboard of these systems depending on the design or the bioretention system.

- **Porous/permeable pavement**: Transportation surfaces constructed of asphalt, concrete or permeable pavers that are designed to infiltrate runoff.

  Infiltration was modeled for the entire porous pavement area with drainage pipes used only as overflow outlets. This design was chosen to maximize infiltration capabilities of the system. While many types of porous pavement systems can be used, modular block type pavers were generally applied in this design category under the assumption that they typically include sufficient volumetric storage in the media layer. [Note: Other types of porous pavement applications are available that support heavy loads and can be designed to temporarily store and infiltrate runoff beneath the surface of the pavement.]

  For these systems, an equivalent of 2 inches of design storage depth was assumed. This design depth could be achieved by specifying 10 inches of media depth that had 20% void space. Similarly, this could be achieved by designing six inches of media depth above the bottom surface, with specified media containing 33% void space. This alternative would have the overflow outlet at the 6 inch depth providing an equivalent water storage depth of 2 inches.

  The soils under the paver blocks may require or be subjected to some compaction for engineering stability. As a result, infiltration into underlying soils was modeled conservatively by applying the minimum infiltration rate for each soil type (see Appendix A).

  Generally, porous pavement is not recommended for high traffic areas or loading bays Because of this the scenarios assumed that only a percentage of total parking and road areas on a site can be converted to porous pavement. The assumed maximum percentage applied in the scenarios was set at 60% of the total paved area. Guidance on porous pavements is available at: http://cfpub.epa.gov/npdes/greeninfrastructure/technology.cfm#permpavements

- **Cistern**: Containers or vessels that are used to store runoff for future use.

  Cisterns were modeled in cases where green roofs were not feasible or where it was necessary to include additional storage volume to meet the goal of onsite rainfall runoff capture. The sizes of cisterns would be calculated based on site-specific rainfall, site-specific spatial and structural conditions, use opportunities and rates, and consideration of cost per volume of storage. For simplicity, cistern volume was reported as a total volume. This total volume could be subdivided into any number of cisterns to provide the total necessary storage but should be based on the impervious area and runoff quantities which will flow to the cistern. The most efficient cost per volume storage would need to be considered on a site-by-site basis (see Appendix A).

- **Green roof**: Roof designed with light weight soil media and planted with vegetation.

  Frequently, green rooftop area is limited by structural capacity. In addition, other rooftop equipment may need to be accommodated in this space including HVAC systems and air handlers. For this reason, and to provide a somewhat conservative rate of application, it was assumed for these modeling analyses that up to 30% of a roof's impervious area could be converted into a green roof. Green roof area was assumed to have 1 inch of total effective stormwater storage, i.e., a 2.5 inch media depth with 40% void space (see Appendix A).

General Approach

Using site aerial photos, spatial analysis should be conducted to estimate the land cover types and areas for each site. The surface conditions of each site can be digitized using geographic information systems (GIS) techniques. Alternatively, computer-aided design (CAD) drawings can be used to estimate the surface area of each land cover type. The schematic in Figure 10 illustrates the processes used for selecting and determining the overall size of stormwater management practices for each site.

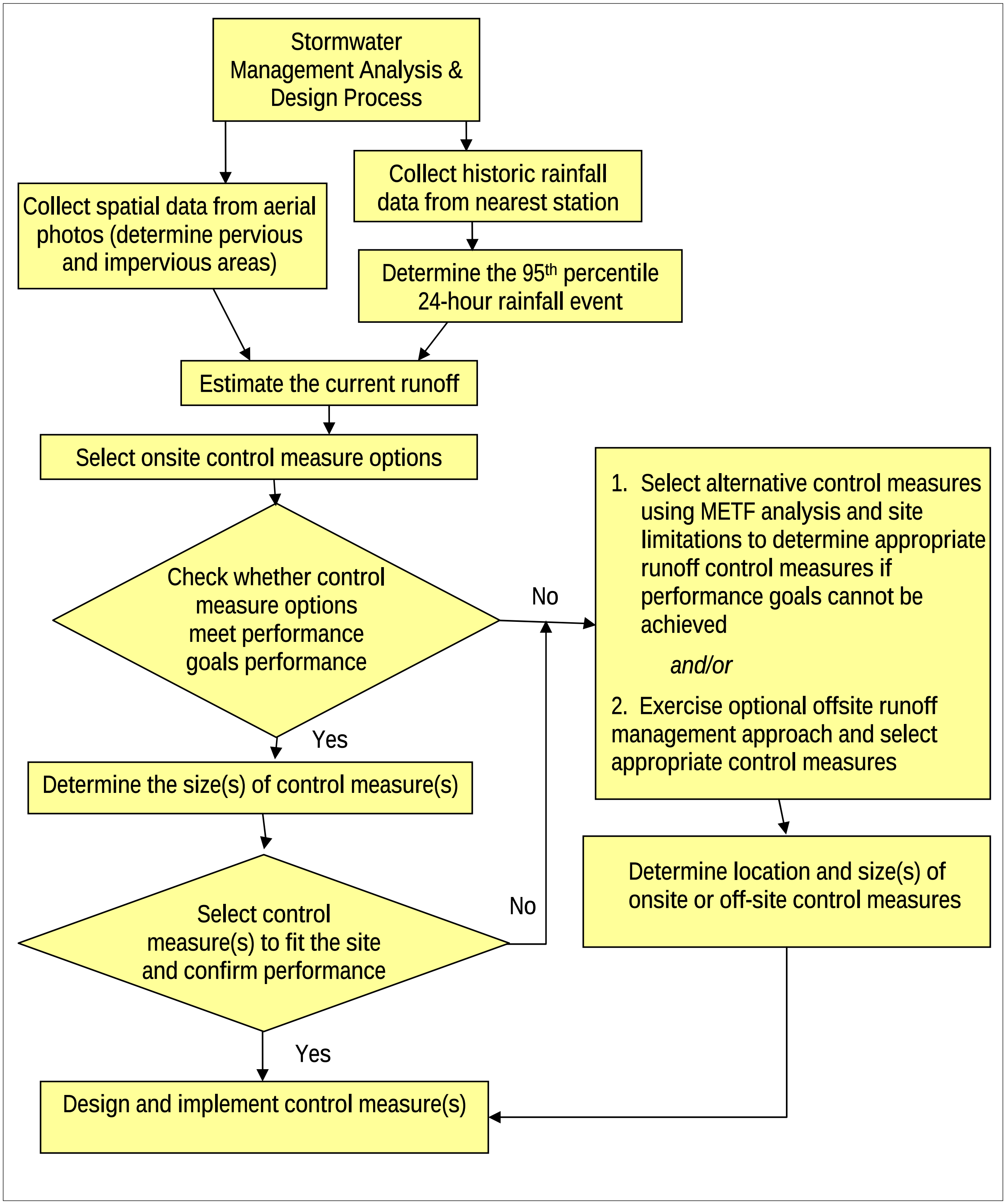

Figure 10. Flow chart depicting the process for determining control measures using the 95th percentile, 24-hour, annual rainfall event.

The following steps provide more detailed information on acquiring and calculating the necessary data to complete the processes indicated in Figure 10. This methodology was used in the scenario analyses that follow.

Collecting spatial data for a site

1. Collect an aerial orthophotograph for the desired site.
2. Digitize land use/land cover conditions using GIS techniques. If CAD drawings of the site exist, they can be used to estimate land cover area (pervious, impervious).
3. Categorize the digitized or planned land use/land cover based on surface hydrologic conditions, e.g., rooftop, pavement, and pervious/landscaped area.
4. Estimate the size of each land use/land cover category (by polygon).

Determining the 95th percentile, 24-hr rainfall event

1. Obtain a long-term 24-hr precipitation data set for the location of interest (i.e., from the NCDC Web site or other source).
2. Import the data into a spreadsheet. *In MS Excel* [Data / Import External Data / Import Data]
3. Rearrange all of the daily precipitation records into one column if the original data set has multiple columns of daily precipitation records.
4. Remove all flagged data points (i.e., erroneous data points) from the selected data set for further analysis.
5. Remove small rainfall events (typically less than 0.1 inches) that may not contribute to rainfall runoff. These small storms often produce little if any appreciable runoff from most sites and for modeling purposes are typically considered as volume captured in surface depression storage.
6. Calculate the 95th percentile rainfall volume by applying the PERCENTILE spreadsheet function to a range of data cells. The PERCENTILE function returns the nth percentile value in the specified precipitation data range. This function can be used to determine the 95th percentile storm event that captures all but the largest 5% of storms. *In MS Excel* [PERCENTILE(precipitation data range,95%)]

Estimating Current Runoff and Placing onsite control measures to capture the 95th percentile rainfall event

1. Collect spatial data for a site, e.g., rooftop, pavement, and pervious areas as above.
2. Check soil type (USDA mapping, borings, or onsite testing) for the site to determine infiltration parameters. For this modeling, many of the assumptions that pertain to generalized soils groups and their infiltration properties come from the EPA Stormwater Management Model (SWMM 4.x) manual (see Appendix A).
3. Determine the current runoff volume that would occur during a 24 hour period by applying the 95th percentile rainfall to the existing site conditions (land use and soil properties) as above using a hydrologic model (such as TR-55 or SWMM). For this analysis, it is assumed that the rainfall amount is distributed over a 24 hour period. Actual rainfall event duration (and intensity) was not considered for determining rainfall runoff (however, timing was considered when modeling infiltration).
4. Determine flow paths so that management practice placements are in locations where flows can be intercepted and routed to practices. Because this is a site specific effort and may require detailed topographic information or further surveys this would be a task to be

completed onsite and therefore is not included as a part of the modeling scenario exercise.

5. Select onsite control practices to capture the current 95th percentile runoff event; base the selection of appropriate options on site conditions, areas available for treatment options, and other factors such as site use and other constraints.

Note: The steps above have been generalized for the purposes of this guidance. It is recommended that a qualified professional engineer determine or verify that stormwater management practices are sized, placed, and designed correctly. It should also be noted that the methodology to determine rainfall amount used a 24 hour time period based on daily records. Actual rainfall events may have occurred over shorter or longer time periods. Similarly, for modeling purposes, the 24 hour rainfall amount was distributed to pervious and impervious areas (and management practices) as a uniform event occurring during a 24-hour period. A large dataset (greater than 50 years) was used to reasonably represent rainfall depth on a daily bases. It stands to reason that more frequent, shorter duration precipitation events are better represented than less frequent, longer duration precipitation events.

Scenarios

Eight locations were selected for the 9 case studies as shown in Figure 11 and Table 2. Case study numbers 3 and 8 were both developed based on the Cincinnati, Ohio facility, although the site parameters were altered to represent differing site conditions and design constraints. Annual average rainfall depths for these locations range from 7.5 inches to 48.9 inches. Analyses of the 95th percentile rainfall events for these locations produced rainfall depths that range from 1.00 inch to 1.77 inches (Table 2).

Figure 11. Locations for Analyzing Onsite Control Measures.

The government facilities in the 8 case study locations were selected because they represent generic sites from the major climatic regions of the U.S. These facilities also were selected because the sites have a range of site characteristics that can be used to illustrate different site designs and stormwater management options, e.g., pervious, roof, and pavement areas (Table 3). Site sizes ranged from 0.7 to 27 acres with percent site imperviousness area ranging from 47% to 95% of the site. Aerial photos of the sites are included along with site specific rainfall runoff and soil results.

Table 2. Summary of Rainfall Data for the Seven Locations.

No	Location	NCDC Daily Precipitation Data		Rainfall Depth (inches)	
		Period of record	Coverage	Annual average	95^{th} percentile rainfall event
1	Charleston, WV	1/1/1948 - 12/31/2006 (59 yrs)	99%	43.0	1.23
2	Denver, CO	1/1/1948 - 12/31/2006 (59 yrs)	96%	15.2	1.07
3	Cincinnati, OH	1/1/1948 - 12/31/2006 (59 yrs)	96%	36.5	1.45
4	Portland, OR	1/1/1941 - 12/31/2006 (66 yrs)	98%	35.8	1.00
5	Phoenix, AZ	1/1/1948 - 12/31/2006 (59 yrs)	99%	7.5	1.00
6	Boston, MA	1/1/1920 - 12/31/2006 (87 yrs)	99%	41.9	1.52
7	Atlanta, GA	1/1/1930 - 12/31/2006 (77 yrs)	100%	48.9	1.77
8	Norfolk, VA	1/1/1957 - 12/31/2006 (50 yrs)	99%	45.4	1.68

The results of the spatial analyses were summarized and divided into three land cover categories; rooftop, pavement, and pervious area, as shown in Table 3.

Table 3. Summary of Land-use Determinations of the Study Sites.

No	Location	Facility Spatial Info (acres)				Site Imperviousness
		Rooftop	Pavement	Pervious	Total	
1	Charleston, WV	0.1	0.4	0.2	0.7	73%
2	Denver, CO	0.5	1.9	2.0	4.5	55%
3	Cincinnati, OH	1.6	8.0	9.4	19	51%
4	Portland, OR	8.8	16.9	1.3	27	95%
5	Phoenix, AZ	0.2	0.7	1.1	2	47%
6	Boston, MA	0.9	1.5	1.1	3.5	69%
7	Atlanta, GA	3.9	10.8	6.2	21	70%
8	Norfolk, VA	0.9	0.55	0.15	1.6	91%

Methods for Determining Runoff Volume

Direct Determination of Runoff Volume

Runoff from each land cover was estimated using a simplified volumetric approach based on the following equation:

Runoff = Rainfall – Depression Storage – Infiltration Loss

Again, this methodology does not consider routing of runoff; therefore slope is not considered when calculating on a volumetric basis.

Infiltration loss is calculated only in pervious areas (e.g., there is no infiltration in impervious areas). In this analysis, infiltration was estimated using Horton's equation:

$$F_t = f_{\min} + (f_{\max} - f_{\min})\, e^{-kt}$$

where, F_t= infiltration rate at time t (in/hr)
$f_{\min}$ = minimum or saturated infiltration rate (in/hr)
$f_{\max}$ = maximum or initial infiltration rate (in/hr)
k = infiltration rate decay factor (/hr) and
t = time (hr) measured from time runoff first discharged into infiltration area

Infiltration loss for the 24-hr rainfall duration was estimated by the following equation with assumptions of a half hour Δt and uniform rainfall distribution in time:

$$Infiltration\ Loss = \sum (f \cdot \Delta t)$$

To more accurately describe the dynamic process of infiltration associated with Horton's equation, infiltration loss was integrated over a 24-hour period using a half hour time step while applying the maximum and minimum infiltration rates (in/hr) with time using the appropriate soil decay factor. The results of this process are further illustrated in Appendix A.

Once runoff from each land cover was estimated, the total runoff from a site can be obtained using an area-weighted calculation as shown below:

$$Runoff_{\text{site}} = \{(Runoff_{\text{roof}} \times A_{\text{roof}}) + (Runoff_{\text{pavement}} \times A_{\text{pavement}}) + (Runoff_{\text{pervious}} \times A_{\text{pervious}})\}/A_{\text{site}}$$

Where $Runoff_{\text{site}}$ = total runoff from the site (inches); A_{site} = site area (acres); $Runoff_{\text{roof}}$ = runoff from rooftop (inches); A_{roof} = rooftop area (acres); $Runoff_{\text{pavement}}$ = runoff from pavement area (inches); A_{pavement} = pavement area (acres); $Runoff_{\text{pervious}}$ = runoff from pervious area (inches); and A_{pervious} = pervious area (acres).

An example demonstrating how to calculate runoff by applying the Direct Determination method is presented below using the Charleston, WV (Scenario #1) site condition presented in Tables 2 and 3.

$Runoff_{\text{roof}}$ = *95th Rainfall – Depression Storage*
= 1.23 – 0.1 = 1.13 inches

$Runoff_{\text{pavement}}$ = *95th Rainfall – Depression Storage*
= 1.23 – 0.1 = 1.13 inches

$Runoff_{\text{pervious}}$ = *95th Rainfall – Depression Storage – Infiltration Loss*
= 1.23 – 0.1 – 9.73 = 0 inches (i.e., no runoff because the result is a negative number)

$$Runoff_{site} = \{(Runoff_{roof} \times A_{roof}) + (Runoff_{pavement} \times A_{pavement}) + (Runoff_{pervious} \times A_{pervious})\}/A_{site}$$
$$= \{(1.13 \times 0.10) + (1.13 \times 0.41) + (0 \times 0.19)\}/0.7 = 0.82 \text{ inches}$$

Infiltration loss was estimated based on soil type B by applying the Horton equation as described above. Because the volume removed from surface runoff through infiltration was substantial, no runoff occurred from the pervious area.

In cases where sites had limited physical space available for stormwater management, a series of practices was used (e.g., treatment train) to simulate the runoff and infiltrative behavior of the system. For example, if there was inadequate area and infiltrative capacity to infiltrate 100 percent of the 95th percentile storm event within a bioretention system another onsite management practice was selected to manage the runoff that could provide the necessary capacity. In this manner, excess runoff was routed to another management practice in the series of treatment cells where possible.

Two types of soils were considered for every site: hydrologic soil group B and C (except for scenario 8 in which hydrologic soil group D was used). Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and either loamy sand or sandy loam textures with some loam, silt loam, silt, or sandy clay loam soil textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam soil textures with some clay, silty clay, or sandy clay textures placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments (USDA-NRCS, 2007). The application of these hydrologic soil groups was intended to give reasonable and somewhat conservative estimates of infiltration capacity.

General hydrologic parameters in this analysis were assumed as follows (see Appendix A for citations of assumptions):

- Depression storage (or initial abstraction)
    - Rooftop: 0.1 inches
    - Pavement: 0.1 inches
    - Pervious area: 0.2 inches

- Horton Infiltration parameters
    - Hydrologic Soil Group B
        - Maximum infiltration rate: 5 in/hr
        - Minimum infiltration rate: 0.3 in/hr
        - Decay factor: 2 /hr

    - Hydrologic Soil Group C
        - Maximum infiltration rate: 3 in/hr
        - Minimum infiltration rate: 0.1 in/hr
        - Decay factor: 3.5 /hr

- Design storage assumptions of control measures
  - Bioretention: up to 10 inches (but variable based on balancing necessary storage volume, media depth for plant survivorship, and surface area limitations)
  - Green roof: 1 inch (2.5 inches deep media with 40% void space)
  - Porous pavement: 4 inches (10 inches deep media with 40% void space)

Other Methods for Estimating Runoff Volume

Runoff from a site after applying the 95th percentile storm can be estimated by using a number of empirical, statistical, or mathematical methods. Several methods were considered in this analysis. The Rational Method can be used to estimate peak discharge rates and the Modified Rational Method can be used to develop a runoff hydrograph. The NRCS TR-55 model can be used to predict runoff volume and peak discharge. TR-55 can also be used to develop a runoff hydrograph. The EPA Stormwater Management Model (SWMM) can be used to simulate rainfall-runoff, pollutant build-up and wash-off, transport-storage-treatment of stormwater flow and pollutants, backwater effects, etc. for a wide range of temporal and spatial scales. The SWMM model can be fit to model a small site with a distributed system. Hydrologic Simulation Program – Fortran (HSPF, USDA) is a watershed and land use based lumped model that can be used to compute the movement of water and pollutants when evaluating the effects of land use change, reservoir operations, water quality control options, flow diversions, etc. In general, regionally calibrated modeling parameters are incorporated into HSPF. QUALHYMO is a complete hydrologic and water quality model, which can be used to factor in snowmelt or soil moisture conditions or to simulate system behavior based on infiltration and ET, ground water storage tracking, baseflow and deep volumetric losses, and other variables.

Many of the existing tools for analyzing distributed systems use some part or all of the principles or formulae of the modeling approaches highlighted above. For example, the Emoryville spreadsheet control measure model (Emoryville, CA) uses a runoff coefficient (i.e., Rational Method) for analyzing lot-level to neighborhood-scale control measure sizing. The Green Calculator (Center for Neighborhood Technologies) estimates the benefit of onsite GI/LID options on a neighborhood-scale by applying the curve numbers (i.e., TR-55) and the Modified Rational Method. The Northern Kentucky Spreadsheet Tool uses a TR-55 based approach for control measure sizing on neighborhood or site level spatial scales. The WWHM (Western Washington Hydrology Model) is a regionally calibrated HSPF model intended for use in sizing stormwater detention and water quality facilities to meet the Washington State Department of Ecology standards. WBM-QUALHYMO is a Canadian model used in conjunction with the Water Balance Model (WBM). This model can be used to continuously simulate stormwater storage routing, stream erosion, drainage area flow routing, and snowmelt runoff (and ultimately freeze-thaw). Table 4 contains a summary of these different methods based on generic modeling features.

Table 4. Potential Methods for Analyzing Control Measures.

Model Considerations		Rational Method	TR-55	SWMM	Direct Determination	HSPF	QUALHYMO
Temporal scale	Single Event	Yes	Yes	Yes	Yes	Yes	Yes
	Continuous Simulation	No	No	Yes	Possible	Yes	Yes
Spatial scale	Lot-level	Yes	Yes[b]	Yes	Yes	No	No
	Neighborhood	Yes	Yes	Yes	Yes	Possible	Possible
	Regional	Yes	Yes[c]	Yes	No	Yes	Yes
Outputs	Peak Discharge	Yes	Yes	Yes	No	Yes	Yes
	Runoff Volume	Yes	Yes	Yes	Yes	Yes	Yes
	Hydrograph	Yes[a]	Yes	Yes	No	Yes	Yes
	Water Quality	No	No	Yes	Possible	Yes	Yes

[a] Modified Rational Method

[b] No less than 1 acre.

[c] No more than 25 square miles (up to 10 subareas).

From the viewpoint of modeling both lot-level and neighborhood scale projects, the Rational Method, NRCS TR-55, SWMM, and Direct Determination approaches were selected for use in scenario analyses. Strength and weakness of these methods are presented below:

Table 5. Comparison of approaches for determining runoff volume.

Method	Strengths	Weaknesses
Direct Determination	• Methodology for runoff determination is same as SWMM • Models basic hydrologic processes directly (explicit) • Simple spreadsheet can be used	• Direct application of Horton's method may estimate higher infiltration loss, especially at the beginning of a storm • Does not consider flow routing
Rational Method	• Method is widely used • Simple to use and understand	• Cannot directly model storage-oriented onsite control measures
TR-55	• Method is widely used • Simple to use and understand	• May not be appropriate for estimating runoff from small storm events because depression storage is not well accounted for
SWMM	• Method is widely used • Can provide complete hydrologic and water quality process dynamics in stormwater analysis	• Needs a number of site-specific modeling parameters • Generally requires more extensive experience and modeling skills

Each method requires specific parameters for estimating runoff from a site. Runoff coefficients for the Rational Method are assumed to be 0.9 for rooftop and pavement areas, and 0.1 and 0.135 for Group B and C soil pervious areas, respectively (Caltrans, 2003). The slope of the pervious area was assumed to be an average of 2%. Applying these runoff coefficients for each surface, the overall area-weighted runoff coefficient can be determined.

When applying the NRCS TR-55 method, Curve Numbers (CNs) should be determined for each drainage area. For rooftop and pavement areas the CN was assumed to be 98, and pervious area CN was determined on the basis of the hydrologic soil group and the status of grass cover condition. Curve numbers for pervious areas were assumed to be 61 and 74 for Group B and C soils, respectively, with an assumption of over 75% grass cover. The overall CN can be estimated by using an area-weighted calculation (USDA-SCS, 1986).

In SWMM modeling, infiltration was modeled using Horton's equation. The same infiltration parameters and depression storage values used in the direct determination method of runoff treatment volume described earlier were applied to the SWMM analyses. The average slope of the pervious area was again assumed to be 2%. The same uniform rainfall distribution and time step was applied for the SWMM model runs.

Runoff Methodology Results

Stormwater management practice sizes (and depth) were determined using the Direct Determination approach to capture the volume of runoff generated in a 95th percentile rainfall event at each location. Total acreage, impervious area, the 95th percentile rainfall event, the current expected runoff for the 95th percentile rainfall event, and the future runoff with stormwater management controls were reported for each site. Results were summarized for the two soil types (three soil types for scenarios #3 and #8 in Cincinnati). The spatial location of onsite control measures was also illustrated in the site aerial photo figures. Note that site practices were placed only on undeveloped or landscaped areas without regard for true flow paths or technical feasibility. It may be preferred to place practices in existing impervious areas, if possible. For the purposes of this modeling exercise, the least cost and most practical solutions were used, i.e., locating bioretention systems on undeveloped or landscaped areas. On an actual site, flow paths would be determined and berms and swales might be used to route runoff to areas that are most suitable for infiltration. In other cases, areas that are currently impervious could be modified to accept runoff, e.g., impermeable pavements removed and replaced by permeable, sidewalks could be redesigned to include sidewalk bioretention cells and streets could be designed with flow through or infiltration curb bumpouts/raingardens.

To compare other approaches of runoff estimation, alternate methodologies were also employed for three scenarios. TR-55 was used for Scenario #1 (Atlanta), the Rational Method was applied to Scenario #2 (Denver), and the SWMM was run for Scenario #7 (Charleston).

Although flood control is not the focus of this guidance, most localities have flood control requirements that will need to be considered in designing control measures to comply with Section 438. For flood control purposes, TR-55 was used to model the 10 year frequency design storm for each site under the assumption that all stormwater management practices were in place. The 10-year design storms were selected from the NRCS TR-55 Manual (USDA, 1986) for both the Eastern U.S. and the Western U.S. Precipitation Frequency Maps (www.wrcc.dri.edu/pcpnfreq.html). The 10-year frequency design storm was selected because it represents a common design standard used by state and local governments in order to manage peak rates of runoff and prevent flooding.

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COST ESTIMATES FOR SELECTED SCENARIOS

Scenarios #2 and 7 include cost estimates comparing the capital costs for a design to comply with Section 438 (retention of the 95th percentile rainfall event) and capital costs for a traditional stormwater management design (e.g., typical curb and gutter, off-site pond for stormwater management). These costs are based on average unit costs to construct both traditional and GI/LID controls.

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Scenario #1 - Charleston, WV

A 0.7-acre site with 73% impervious area was selected from Charleston, West Virginia (Figure 12). If the 95th percentile rainfall event (1.23 inches) occurred on the existing site (i.e., with no control measures), 0.82 inches of runoff using the Direct Determination method would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.03 acres if hydrologic soil group B is present, or 0.06 acres if hydrologic soil group C (Table 6) is the predominant soil type on the site. Assuming that bioretention practices are placed in areas that are currently pervious or landscaped, a total of 0.2 acres of pervious area would be available for the placement of bioretention systems. The effective design storage depth within the designated bioretention area was 8 inches.

Figure 12. Actual Site and Onsite Control Measures (Charleston, WV)

Table 6. Estimated Sizes of Onsite Control Measures for Scenario #1 (Charleston, WV)

Total Area (acres)		0.7	
Estimated Imperviousness (%)		73%	
95th Percentile Rainfall Event (inches)		1.23	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.82	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by Direct Determination method (acres)		0.03	0.06
Bioretention estimated by SWMM (acres)		0.03	0.05
Off-site storage necessary to control the 10-yr event of 3.9 inches (acre-ft)	With onsite controls	0.10	0.12
	Without onsite controls	0.16	0.17

Note: The two hydrologic methods used (direct determination and SWMM) estimated similar bioretention sizes.

Scenario #2 - Denver, CO

A 4.5-acre site with 55% impervious area was selected from Denver, Colorado (Figure 13). If the 95th percentile rainfall event (1.07 inches) occurred on the existing site (i.e., with no control measures), 0.53 inches of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.16 acres if the hydrologic soil group B is present or 0.3 acres if hydrologic soil group C (Table 7) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 2 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 6 inches.

Figure 13. Actual Site and Onsite Control Measures (Denver, CO)

Table 7. Estimated Sizes of Onsite Control Measures for Scenario #2 (Denver, CO)

Total Area (acres)		4.5	
Estimated Imperviousness (%)		55%	
95th Percentile Rainfall Event (inches)		1.07	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.53	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination method (acres)		0.16	0.3
Bioretention estimated by Rational Method (acres)		0.16	0.28
Off-site storage necessary to control the 10-yr event of 3.2 inches (acre-ft)	With onsite controls	0.35	0.52
	Without onsite controls	0.64	0.64

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Cost estimates were also developed for this scenario (Table 8) to compare the costs of installing onsite control measures to retain the 95th percentile rainfall event versus the costs to install traditional stormwater management controls (e.g., curbs and gutters combined with off-site retention such as extended detention wet ponds). In a GI/LID scenario, the bioretention cell would occupy a specified area. This same area in a traditional design would be covered in turf since the pond would typically be offsite and not occupy the area planted in turf. Table 8 includes this cost under the traditional column. Note: typical land development practices involve mass clearing and grading so little or no pre-existing vegetation is typically retained. It is also assumed that the use of GI/LID practices would require less underground infrastructure because the traditional design typically routes stormwater underground to an off-site pond via pipes or culverts while GI/LID practices are designed to manage runoff onsite and as close to its source as possible. They are also dispersed across the site and routing occurs through surface drainage via bioswales and overland flow. As a result GI/LID practices do not require as much or any hard or grey infrastructure. The cost estimates were developed for Hydrologic Soil Group B.

Table 8. Estimated Costs for Scenario #2 (Denver, CO)

Sizes of Onsite Control Practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.07	
Bioretention (acres)		0.1	
Paver blocks (acres)		0	
Green roof (acres)		0	
Off-site Pond	WQV (ac-ft)	-	0.18
	10-Yr Fld Cntr (ac-ft)	0.15	0.14
Total Off-Site Requirement (ac-ft)		0.15	0.32
Land Area (assumes avg 3 ft depth)		0.05	0.11
% of the site		2.8%	
Costs of Onsite Control Practices			
Biorention/alternative		$32,495	$4,187
Off-site Pond	WQV (ac-ft)		$14,833
	10-Yr Fld Cntr (ac-ft)	$10,073	$9,527
Infrastructure	Pipe	$8.990	$16,982
	Inlet	$9.920	$14,880
Land Area (assumes $300K/acre)		$14,500	$31,500
Sum		**$75,978**	**$91,909**
% difference from Traditional		**-17.3%**	

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Scenario #3 - Cincinnati, OH

A 19-acre site with 51% impervious area was selected in Cincinnati, Ohio (Figure 14). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., no control measures were in place), 0.68 inches of runoff from the site would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.8 acres if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 9) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Figure 14. Actual Site and Onsite Control Measures (Cincinnati, OH)

Table 9. Estimated Sizes of Onsite Control Measures for Scenario #3 (Cincinnati, OH)

Total Area (acres)		19	
Estimated Imperviousness (%)		51%	
95th Percentile Rainfall Event (inches)		1.45	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.68	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.8	1.3
Off-site storage necessary to control the 10-yr event of 4.2 inches (acre-ft)	With onsite controls	2.42	3.24
	Without onsite controls	3.29	3.73

Scenario #4 - Portland, OR

A 27-acre site with 95% impervious area was selected in Portland, Oregon (Figure 15). If the 95th percentile rainfall event (1.0 inches) occurred on the existing site (i.e., no control measures), 0.86 inches of runoff would be generated and require management. This site has the greatest imperviousness among the 7 sites.

Given these site conditions, there is not enough pervious area to manage the entire runoff volume discharged by the 95th percentile rainfall event with bioretention. As a result, other practices were evaluated and selected. The practices integrated into the design included a green roof, cisterns, and porous pavement. Based on the technical considerations of constructing and maintaining control measures at the site, it was assumed that approximately 30% of the available pervious area could be converted into bioretention cells; 20% of total rooftop area could be converted into green roofs; 40% of paved area could be converted into paver blocks; and 50,000 gallons of total volume could be captured in cisterns for use on this urbanized site. Using this system of four different practices, all runoff for the 95th percentile rainfall event would be retained (Table 10).

Figure 15. Actual Site and Onsite Control Measures (Portland, OR)

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Table 10. Estimated Sizes of Onsite Control Measures for Scenario #4 (Portland, OR)

Total Area (acres)		27	
Estimated Imperviousness (%)		95%	
95th percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.86	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Paver block area estimated by Direct Determination (acres)		1.4	3.5*
Bioretention estimated by Direct Determination (acres)		0.4	
Green Roof estimated by Direct Determination (acres)		1.7	
Cistern volume estimated by Direct Determination (gallons)		50,000	
Off-site storage necessary to control the 10-yr event of 3.7 inches (acre-ft)	With onsite controls	5.37	5.62
	Without onsite controls	7.70	7.71

*The size of porous pavement area was increased because the other control options were maximized based on the site-specific design assumptions.

A total of 1.3 acres of the site is pervious area or landscaped of which, 0.4 acres (30% of the pervious area) could be converted to bioretention cells that have a storage depth of 10 inches. Of the 8.8 acres of current rooftop area, 1.7 acres (20% of the rooftop area) could be retrofitted into green roof areas. Of the 16.9 acres of paved area, 1.4 acres (8% of the paved area) for hydrologic soil group B, or 3.5 acres (20% of the paved area) for hydrologic soil group C, of paver block systems could be implemented. One or more cisterns (as indicated in Figure 15) could be used to capture up to 50,000 gallons of runoff from rooftop areas. Note: The high percentage of imperviousness of the site (95%) requires that all infiltration designs be based on resident soil type and design volumes, or with adequate sub-bases or amended soils.

Scenario #5 – Near Phoenix, AZ

A 2-acre site with 47% impervious area was selected near Phoenix, Arizona (Figure 16). If the 95th percentile rainfall event (1.0 inches) occurred on the existing site (i.e., with no control measures), 0.42 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by installing bioretention systems totaling 0.06 acres if the hydrologic soil group B is present or 0.1 acres if hydrologic soil group C (Table 11) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 1.1 acres of pervious area is available for the placement of these practices. The design storage depth of media within the designated bioretention area was 6 inches. Note: If the design storage depth were increased to 10 inches, the off-site storage necessary for the 10-year event could be reduced to 0.03 acre-ft for type B soils and 0.08 acre-ft for type C soils.

Figure 16. Actual Site and Onsite Control Measures (Phoenix, AZ)

Table 11. Estimated Sizes of Onsite Control Measures for Scenario #5 (Phoenix, AZ)

Total Area (acres)		2	
Estimated Imperviousness (%)		47%	
95th Percentile Rainfall Event (inches)		1.00	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.42	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.06	0.1
Off-site storage necessary to control the 10-yr event of 2.4 inches (acre-ft)	With onsite controls	0.05	0.12
	Without onsite controls	0.18	0.18

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Scenario #6 - Boston, MA

A 3.5-acre site with 69% impervious area was selected in Boston, Massachusetts (Figure 17). If the 95th percentile rainfall event (1.52 inches) occurred on the existing site (i.e., with no control measures), 0.98 inches of runoff would be generated and require management. Given these site characteristics, there is adequate area to place appropriately sized bioretention cells to capture the 95th percentile storm event. However, for the purposes of this analysis, unspecified conditions preclude the use of bioretention. As a result, a paver block system was selected as the best onsite control measure and the system was designed such that the necessary design parameters could be achieved by storing some of the volume in the paver media and by infiltrating the remainder of the volume. The runoff from the 95th percentile rainfall event could be retained by installing a paver block area totaling 0.4 and 0.8 acres assuming soil types B and C, respectively (Table 12). For the purposes of this case study, a total of 1.5 acres of parking lot was made available to accommodate the paver block system. The area retrofitted with paver blocks would primarily be dedicated for use as parking stalls.

Figure 17. Actual Site and Onsite Control Measures (Boston, MA)

Table 12. Estimated Sizes of Onsite Control Measures for Scenario #6 (Boston, MA)

Total Area (acres)		3.5	
Estimated Imperviousness (%)		69%	
95th Percentile Rainfall Event (inches)		1.52	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		0.98	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
	Paver block area estimated by Direct Determination (acres)	0.4	0.8
Off-site storage necessary to control 10-yr event of 4.5 inches (acre-ft)	With onsite controls	0.59	0.71
	Without onsite controls	0.89	0.96

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<u>Scenario #7 - Atlanta, GA</u>

A 21-acre site with 70% impervious area was selected in Atlanta, Georgia (Figure 18). If the 95th percentile rainfall event (1.77 inches) occurred on the existing site (i.e., with no control measures), 1.17 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could not be adequately retained solely with bioretention systems. Based on the technical considerations of constructing and maintaining control measures at the site, it was assumed that up to 15% of the pervious area could be converted into bioretention cells and up to 40% of paved area could be converted into a paver block system. If the stormwater management techniques used on the site includes both bioretention and paver blocks as presented in Table 13, then all runoff for the 95th percentile rainfall event would be controlled.

Figure 18. Actual Site and Onsite Control Measures (Atlanta, GA)

Table 13. Estimated Sizes of Onsite Control Measures for Scenario #7 (Atlanta, GA)

Total Area (acres)		21	
Estimated Imperviousness (%)		70%	
95th Percentile Rainfall Event (inches)		1.77	
Expected Runoff for the 95th Percentile Rainfall Event (inches)		1.17	
Stormwater Management Area Required		Hydrologic Soil Group	
		B	C
Bioretention estimated by the Direct Determination (acres)		0.9	
Paver block area estimated by the Direct Determination (acres)		0.9	3.2*
Bioretention estimated by TR-55		0.8**	0.9
Paver block area estimated by TR-55		0**	1.84
Off-site storage necessary to control 10-yr event of 6.0 inches (acre-ft)	With onsite controls	5.85	6.62
	Without onsite controls	7.25	8.49

*The size of porous pavement was increased because the bioretention already reached its maximum size based on the site-specific design assumptions.

**Because TR-55 estimated smaller runoff in this scenario, bioretention can retain all of the 95th percentile runoff if the site has soil group B.

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For the example site in Atlanta, GA, areas of 1.8 acres for hydrologic soil group B, and 4.1 acres for hydrologic soil group C, would be required to manage the runoff discharged from a 95th percentile rainfall event. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 6.2 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 10 inches. Permeable pavement systems could be used to treat the remaining volume on the 10.8 acres of existing paved area.

In applying the TR-55 model, the overall curve numbers for the site were 87 and 91 for Group B and C soils, respectively. TR-55 was used to estimate 0.73 inches of runoff for soil group B and 0.97 inches for soil group C, which are smaller numbers than the 1.17 inches of runoff estimated by the Direct Determination method. As a result, the sizes of the onsite control measures designed using the TR-55 model were smaller than those designed using the Direct Determination method. Note: It is recommended that caution be exercised when using TR-55 to model storms less than 0.5 inches per event. See application of TR-55 in Table 5.

Cost estimates were also developed for this scenario (Table 14) to compare the costs to install onsite control measures to retain the 95th percentile rainfall event, and costs to install traditional stormwater management controls (e.g., primarily curb and gutter with off-site retention). The cost estimates were developed for Hydrologic Soil Group B.

Table 14. Estimated Costs for Scenario #7 (Atlanta, GA)

Sizes of Onsite Control Practices			
		Controls for 95th Percentile Event	Traditional Stormwater Controls
Rainfall depth (in)		1.77	
Bioretention (acres)		0.94	
Paver blocks (acres)		0.86	
Off-site Pond	WQV (ac-ft)	-	1.75
	10-Yr Fld Cntr (ac-ft)	0.84	0.0
Total Off-Site Requirement (ac-ft)		0.84	1.75
Land Area (assumes avg 3 ft depth)		0.28	0.58
% of the site		8.5%	
Costs of Onsite Control Practices			
Biorention/alternative		$232,923	$30,617
Paver block/alternative		$236,878	$88,409
Off-site Pond	WQV (ac-ft)	$0	$72,888
	10-Yr Fld Cntr (ac-ft)	$39,648	$0
Infrastructure	Pipe	$54,827	$191,095
	Inlet	$52,080	$79,360
Land Area (assumes $300K/acre)		$84,000	$175,000
Sum		**$700,356**	**$637,368**
% difference from Traditional		**9.9%**	

Scenario #8 - Cincinnati, OH

A 19-acre site with 51% impervious area was selected in Cincinnati, Ohio (Figure 19). If the 95th percentile rainfall event (1.45 inches) occurred on the existing site (i.e., with no control measures), 0.68 inches of runoff would be generated and require management. The runoff from the 95th percentile rainfall event could be retained by the installation of bioretention systems totaling 0.8 acres if the hydrologic soil group B is present or 1.3 acres if hydrologic soil group C (Table 9) is the predominant soil type on the site. Assuming that bioretention practices are only placed in areas that are currently pervious or landscaped, a total of 9.4 acres of pervious area is available for the placement of bioretention systems. The design storage depth of media within the designated bioretention area was 8 inches.

Scenario #8 represents an alternative to the Cincinnati, scenario in #3 (Figure 14). In this case, hydrologic soil group D was selected to represent the soil characteristics present for the entire site. Alternatively, simulations could have been run under the assumption that the use of infiltration practices were precluded by contaminated soils or high ground water tables. Under these site conditions, bioretention options are severely limited and cannot be used to adequately capture the entire 95th percentile storm event. As a result, options such as cisterns and green roofs were considered. In the absence of management practices, the 95th percentile rainfall event discharges 1.45 inches of stormwater and 0.53 inches of this runoff is captured by onsite depression storage. The difference, 0.92 inches of runoff, would then require capture and management. Based on the technical considerations of constructing and maintaining controls at the site, it was assumed that up to 20% of pervious area can be converted into bioretention areas; up to 30% of paved area can be converted into porous pavement; and up to 30% of the rooftop area can be converted into green roofs. Cisterns can be added to the system if additional storage volume is required. It should be noted that green roofs were selected lowest in the hierarchy of practices evaluated because of cost and potential structural issues associated with design and placement on existing buildings. By using the four onsite control options as presented in Table 15, all runoff for the 95th percentile rainfall event would be retained. From a management perspective, it was assumed that the design storage depth within the designated bioretention area was 6 inches because of the low infiltration rates adopted for this scenario.

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Figure 19. Actual Site and Onsite Control Measures (Cincinnati, OH)

Table 15. Estimated Sizes of Onsite Control Measures for Scenario #8 (Cincinnati, OH)

Total Area (acres)	19
Estimated Imperviousness (%)	51%
95th Percentile Rainfall Event (inches)	1.45
Expected Runoff for the 95th Percentile Rainfall Event (inches)	0.92
Stormwater Management Applied	Hydrologic Soil Group D
Bioretention estimated by Direct Determination (acres)	1.9
Paver block area estimated by Direct Determination (acres)	2.4
Green Roof estimated by Direct Determination (acres)	0.5
Cisterns estimated by Direct Determination (gallons)	13,000

This site contains a total of 9.4 acres of pervious area, 8.0 acres of paved area, and 1.6 acres of rooftop area. If 1.9 acres (20%) of the pervious area were converted to bioretention cells; 2.4 acres (30%) of parking lot converted to paver blocks; and 0.5 acres (30%) of rooftop area were retrofitted to green roof areas for this site, then 97% of stormwater runoff from the 95th percentile storm would be captured on site. By also adding one or more cisterns (as indicated in Figure 19), an additional 13,000 gallons could be captured, thus illustrating that 100% of the rainfall from the 95th percentile event can be managed onsite with GI/LID practices.

Scenario #9 – Norfolk, VA

A 1.6 acre site with 91% impervious area was selected from Norfolk, Virginia. Table 16 contains the land use categories for the site. Figure 20 depicts the site and associated facilities. Site specific factors based on an METF analysis allow management of 75 % of the 95th percentile storm onsite (1.27 inches). The remaining portion of the 95th percentile rainfall event (0.41 inches would be discharged off of the site.

Table 16. Land Use Determination After Redevelopment

Land Use	Acres	Site Coverage Percent
Building	0.90	56.3
Parking	0.35	21.9
Streets/Sidewalks	0.20	12.5
Undeveloped	0.15	9.3
Total	**1.60**	**100%**

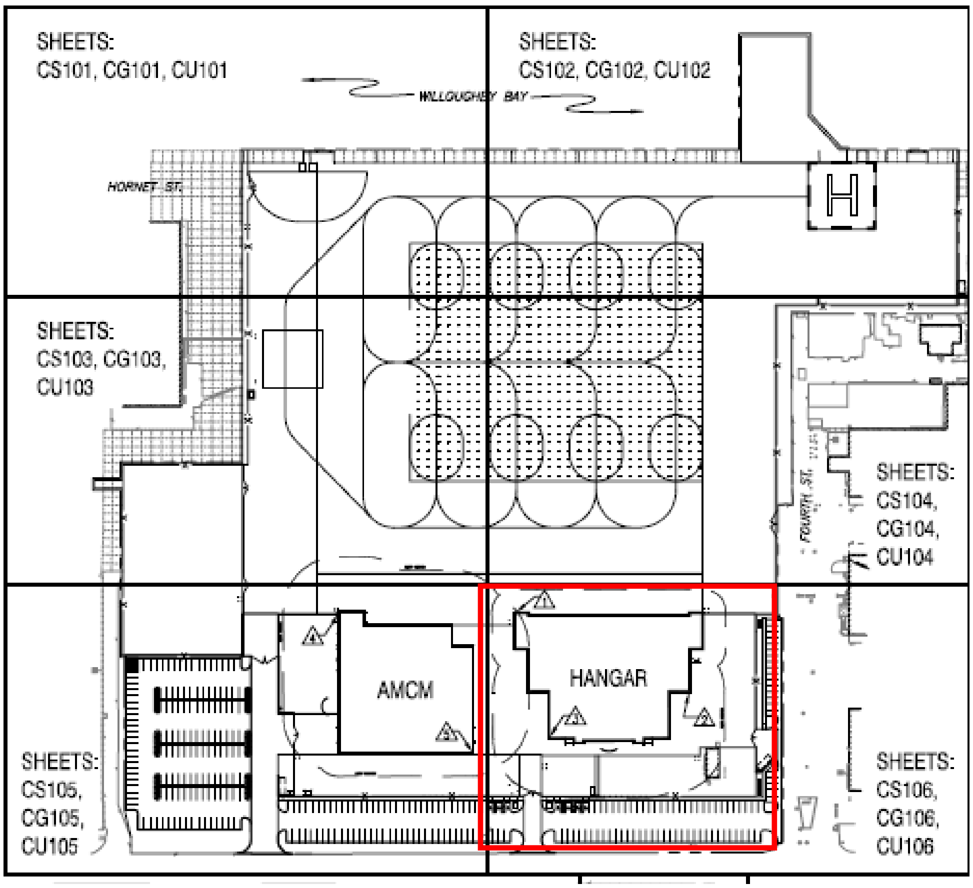

Figure 20. Proposed Redevelopment Scenario

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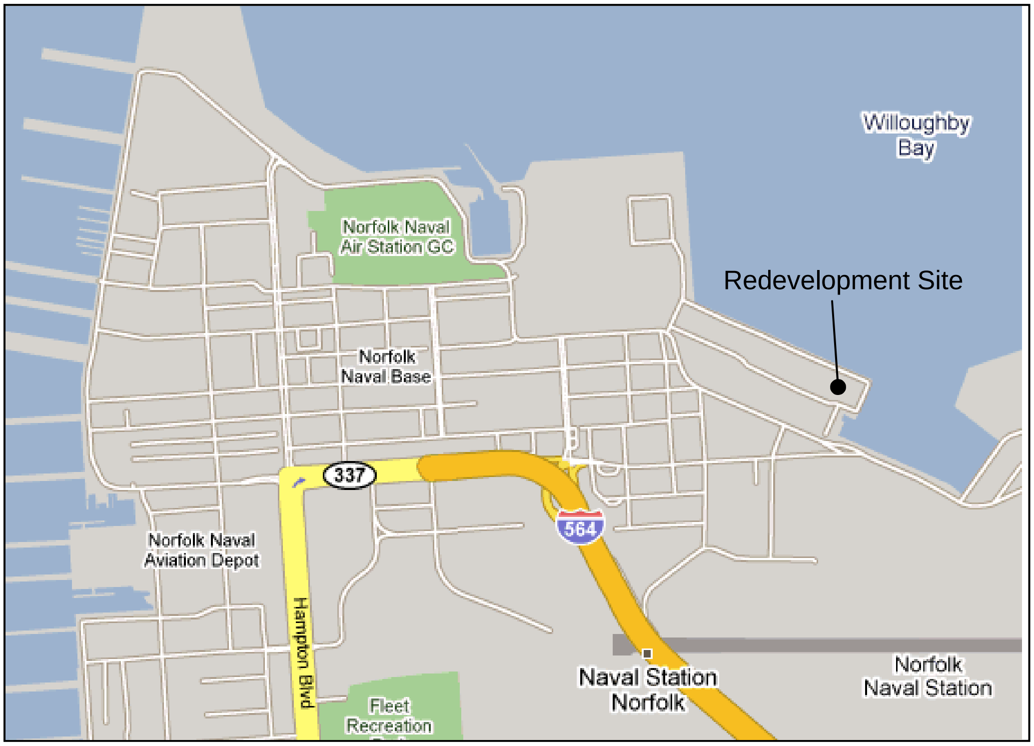

Figure 21. Location of Facility (Norfolk, VA)

Site conditions and intended uses limited the number of practices that were technically feasible to use onsite to manage runoff. For example, the use of a green roof was not feasible because the project includes the construction of an airplane hanger which lacks the structural strength to support a green roof. Cisterns were also not included in the set of suitable practices based on the analysis, which considered the number of people and amount of daily water use at the site, i.e., 40 people x 3.5 toilet flushes per day would use only 280 gallons of runoff per day or 2,000 gallons per week. Stormwater use for HVAC make-up would also be negligible based on the typical cooling system design. To put things in perspective, if the hanger rooftop covers the entire building footprint, 41,000 gallons of runoff would be generated from a 1.68 inch rainfall. Assuming a drawdown of 2,000 gallons per week based on toilet flushing, the users would only use 5% of the 95th percentile event. Because of the relatively large volume of water that would need to be collected and used, cisterns were not considered a feasible option to manage a significant volume of runoff at the site.

However, site conditions did allow for the use of both permeable pavement and bioretention practices. Approximately 0.15 acres (6,500 sf) of the proposed site is undeveloped and available for bioretention. Based on Department of Defense facility requirements, ten percent of the parking area is designed with landscaping, usually around the perimeter and in landscaped islands. If this ten percent were designed as bioretention cells, then 0.035 acres of bioretention would be achieved. If bioretention cells were also placed in about 30% of the undeveloped area of the project, then an additional 0.045 acres of bioretention could be implemented. Note: not all undeveloped land was assumed to be available for bioretention because of conflicts with site

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utilities, security and anti-terrorism requirements and slopes that limited the use of infiltration practices directly adjacent to the hanger.

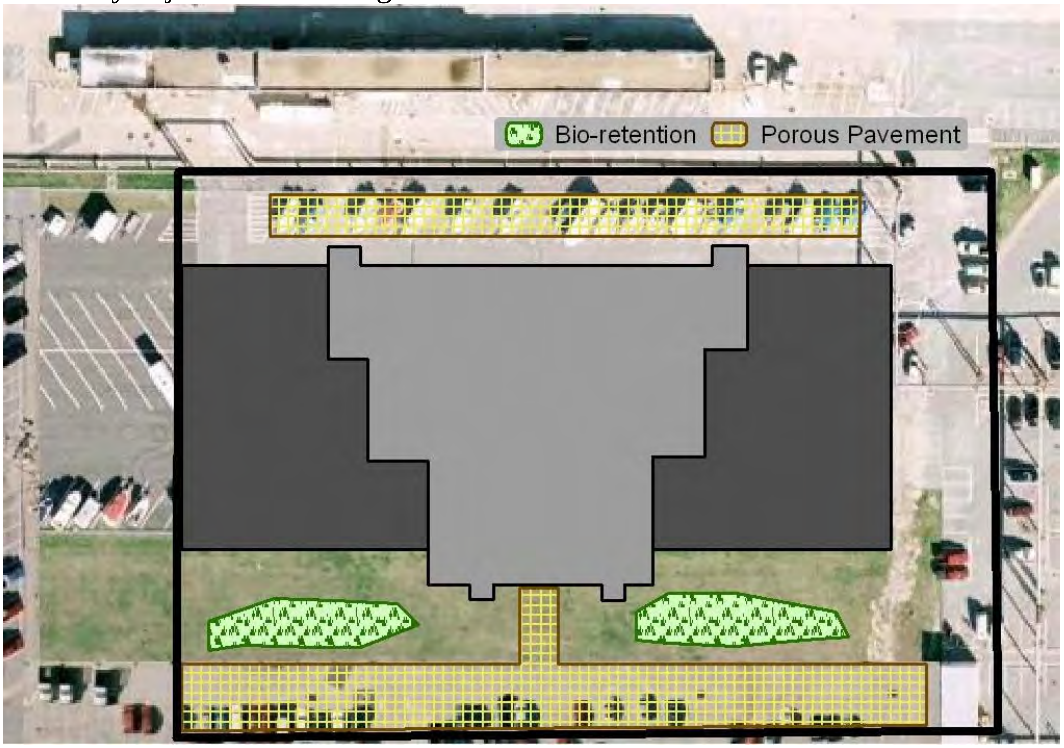

Figure 22. Actual Site and Onsite Control Measures (Norfolk, VA)

Table 17. Estimated Sizes of Onsite Control Measures for Scenario #9 (Norfolk, VA)

Total Area (acres)	1.6
Estimated Imperviousness (%)	91%
95th Percentile Rainfall Event (inches)	1.68
Expected Runoff for the 95th Percentile Rainfall Event (inches)	1.50
Stormwater Management Area Required	Hydrologic Soil Group D
Porous Pavement estimated by Direct Determination method (acres)	0.21
Bioretention estimated by Direct Determination method (acres)	0.08

The bioretention cells were designed with an effective storage depth of 10 inches, which included a depth from media surface to outlet of 10 inches. In this case study, state regulations precluded the project from taking credit for the storage potential provided by the void space within the bioretention cell media. Similarly, approximately 0.55 acres of the proposed site is impervious due to parking lots, streets, and sidewalks. Due to manufacturer's recommendations that permeable pavement materials not be used in applications subject to heavy loads and potential pollutant exposure the access roads and parking lot access isles were assumed to be constructed from conventional impervious concrete or asphalt. Thus 60% of the parking area (primarily parking stalls and sidewalks), which is about 38% of the entire paved area, is assumed to be suitable for paver blocks. A high water table at the site limited the modeled net storage depth under paver blocks placed in the parking areas and sidewalks to four inches. This storage was calculated using the assumption that the pavement sub-base of 12 inches would have a minimum void space of approximately 30%.

COMPARISON OF THE RUNOFF ESTIMATION METHODS

As illustrated in each of the case studies above, runoff of the 95th percentile storm was estimated in order to size onsite control measures. These estimates were produced by applying four different methods: the Direct Determination method, the Rational Method, the NRCS TR-55, and the EPA SWMM. The results comparing each of these methods for scenarios 1-7 are presented in Table 18.

Table 18. Comparison of the estimated runoff (unit: inches)

	Method	Direct Determination		Rational Method		TR-55		SWMM	
	Soil Groups	B	C	B	C	B	C	B	C
1	Charleston, WV	0.82	0.82	0.83	0.84	0.36	0.53	0.82	0.83
2	Denver, CO	0.53	0.53	0.57	0.59	0.12	0.26	0.53	0.53
3	Cincinnati, OH	0.68	0.68	0.73	0.76	0.26	0.46		
4	Portland, OR	0.86	0.86	0.86	0.86	0.63	0.71		
5	Phoenix, AZ	0.42	0.42	0.46	0.48	0.06	0.17		
6	Boston, MA	0.98	0.98	0.99	1.00	0.51	0.70		
7	Atlanta, GA	1.17	1.17	1.17	1.19	0.73	0.97	1.19	1.23

As shown in the above table, the estimated runoff results from direct determination, the Rational Method, and SWMM are relatively similar. Runoff volumes using TR-55 are lower than the other estimates. SWMM modeling results using NRCS 24-hour rainfall distributions were nearly identical to the results based on uniform distribution.

Table 19. Applicability of the methods for analyzing onsite control measures

Purpose	Direct Determination	Rational Method	TR-55*	SWMM
Planning Tool	Applicable	Applicable	Applicable	Applicable
Preliminary Design	Applicable	Applicable	Applicable	Applicable
Detailed Design	Not applicable	Not applicable	Not applicable	Applicable
Actual Assessment (Long-term)	Not applicable	Not applicable	Not applicable	Applicable
Water Quality	Not applicable	Not applicable	Not applicable	Applicable

*Use with caution when applying this method for small storms

CONCLUSIONS

Although sites varied in terms of climate and soil conditions, in most of the scenarios selected, the 95th percentile storm event could be managed onsite with GI/LID systems. There are other infiltration, evapotranspiration and capture and use stormwater management options available than those used in these analyses. These options provide site managers additional flexibility to choose appropriate systems and practices to manage site runoff.

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APPENDIX A: Runoff Methodology Parameter Assumptions

Runoff from each land cover was estimated by the following equation:

$$Runoff = Rainfall - Depression\ Storage - Infiltration\ Loss \quad (1)$$

Depression Storage

Reference depression storage (inches)

Reference	Impervious	Pervious
1	0.05 - 0.1	0.1 - 0.3
2	0.01 - 0.11	0.02 - 0.6
3	0.1	0.2

1. ASCE, (1992). *Design & Construction of Urban Stormwater Management Systems*. New York, NY.
2. Marsaleck, J., Jimenez-Cisreros, B., Karamouz, M., Malmquist, P-R., Goldenfum, J., and Chocat, B. (2007). *Urban Water Cycle Processes and Interactions. Urban Water Series,* UNESCO-IHP, Tyler & Francis.
3. Walesh, S. G. (1989).*Urban Surface Water Management*. John Wiley & Sons, Inc.

Based on the above reference data, depression storage (or initial abstraction, the rainfall required for the initiation of runoff) to the direct determination method was assumed as follows:

- Rooftop: 0.1 inches
- Pavement: 0.1 inches
- Pervious area: 0.2 inches

Infiltration

Infiltration loss occurs only in pervious areas. In this analysis, infiltration was estimated by Horton's equation:

$$F_t = f_{min} + (f_{max} - f_{min})\, e^{-k\,t} \quad (2)$$

where, F_t = infiltration rate at time t (in/hr),
f_{min} = minimum or saturated infiltration rate (in/hr),
f_{max} = maximum or initial infiltration rate (in/hr),
k = infiltration rate decay factor (/hr), and
t = time (hr) measured from time runoff first discharged into infiltration area

Reference infiltration parameters

Maximum infiltration rate (in.hr), f_{max}

Infiltration (in/hr)	Partially dried out with		Dry soils with	
	No vegetation	Dense vegetation	No vegetation	Dense vegetation
Sandy	2.5	5	5	10
Loam	1.5	3	3	6
Clay	0.5	1	1	2

Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Minimum infiltration rate (in/hr), f_{min}

Hydrologic Soil Group	Infiltration (in/hr)
A	0.45 - 0.30
B	0.30 - 0.15
C	0.15 - 0.05
D	0.05 - 0

A: well drained sandy; D: poorly drained clay
Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Decay coefficient, k

Soils	k (sec^{-1})	k (hr^{-1})
Sandy	0.00056	2
⇕	0.00083	3
	0.00115	4
Clay	0.00139	5

Reference: Huber, W. C. and Dickinson, R. (1988). *Storm Water Management Model User's Manual, Version 4*. EPA/600/3-88/001a (NTIS PB88-236641/AS), U.S. Environmental Protection Agency, Athens, GA.

Based on the above reference data, infiltration parameters to the direct determination method were assumed as follows:

- Hydrologic Soil Group B
  - Maximum infiltration rate: 5 in/hr
  - Minimum infiltration rate: 0.3 in/hr
  - Decay factor: 2 /hr
- Hydrologic Soil Group C
  - Maximum infiltration rate: 3 in/hr
  - Minimum infiltration rate: 0.1 in/hr
  - Decay factor: 3.5 /hr
- Hydrologic Soil Group D
  - Maximum infiltration rate: 1 in/hr
  - Minimum infiltration rate: 0.02 in/hr
  - Decay factor: 5 /hr

Infiltration loss for the 24-hr rainfall duration was estimated by the following equations with assumptions of a half hour Δt:

$$\textit{Infiltration Loss at the } n^{th} \textit{ time-step} = (f \cdot \Delta t) = \{(f_{n-1} + f_n)/2) \cdot \Delta t\} \quad (3)$$

$$\textit{Integrated Infiltration Loss for 24 hours} = \sum (f \cdot \Delta t) \quad (4)$$

RB-AR34505

Integrating infiltration loss during 24 hours with a half hour Δt

time-step	t (hr)	Infiltration rate (in/hr) [a]			Infiltration volume (inches) [b]		
		Soil B	Soil C	Soil D	Soil B	Soil C	Soil D
0	0	5	3	1	0	0	0
1	0.5	2.03	0.60	0.100	1.757	0.901	0.275
2	1	0.94	0.19	0.027	0.741	0.198	0.032
3	1.5	0.53	0.12	0.021	0.368	0.076	0.012
4	2	0.39	0.10	0.02	0.230	0.054	0.01
5	2.5	0.33	0.1	0.02	0.179	0.05	0.01
6	3	0.31	0.1	0.02	0.161	0.05	0.01
7	3.5	0.30	0.1	0.02	0.154	0.05	0.01
8	4	0.3	0.1	0.02	0.15	0.05	0.01
9	4.5	0.3	0.1	0.02	0.15	0.05	0.01
10	5	0.3	0.1	0.02	0.15	0.05	0.01
11	5.5	0.3	0.1	0.02	0.15	0.05	0.01
12	6	0.3	0.1	0.02	0.15	0.05	0.01
13	6.5	0.3	0.1	0.02	0.15	0.05	0.01
14	7	0.3	0.1	0.02	0.15	0.05	0.01
15	7.5	0.3	0.1	0.02	0.15	0.05	0.01
16	8	0.3	0.1	0.02	0.15	0.05	0.01
17	8.5	0.3	0.1	0.02	0.15	0.05	0.01
18	9	0.3	0.1	0.02	0.15	0.05	0.01
19	9.5	0.3	0.1	0.02	0.15	0.05	0.01
20	10	0.3	0.1	0.02	0.15	0.05	0.01
21	10.5	0.3	0.1	0.02	0.15	0.05	0.01
22	11	0.3	0.1	0.02	0.15	0.05	0.01
23	11.5	0.3	0.1	0.02	0.15	0.05	0.01
24	12	0.3	0.1	0.02	0.15	0.05	0.01
25	12.5	0.3	0.1	0.02	0.15	0.05	0.01
26	13	0.3	0.1	0.02	0.15	0.05	0.01
27	13.5	0.3	0.1	0.02	0.15	0.05	0.01
28	14	0.3	0.1	0.02	0.15	0.05	0.01
29	14.5	0.3	0.1	0.02	0.15	0.05	0.01
30	15	0.3	0.1	0.02	0.15	0.05	0.01
31	15.5	0.3	0.1	0.02	0.15	0.05	0.01
32	16	0.3	0.1	0.02	0.15	0.05	0.01
33	16.5	0.3	0.1	0.02	0.15	0.05	0.01
34	17	0.3	0.1	0.02	0.15	0.05	0.01
35	17.5	0.3	0.1	0.02	0.15	0.05	0.01
36	18	0.3	0.1	0.02	0.15	0.05	0.01
37	18.5	0.3	0.1	0.02	0.15	0.05	0.01
38	19	0.3	0.1	0.02	0.15	0.05	0.01
39	19.5	0.3	0.1	0.02	0.15	0.05	0.01
40	20	0.3	0.1	0.02	0.15	0.05	0.01
41	20.5	0.3	0.1	0.02	0.15	0.05	0.01
42	21	0.3	0.1	0.02	0.15	0.05	0.01
43	21.5	0.3	0.1	0.02	0.15	0.05	0.01
44	22	0.3	0.1	0.02	0.15	0.05	0.01

45	22.5	0.3	0.1	0.02	0.15	0.05	0.01
46	23	0.3	0.1	0.02	0.15	0.05	0.01
47	23.5	0.3	0.1	0.02	0.15	0.05	0.01
48	24	0.3	0.1	0.02	0.15	0.05	0.01
Sum: Infiltration loss during 24 hours [c]					9.743	3.430	0.769

[a] Calculated infiltration rate at each time by Equation (2)
[b] Calculated infiltration volume from the previous time to the current time by Equation (3)
[c] Integrated infiltration volume for 24 hours with a half hour Δt by Equation (4)

Based on the above calculation, 24-hr infiltration losses for pervious areas and bioretention areas were modeled as follows:

- Soil Group B: 9.743 inches
- Soil Group C: 4.430 inches
- Soil Group D: 0.769 inches

Infiltrations of underlying soils at paver blocks were modeled conservatively by applying the minimum infiltration rate for each soil type (Infiltration loss = $f_{min} \cdot 24$) because the soils under the paver blocks may require or be subjected to some compaction for engineering stability. The estimated infiltration losses for each soil are presented below:

- Soil Group B: (0.3 in/hr) · (24 hrs) = 7.2 inches
- Soil Group C: (0.1 in/hr) · (24 hrs) = 2.4 inches
- Soil Group D: (0.02 in/hr) · (24 hrs) = 0.48 inches

Design Storage of Management Practices

Bioretention

Reference	Ponding (inches)[1]	Mulch (inches)	Soil media (ft)	Soil Media Porosity	Underdrain
1	up to 12	2 - 4 (optional)	1 - 1.5	about 40%	bioretention systems utilize infiltration rather than an underdrain
2	6 - 12	2 - 3	2.5 - 4	about 40%	recommended, especially if initial testing infiltration rate < 0.52 in/hr
3	6 - 12		2 - 4		
4		2 - 3	1.5 - 4		if necessary
5	up to 6		1.5 - 2	30 - 40%	Optional
6	6 - 18	as needed	2 - 4		if necessary

1. State of New Jersey. (2004). *New Jersey Stormwater Best Management Practices Manual* www.nj.gov/dep/stormwater/tier_A/pdf/NJ_SWBMP_9.1 print.pdf.
2. Maryland Department of the Environment (MDE), (2000). *2000 Maryland Stormwater Design Manual, Volumes I & II*, prepared by the Center for Watershed Protection and the Maryland Department of the Environment, Water Management Administration, Baltimore, MD. www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp.

[1] Ponding is a measure of retention capacity

3. Clar, M. L. and R. Green, (1993). *Design Manual for Use of Bioretention in Storm Water Management*, prepared for the Department of Environmental Resources, Watershed Protection Branch, Prince George's County, MD, prepared by Engineering Technologies Associates, Inc. Ellicott City, MD, and Biohabitats, Inc., Towson, MD.
4. U.S. Environmental Protection Agency. (1999). *Storm Water Technology Fact Sheet: Bioretention*. EPA 832-F-99-012. Office of Water. US Environmental Protection Agency. Washington, D.C. www.epa.gov/owm/mtb/biortn.pdf.
5. Prince George's County. *Bioretention Design Specifications and Criteria*. Prince George's County, Maryland. www.co.pg.md.us/Government/AgencyIndex/DER/ESG/Bioretention/pdf/bioretention_design_manual.pdf.
6. City of Indianapolis. (2008). *Indianapolis Stormwater Design Manual*. www.sustainindy.org/assets/uploads/4_05_Bioretention.pdf.

Paver Blocks

Reference	Media (inches)	Void Space
1	12 or more	40%
2	9 or more	40%
3	12 - 36	40%

1. Univ. of California at Davis. (2008). Low Impact Development Techniques: Pervious Pavement. http://extension.ucdavis.edu/unit/center_for_water_and_land_use/pervious_pavement.asp.
2. AMEC Earth and Environmental, Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and Atlanta Regional Commission. (2001). Georgia Stormwater Management Manual Volume 2: Technical Handbook www.georgiastormwater.com/.
3. Subsurface Infiltration Bed. www.tredyffrin.org/pdf/publicworks/CH2 - BMP4 Infiltration Bed.pdf.

Green Roofs

Reference	Media (inches)
1	3 - 4
2	1 - 6
3	2 - 6

1. Charlie Miller. (2008). Extensive Green Roofs. Whole Building Design Guide (WBDG). www.wbdg.org/resources/greenroofs.php.
2. Great Lakes WATER Institute. Green Roof Project: Green Roof Installation. www.glwi.uwm.edu/research/genomics/ecoli/greenroof/roofinstall.php.
3. Paladino & Company. (2004). Green Roof Feasibility Review. King County Office Project. http://your.kingcounty.gov/solidwaste/greenbuilding/documents/KCGreenRoofStudy_Final.pdf.

Based on the above reference data, design storages to the direct determination method were assumed as follows:

- Bioretention: up to 10 inches (depending on practice used, site conditions, etc.)
- Green roof: 1 inch (2.5 inches deep media with 40% void space)
- Porous pavement: 4 inches (10 inches deep media with 40% void space)

Factors that influence total storage available include, ponding depth, available media void space, and supplemental storage if the system is designed with gravel or open pipes underneath the media.

RB-AR34508

GREEN ROOF PROJECT

Prepared By:
Adam Garcia, Joe Marci, Dave Norman, Matthew Parrent,
Michael Pasternak, Maria Quezada, Melissa Reggiardo

Sponsors:
Sustainable Urban Network,
UCLA Campus Programs Committee, HydrotechUSA

Executive Summary

The Green Roof Project was born from a motivation to transform an under utilized space into a community asset. The space in question is the 3rd floor terrace on the southwest corner of the Public Affairs Building (PAB) at UCLA.

School of Public Affairs, UCLA

The idea developed as a project from the Sustainable Urban Network (SUN) in Spring 2007 and brought together graduates from the departments of Public Health, Architecture, Engineering, Anderson, Law as well as faculty, staff, administrators, and community members around a dialogue of environmental preservation and promotion, social enhancement, and passive building design. This report briefly traces the process of the student-led effort to develop a green roof on the PAB, includes a community-generated proposal for a roof garden on the 3rd floor terrace, as well as posters on environmental design and green campus initiatives at UCLA.

Initial project efforts began by approaching Facilities Management with a proposal to install an extensive green roof on the Public Affairs Building as a design strategy to capture rainwater, increase the insulation of the computer lab and provide a more habitable space for the many passing students and other local species. In addition, students proposed such an installation could contribute to the concurrent green building and energy efficiency renovation. However, the University is adopting a more cost-effective method for improving building efficiency by installing white roofs which reflect a great amount of light and heat away from the structure, thereby minimizing the energy demand of heating and cooling the building. A white roof, in fact was installed on the PAB a few years prior and Facilities Management was not interested in doubling their costs for an additional installation.

Despite this, SUN acquired the building plans and passed them off to Professor Sobal in Civil and Environmental Engineering to determine if the PAB's roof could support the additional load of an extensive roof. He informed SUN that there were in fact two separate buildings, a much older structurally weaker building on the southeast side, and a stronger more reinforced building on the southwest built as a library whose roof currently functions as the 3rd floor terrace.

With this knowledge, the student effort modified its campaign to develop a roof garden on the terrace of the PAB. This shift came at an opportune time and was integrated into the LEED class as a project to develop a proposal for the roof garden. The group took a field trip to Pasadena's Art Center College of Design to observe an extensive green roof renovation, held a design charrette to develop ideas for a PAB roof garden proposal, and opened the 3rd floor terrace to the campus for a celebration of green building and environmental stewardship. The result of the project's effort manifested as a green demonstration area on the PAB terrace showcasing green roof planter boxes with California native plants and posters exemplifying environmental design, vision and leadership at UCLA.

The Process: Green Roof Demonstration Area

RB-AR34509

Field Trip to Pasadena

A field trip to the Art Center College of Design in Pasadena provided students with inspiration and insight into the possibilities for a Green Roof on the School of Public Affairs

The Design Charrette

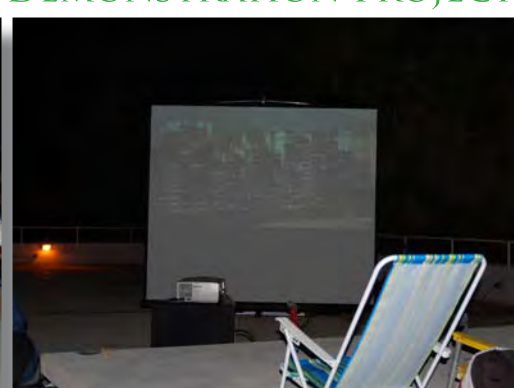
The Design Charrette attracted students and professionals to collaborate on creating a vision for a the Green Roof. The ideas were then incorporated into the final design proposal.

Constructing the Green Roof Demonstration Project

The Green Roof Demonstration project was assembled and planted with California native and drought tolerant species. Educational posters accompany the planters to affect change on campus.

Unveiling the Demonstration Project

UCLA students and faculty gathered on the Public Affairs Building Patio to learn about the Green Roof Demonstration Project and UCLA Green initiatives. The event included a screening of the film Baraka.



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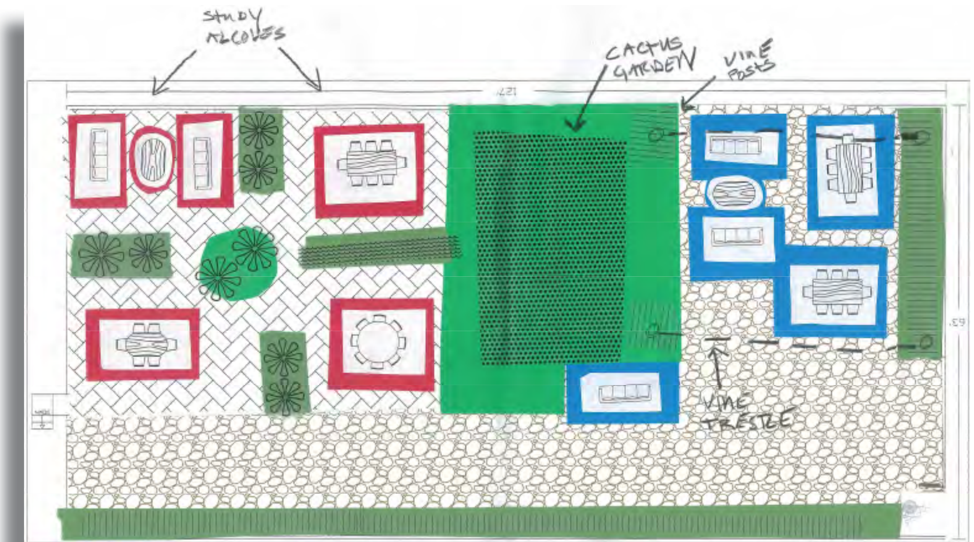
Design Charrette: Roof Garden Proposals

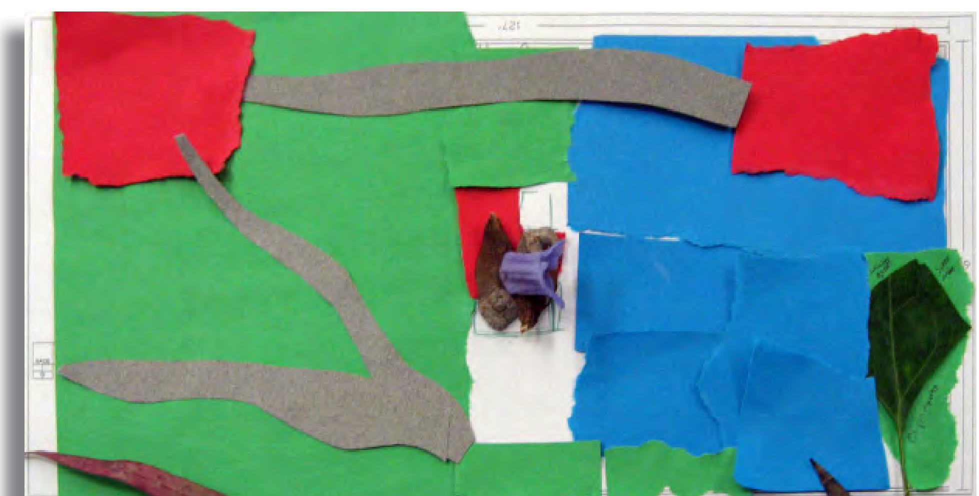
Public Affiars Building - 3rd Floor Terrace

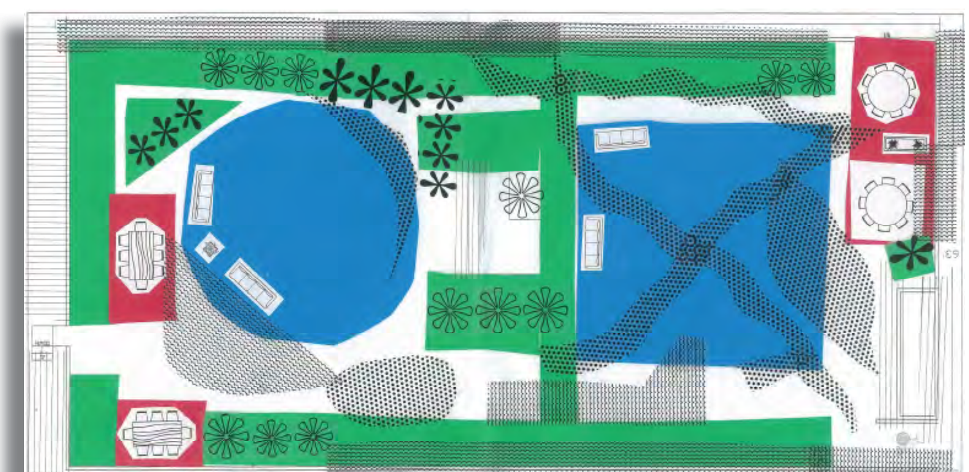
Green Roof Habitat

Quiet Study Space

Social Gathering Area







RB-AR34511

ENVIRONMENTAL DESIGN

SMART BUILDING :: CAMPUS VISION :: RECLAIMING SPACE :: GREENROOFS

PASSIVE SOLAR

Passive solar design refers to the use of the sun's energy for the heating, cooling and day-lighting of living spaces

- Building face to the equator
- Extending the building along the east/west axis
- Use windows to face the midday sun in the winter and be shaded in the summer, minimizing western windows *(trees, shrubs...)*
- Erecting appropriate overhangs, or shading elements
- Using insulation *(green roof)* to minimize seasonal excessive heat gain or loss
- Using thermal mass to store excess solar energy during winter

ZERO ENERGY

Visionary office rehab demonstrates that the technology and know-how exist for buildings to produce zero carbon dioxide

1 Private office
2 Open office
3 Sunshade w/ building integrated photovoltaics
4 Roof w/ building integrated photovoltaics
5 Skylight
6 Energy efficient and occupancy sensor controlled light fixtures
7 Electrochromic glass
8 Radiant heat floor
9 Natural ventilation
10 High performance glass
11 Reduction of outdoor light pollution
12 Water efficient landscaping
13 Ground source heat pump

Integrated Design Associates, San Jose, CA

PROJECT SPONSORS

UCLA Campus Programs Committee

School of Public Affairs

SUN

Hydrotech

CAMPUS VISION

Source: Microsoft Virtual Earth

RECLAIMING SPACE

Imagine a rooftop that is visible because it demands your attention

Greenroofs are more than a function of environmentally sensitive design and practice; they are an opportunity to activate the forgotten spaces of our cities. Rooftops offer the finest scenic outlooks over campus, but often access is denied. Consequently, our roofs gather more particulate matter than people. It is policy, not placement or function, which renders our rooftop spaces invisible.

Imagine a rooftop space that:

- Replaces green areas consumed by building footprints
- Fills spatial voids with the lively buzz of people
- Services the needs of buildings, environment, and people
- Provide open access to views
- Inspires creativity and harmony with its surroundings

GREENROOF TYPES

A green roof is a green space created by adding layers of growing medium and plants on top of a traditional roofing system.

Source: American Hydrotech

EXTENSIVE

- low weight
- low capital cost
- low plant diversity
- minimal maintenance requirements

Canary Wharf, London

Atlanta City Hall

INTENSIVE

- deeper soil and greater weight
- higher capital costs
- increased plant diversity
- more maintenance requirements

Source: American Hydrotech

RB-AR34512

GREEN CAMPUS INITIATIVES

ENERGY CONSERVATION :: LEED BUILDING :: RECYCLING PROGRAMS :: BUILDING REHABILITATION

Energy Conservation

Source: UCLA

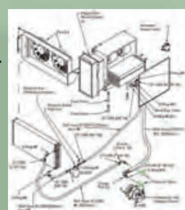
Combined Heat and Power

- UCLA operates its own power plant using a blend of natural and landfill gas while also capturing and distributing excess heat to the campus
  - A 20,900-ton chilled water and 44 MW cogeneration facility
  - Overall campus emissions reduced by 34% after construction in 1993
  - Saved LA basin from 36 tons of smog-forming pollutants each year
  - Over 20,000 lbs of CFC refrigerants have been eliminated by discontinuing use of 18 building-mounted chillers

Source: International District Energy Assocation

HVAC Modernization

- UCLA will be converting its HVAC systems in 25 buildings to the latest technology in air distribution systems and control equipement.
  - Saving 17,000 tons of CO_2 per year
  - Reducing 1/2 the HVAC energy demand
- Because HVAC systems account for half a building's total energy use, the project will reduce energy use in each building by 25%.
  - Project cost $16 Million
  - $4.2 Million in annual savings



Source: Mobile Climate Control

Building Rehabilitation

Source: UCLA

Focus on Existing Building

- Buildings account for 35% of North America's CO_2 emissions
- Upgrading an older building is often preferable to building a new 'green' one because it saves resources and energy
- The Public Affairs Building will be the first at UCLA to go through LEED's Existing Building certifiction, aiming to maximize its operational efficiency while minimizing its environmental impacts:
  - Water and electricity conservation
  - Increase recycling capacity
  - Using green cleaning practices
  - Reduce the building's heat island effect

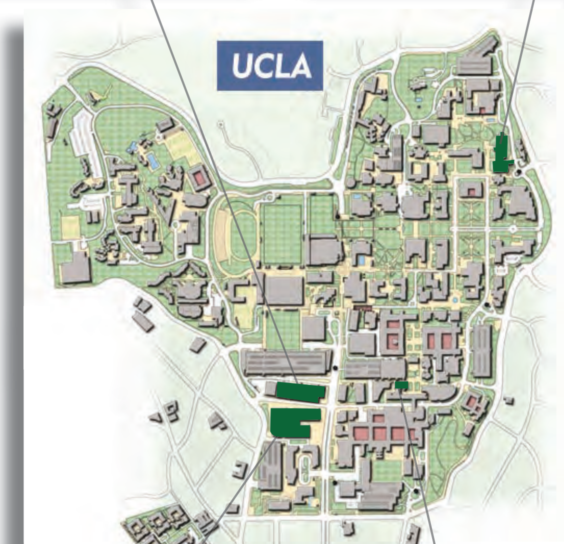
Building Controls Upgrade

- A multi-year program to replace the University's Central Control System with digital building management control, offering precise HVAC regulation and improved occupant comfort

Lighting Retrofit Program & Advanced Sensors

- Over the past six years, UCLA has upgraded its lighting system to use energy efficient fixtures in its buildings
  - Retrofit reduced energy consumption by 7.5 kilowatt-hours
- Twenty-five buildings on campus will be installed with advanced lighting technology, including:
  - Occupancy and smart sensors
  - Daylighting controls
  - Bi-level stairwell lights

Source: smarthome.com



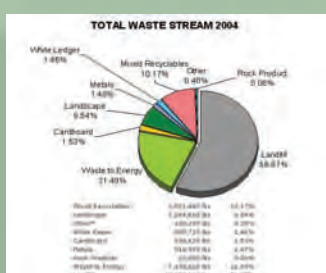
Source: UCLA

Recycling

Source: UCLA Facilities Management

Water Recycling

- Cooling towers on cogeneration plant decreased Bruin water consumption 60% by reusing campus grey water
- These sources include air conditioning systems, vacuum pumps, laboratory experiments and other non-contaminated sources
- Expanded grey water reuse program through the Ronald Reagan Hospital saves the campus $200,000 annually



Source: UCLA Facilities Management

Waste Recycling

- Since 1990, UCLA's Recycling Program has recycled 8.6 million pounds of waste annually - over 23% of the campus waste stream

Source: youarehere.com

Source: UCLA Facilities Management

- Recyclables include:
  - White paper
  - Mixed paper
  - Cardboard
  - Newspaper
  - Green waste
  - Rock product

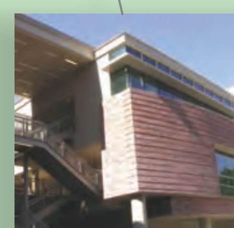
LEED Building

Source: UCLA Spotlight

LEED Certification

Leadership in Energy & Environmental Design

- LEED is a third-party green building rating system designed by the US Green Building Council. It certifies new construction projects, homes, existing buildings, and will soon have a program for green neighborhood dvelopment
- In 2003, UC students across the state demanded the Regents to enact policy requiring all new buildings and retrofits meet the US Green Building Council's LEED certified level
- Since then, La Kretz Hall received a New Construction LEED rating of Silver and several new buildings are expected to receive certification
- La Kretz earned LEED points for:
  - Built on existing storage tank
  - Renewable and low-emitting materials
  - Operable windows
  - Displacement air system
  - Photovoltaic panels



Source: UCLA Spotlight

Thermal Energy Storage Tank at La Kretz

- Installed 5,000,000 gallon Thermal Energy Storage (TES) system for air conditioning the campus
- Stores excess chilled water at night when energy prices are low, then distributes chilled air during the day when energy prices are high
- New air conditioning system near Boelter Hall enhances TES system and does not use CFCs
- System operational since July 2006 and provides $600,000 in annual savings

ROOF GARDEN PROPOSAL

IDEAS :: EXCHANGE :: DISCUSSION :: RESULTS

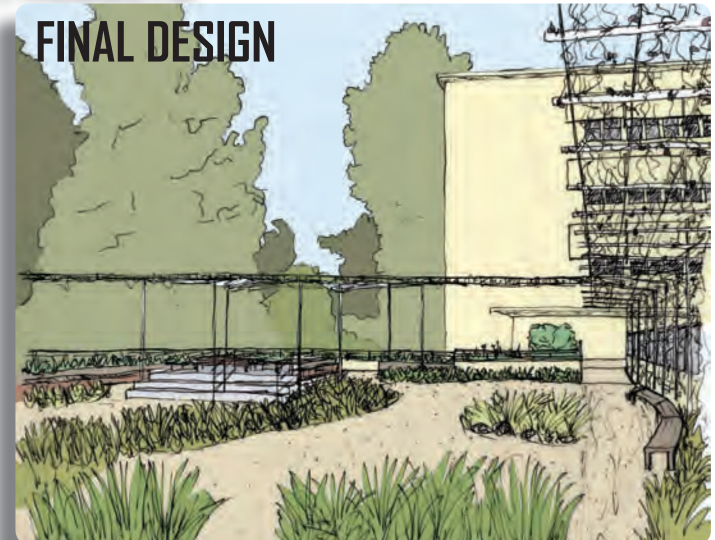
PROCESS

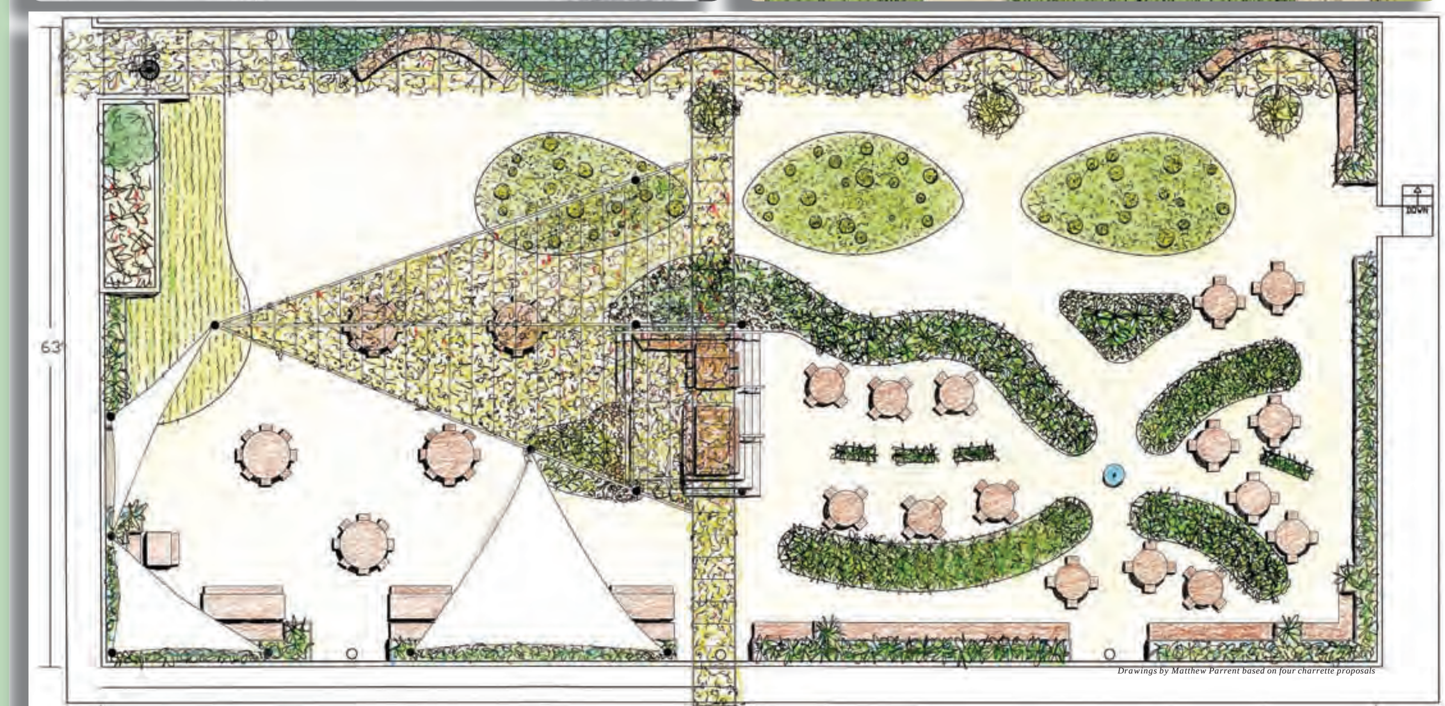
On May 13th a design charrette was held to gather public input on what type of green roof should be created on the third floor of the School of Public Affairs Building. The workshop started with a slideshow presentation outlining the various kinds of green roofs and the environmental benefits each provides. Participants were then taken on tour of the roof as way to see how it is currently being used and given a sense of the parameters of the project. Following this the group was divided into teams and given an assortment of supplies to come up with their ideal vision of the green roof they would most like see on the third floor. After conversing and exchanging opinions on how best the roof could be utilized the groups came up with design proposals that focused on an array aspects.

OUTCOME

Each group produced a schematic map of the third floor patio illustrating the green roof setup they believe would be best suited for the project area. While each green roof proposal was unique it bacame evident that there were several similarities betweeen the groups. The following lists the common threads and ideas each group produced:

- A vast increase in the amount of tables and chairs located on the roof
- The desire to have much larger shaded portions
- The planting of native flora on both extensive and intensive green roof types
- A clear delineation between a study area and a recreational or gathering section
- Using the HVAC portion of the roof as a raised garden or planter bed





Next Steps to Implementation

1) Work with the UCLA Facilities Mangement, campus architect and a structural engineer to make a final determinitation about weight load the roof can support.

Campus Architect
Jeffrey Averill (310-825-9677 , javerill@capnet.ucla.edu)

Structural Engineer
Prof. Thomas A. Sabol, Ph.D. (310-825-2843, TSabol@ucla.edu)

2) Work with green roofing contractor(s) to finalize design and begin addressing issues of weight load capacity, irrigation/drainage, appropriate plant types and estimated cost.

Hydrotech USA (extensive and intensive green roof)
Charles Cronenweth (310-577-6125, ccronenweth@hydrotechusa.com)

FloraSource (modular green roof - LiveRoof distributor)
Tom Hawkins (949-498-1131)

Eberhard Roofing (LA green roof contractor)
Rick Boyce (818-373-7584)

3) Initiate fundraising campaign to gather necessary monies for green roof development through School of Public Affairs alumni, UCLA grants and/or loans, local Bel-Air movie stars, as well as potential City, State & Federal grants.

UCLA Capital Programs - Planning & Finance
Tovah Lelah (310-206-5482, tlelah@capnet.ucla.edu)

4) Implement roof garden design and construction through participation of Facilities Managment, School of Public Affairs, students, faculty and staff

RB-AR34515

GREEN ROOF

CHARRETTE

JOIN US TO ENVISION A DESIGN FOR

A NEW SUSTAINABLE ROOF PATIO

FOR THE SCHOOL OF PUBLIC AFFAIRS

Date: Tuesday, May 13th

Time: 8:00pm

Location: PAB Room 4320A

To RSVP or for more information contact: sunetwork@ucla.edu

Brought to you by: Sustainable Urban Network & Campus Programs Committee

Sustainable Urban Network

SUN

RB-AR34516


COOL ROOF
3RD FLOOR
SCHOOL OF PUBLIC AFFAIRS UCLA
FREE look inside!
greenroof demostration project
screening of baraka, a film by ron fricke
free food + drinks
PATIO PARTY
2008 MAY 27TH 8 PM
brought to you by:
SUN Sustainable Urban Network
Campus Programs Commitee
ASUCLA GSA
SUN
Funded by UCLA gsa GRADUATE STUDENTS ASSOCIATION

RB-AR34517

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION IX
75 Hawthorne Street
San Francisco, CA 94105-3901

APR 10 2008

Ms. Tam M. Doduc, Chair
Ms. Dorothy R. Rice, Executive Director
State Water Resources Control Board
1001 I Street
Sacramento, CA 95814

Dear Ms. Doduc and Ms. Rice:

I understand that certain specific provisions of the 2001 Municipal Separate Storm Sewer System ("MS4") permit for the County of Los Angeles have been called into question as going beyond what is required under section 402(p) of the CWA. (Commission on State Mandates, File Nos. 03-TC-04, 03-TC-19, 03-TC-20, and 03-TC-21.) The permit conditions at issue are: 1) the requirements for conducting inspections at industrial and commercial facilities including, restaurants and automobile servicing, [Parts 4.C.2.a. and b.] and, 2) the requirement for permittees not subject to the Trash TMDL to locate and maintain trash receptacles at transit stops [Part 4.F.5.c.3.]. California RWQCB, Los Angeles Region, Order No. 01-182, NPDES No. CAS004001 (Dec. 13, 2001). This letter discusses these permit conditions in the context of EPA's expectations for MS4 permits.

Section 402(p) of the Clean Water Act, 33 U.S.C. 1342(p), requires EPA (or authorized states) to issue National Pollutant Discharge Elimination System ("NPDES") permits to regulate the discharge of stormwater from MS4s. Typically, these MS4s are owned and operated by cities and counties. Pursuant to the Clean Water Act, these permits must require the MS4 to: 1) "effectively prohibit" non-stormwater discharges, and 2)"reduce the discharge of pollutants to the maximum extent practicable, including management practices, control techniques and system, design and engineering methods, and such other provisions as the Administrator or the State determines appropriate for the control of such pollutants." 33 U.S.C. 1342(p)(3)(B)(ii) and (iii).

The NPDES regulations require medium and large MS4s to develop stormwater management programs that the permitting authority will consider when developing permit conditions to reduce pollutants in discharges to the maximum extent practicable. Stormwater permitting has generally relied on the use of best management practices ("BMPs"), including both structural and non-structural controls, for achieving compliance with these requirements. The EPA also expects stormwater permits to follow an iterative process whereby each successive permit becomes more refined, detailed, and expanded as needed, based on experience under the previous permit. See, 55 Fed. Reg. 47990, 48052 ("EPA anticipates that storm water management programs will evolve and mature over time."); 64 Fed. Reg. 68722, 68754 (Dec. 8, 1999) ("EPA envisions application of the MEP standard as an iterative process."); Interim Permitting Approach for Water Quality-Based Effluent Limitations in Stormwater Permits (Sept. 1, 1996) ("The interim permitting approach uses BMPs in first-round storm water permits, and expanded or better-tailored BMPs in subsequent permits, where necessary, to provide for the attainment of water quality standards"). See also, "Evaluating the Effectiveness of Municipal Stormwater Programs" (January 2008) (http://www.epa.gov/npdes/pubs/region3_factsheet_swmp.pdf). While the standard of "maximum extent practicable" (MEP) allows for flexibility, that flexibility is not boundless and requires some level of vigor. EPA has created a national menu of stormwater BMPs to provide additional guidance concerning appropriate BMPs for stormwater management plans. Other factors to consider in ensuring appropriate controls include "technical feasibility, cost, public acceptance, regulatory compliance, and effectiveness." Building Indus. Ass'n v. State Water Res. Control Bd., 124 Cal. App. 4th 866, 889 (2004). See also "In re Cities of Bellflower, et al.", SWRCB 2000-11.

At the outset, I note the Los Angeles MS4 permit is a third generation Phase I MS4 permit that should be building upon the experiences from previous permits. Both of the provisions at issue here seem well within a reasonable expectation of controls that reduce pollutants to the "maximum extent practicable." EPA regulations at 40 C.F.R. §122.26(d)(2)(iv) set forth the basic elements to be included in a Phase I MS4's stormwater management program. Subparagraph (A) requires a description of "source control measures to reduce pollutants from runoff from commercial and residential areas that are discharged from the [MS4] that are to be implemented during the life of the permit." Subparagraph (B) requires a program for detection and removal of illicit discharges and improper disposal into the storm sewer, including a program for inspections and enforcement. A program for commercial and industrial facility inspection and enforcement that includes restaurants and automobile facilities, would appear to be both practicable and effective. Such an inspection program ensures that stormwater discharges from such facilities are reducing their contribution of pollutants and that there are no non-stormwater discharges or illicit connections. Thus these programs are founded in both 402(p)(3)(B)(ii) and (iii) and are well within the scope of 40 C.F.R. §122.26(d)(2)(iv)(A) and (B).[1]

Similarly, maintaining trash receptacles at all public transit stops is well within the scope of these regulations. Among the minimum controls required to reduce pollutants from runoff from commercial and residential areas are practices for "operating and maintaining public streets, roads, and highways . . . ." §122.26(d)(2)(iv)(A)(3). I believe these requirements are also practical and effective.[2] Moreover, this permit provision is consistent with EPA's national menu

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[1]EPA's "MS4 Program Evaluation Guidance" (January 2007) envisions that an MS4 permit would include a requirement for an inspection program for common industrial/commercial businesses, such as restaurants and gas stations, within the jurisdiction of the MS4. Id. at 76 - 77, 81. The inspection requirements of the LA MS4 permit are consistent with the recommended activities in the Guide.

[2]The provision applicable to the TMDL permittees is also clearly consistent with EPA's 2002 guidance on TMDLs and storm water permitting. "Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit

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of BMPs for stormwater management programs, which recommends a number of BMPs to reduce trash discharges. See http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=5. Among the recommendations is "improved infrastructure" for trash management when necessary, which includes the placement of trash receptacles at appropriate locations based on expected need. The requirements of the Los Angeles County MS4 permit are consistent with this recommendation. See also, "MS4 Program Evaluation Guidance" (January 2007) at pp. 50, 79. EPA's expectations of the programs to reduce pollutants to the maximum extent practicable specifically refer to control of litter and trash, regardless of whether the particular receiving water is already impaired for trash.

I hope that this explanation helps clarify EPA's expectations for MS4 permit requirements under the Clean Water Act. I look forward to continuing to work with the State on our shared goal of ensuring consistency and effectiveness in storm water permitting as a vital tool in protecting the quality of our waters. Should you have further questions about these issues, please have your staff contact Douglas Eberhardt of my staff at (415) 972-3420 or have your counsel's office contact Laurie Kermish of the Office of Regional Counsel at (415) 972-3917.

Sincerely,

Alexis Strauss 10 April 2008
Alexis Strauss
Director, Water Division

cc: Mr. Michael Lauffer, Chief Counsel
State Water Resources Control Board

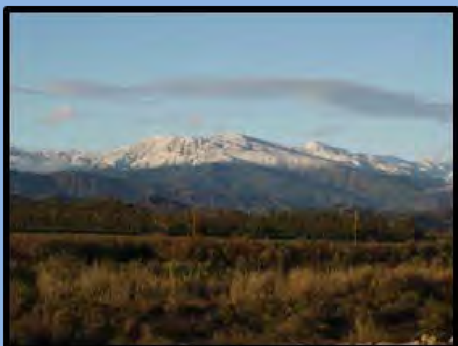
Ms. Paula Higashi, Executive Director
Commission on State Mandates

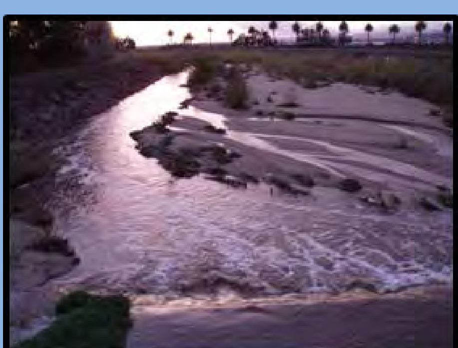
Requirements Based on Those WLAs" (November 22, 2002) which is available at: http://cfpub.epa.gov/npdes/pubs.cfm?program_id=6

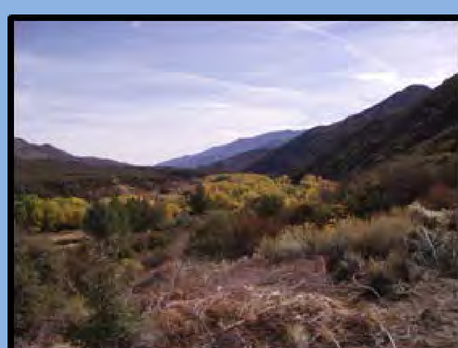
RB-AR34520

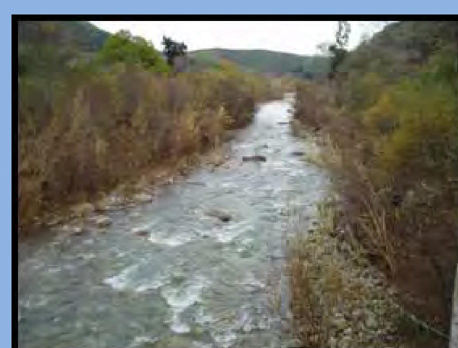
Ventura County Technical Guidance Manual for Stormwater Quality Control Measures

Manual Update 2011









Ventura Countywide Stormwater Quality Management Program

Geosyntec consultants

LARRY WALKER ASSOCIATES

Prepared by

Larry Walker Associates
707 Fourth Street, Suite 200
Davis, CA 95616

Geosyntec Consultants
1111 Broadway, 6th Floor
Oakland, CA 94607

July 13, 2011

Manual Updates: The 2011 TGM may be periodically updated to correct minor errors and unintentional omissions. Additionally, due to the evolving nature of stormwater quality management, the 2011 TGM may also be updated to incorporate new and innovative control measures. 2011 TGM users should ensure that they are referencing the most current edition by checking www.vcstormwater.org or contacting the local permitting agency.

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APPENDICES

1 INTRODUCTION

This *Technical Guidance Manual for Stormwater Quality Measures* (2011 TGM) provides guidance for the implementation of stormwater management control measures in new development and redevelopment projects in the County of Ventura and the incorporated cities therein. These guidelines are intended to improve water quality and mitigate potential water quality impacts. These guidelines have been developed to meet the Planning and Land Development requirements contained in Part 4, Section E of the Los Angeles Regional Water Quality Control Board's (Regional Board) municipal separate storm sewer system (MS4) permit (Order R4-2010-0108) for new development and redevelopment projects.

The Planning and Land Development requirements are not implemented at the discretion of the local permitting agency; they are requirements in Order R4-2010-0108 that must be complied with. The 2011 TGM does not attempt to expand or circumvent these requirements, but rather it provides guidance on how to meet them.

When used in this Manual, the verb "shall" indicates a statement of required, mandatory, or specifically prohibited practice. Statements that are not mandatory, but are recommended practice in typical situations, with allowable deviations if engineering judgment or scientific study indicates them appropriate, are typically stated with the verb "should." In both cases specific options may be provided that are allowable modifications.

1.1 Goals

The 2011 TGM has been prepared by the Ventura Countywide Stormwater Quality Management Program to accomplish the following goals:

- Ensure that new development and redevelopment projects reduce urban runoff pollution to the "maximum extent practicable" (MEP);
- Ensure that the implementation of measures in the 2011 TGM are consistent with Regional Water Quality Control Board Order R4-2010-0108 and other state requirements;
- Provide guidance to developers, design engineers, agency engineers, and planners on the selection and implementation of appropriate stormwater management control measures; and
- Provide maintenance procedures to ensure that the selected stormwater management control measures will be properly maintained to provide effective, long-term pollution control.

1.2 Regulatory Background

In 1972, the Federal Water Pollution Control Act [later referred to as the Clean Water Act (CWA)] was amended to require National Pollutant Discharge Elimination System (NPDES) permits for the discharge of pollutants to waters of the United States from any point source. In 1987, the CWA was amended to require the United States Environmental Protection Agency (USEPA) to establish regulations permitting municipal and industrial stormwater discharges under the NPDES permit program. The USEPA published final regulations regarding stormwater discharges on November 16, 1990. The regulations require that MS4 discharges to surface waters be regulated by a NPDES permit.

The Ventura County Watershed Protection District, County of Ventura, and the cities of Camarillo, Fillmore, Moorpark, Ojai, Oxnard, Port Hueneme, San Buenaventura, Santa Paula, Simi Valley, and Thousand Oaks have joined together to form the Ventura Countywide Stormwater Quality Management Program (Program)and are named as co-permittees under a revised countywide municipal NPDES permit for stormwater discharges issued by the Regional Water Quality Control Board in 2010 (Order R4-2010-0108).

Prior to the issuance of Order R4-2010-0108, stormwater discharges from the Ventura County MS4 were covered under the countywide waste discharge requirements contained in three previous MS4 NPDES Permits (Order 09-0057, Order 00-108, and Order No. 94-082).

Under Order R4-2010-0108, the co-permittees are required to administer, implement, and enforce a Stormwater Quality Management Program (Program) to reduce pollutants in urban runoff to the MEP. The Program emphasizes all aspects of pollution control including, but not limited to, public awareness and participation, source control, regulatory restrictions, water quality monitoring, and treatment control.

For the Program to be successful, it is critical to control urban runoff pollution from new development and redevelopment projects during and after construction. Therefore, the co-permittees implemented the Planning and Land Development Program, one element within the Program, to specifically control post-construction urban runoff pollutants from new development and redevelopment projects. The goal of the Planning and Land Development Program is to minimize runoff pollution typically caused by land development and protect the beneficial uses of receiving waters by limiting effective impervious area (EIA) to no more than 5% of the project area and retaining stormwater on site. This goal can be achieved by employing a sensible combination of Site Design Principles and Techniques, Source Control Measures, Retention Best Management Practices (BMPs), Biofiltration BMPs, and Treatment Control Measures to the level required in Order R4-2010-0108.

“Site Design Principles and Techniques,” “Source Control Measures,” “Retention

BMPs," "Biofiltration BMPs," and "Treatment Control Measures," as used in the 2011 TGM refer to BMPs and features incorporated into the design of a new development or redevelopment project, which prevent and/or reduce pollutants in stormwater runoff from the project. These measures are described below:

1) ***Site Design Principles and Techniques*** are a stormwater management strategy that emphasizes conservation and use of existing site features to reduce the amount of runoff and pollutant loading that is generated from a project site.

2) ***Source Control Measures*** limit the exposure of materials and activities so that potential sources of pollutants are prevented from making contact with stormwater runoff.

3) ***Retention BMPs*** are stormwater BMPs that are designed to retain water onsite, and achieve a g reater reduction in surface runoff from a project site than traditional stormwater Treatment Control Measures. The term "Retention BMPs" encompasses infiltration, rainwater harvesting[1], and evapotranspiration BMPs. Retention BMPs are preferred and shall be selected over biofiltration BMPs and Treatment Control Measures where technically feasible to do so.

4) ***Biofiltration BMPs*** are vegetated stormwater BMPs that remove pollutants by filtering stormwater through vegetation and soils.

5) ***Treatment Control Measures*** are engineered BMPs that provide a reduction of pollutant loads and concentrations in stormwater runoff.

Applicable projects (Section 1.4) must reduce Effective Impervious Area (EIA) to less than or equal to five percent (≤5%) of the total project area, unless infeasible. Impervious surfaces are rendered "ineffective" if the design storm volume is fully retained onsite using Retention BMPs. Biofiltration BMPs may be used to achieve the 5% EIA standard if Retention BMPs are technically infeasible (see Section 3.2).

The 2011 TGM contains guidance for the design and implementation of all of these types of stormwater management control measures for new development and redevelopment projects. In addition to the requirements of Order R4-2010-0108, owners and developers of some of the sites in the County may also be subject to the State of California's general permit for stormwater discharge from industrial activities (Industrial General Permit) and general permit for stormwater discharge from construction activities (Construction General Permit). The stormwater management control measures provided in the 2011 TGM may also assist the owner or developer in meeting the requirements of the State's construction and industrial permits. The stormwater management staffs of the governing co-permittee agencies are available to provide assistance regarding all of the State stormwater permit

[1] Rainwater harvesting is a BMP that stores and uses rainwater or stormwater runoff. This is consistent with the use of the term "reuse" contained in Order R4-2010-0108.

requirements.

1.3 Impacts of Land Development

The Cities and County of Ventura have separate stormwater and sanitary sewer conveyance systems. Land development typically creates an increase in impervious surfaces, which increases the amount of runoff and pollutants entering stormwater conveyance systems. Pollutants that enter the conveyance system in stormwater are typically transported directly to receiving waters (i.e. local channels, rivers, and the ocean), and are not treated in a wastewater treatment plant. Pollutants in untreated stormwater runoff from impervious surfaces that drains to streets and enters storm drains directly contribute to water pollution.

Typically, as stormwater runs over impervious surfaces (e.g., rooftops, roadways, and parking lots), it:

- Does not infiltrate or evapotranspire, which increases runoff volumes, velocities, and flow rates;
- Moves more quickly, which increases runoff velocities; and
- Entrains (i.e., accumulates) pollution and sediment, which increases nutrients, bacteria, and other pollutant concentrations in receiving waters (i.e., local channels, rivers, and the ocean).

The impacts of these alterations due to development may include:

- Increased concentrations of nutrients, toxic pollutants, and bacteria in surface receiving waters, including adjacent land and habitat (e.g., beaches) creeks, estuaries, and storm drain outlets.
- Increased flooding due to higher peak flow rates and runoff volumes produced by a storm.
- Decreased wet season groundwater recharge due to a decreased infiltration area.
- Increased dry season groundwater recharge due to outdoor irrigation with potable or reclaimed water.
- Introduction of baseflows in ephemeral streams due to surface discharge of dry weather urban runoff.
- Increased stream and channel bank instability and erosion due to increased runoff volumes, flow durations, and higher stream velocities ("hydromodification impacts"); and

- Increased stream temperature due to loss of riparian vegetation as well as runoff warmed by impervious surfaces, which decreases dissolved oxygen levels and makes streams inhospitable to some aquatic life requiring cooler temperatures for survival.

1.4 Stormwater Management Principles

Stormwater management principles such as Integrated Water Resource Management (IWRM) and Low Impact Development (LID) can be used to help mitigate the impacts of development. These principles are described below.

The emergence of LID falls under the umbrella of the over-arching concept of IWRM. IWRM is a process which promotes the coordinated development and management of water, land, and related resources. IWRM links traditional development topics such as land use, water supply, wastewater treatment/reclamation, flood control/drainage, water quality, and hydromodification management into a cohesive hydrologic system that recognizes their interdependencies and minimizes their potentially negative effects on the environment. An example of IWRM includes recharging groundwater with reclaimed wastewater to support the water supply. Another example is combining stormwater treatment, hydromodification control, and flood control in a single regional infiltration basin that recharges groundwater, incorporates recreation, and provides habitat. Another example is using Smart Growth principles to help reduce the environmental footprint while still accommodating growth.

Generally, the 2011 TGM advises to first design for the largest hydrologic controls (such as matching post development 100-year flows with pre-project 100-year flows for flood mitigation requirements), according to the appropriate City or County drainage requirements (not included in the 2011 TGM). Secondly, the 2011 TGM advises to check if flood mitigation will reduce or satisfy the stormwater management requirements (as set forth in the 2011 TGM). If it does not, then add more controls as necessary. Flood mitigation may provide the necessary sediment and pollution control, thereby reducing maintenance requirements for the stormwater management BMPs. A sequence of hydrologic controls should be considered, such as site design, flood drainage mitigation, and Retention BMPs. Biofiltration BMPs and Treatment Control Measures can be considered where the use of Retention BMPs is technically infeasible. Each of these controls will have an influence on stormwater runoff from the new development or redevelopment project.

Similar to Source Control Measures, which prevent pollutant sources from contacting stormwater runoff, Retention BMPs use techniques to infiltrate, store, use, and evaporate runoff onsite to mimic pre-development hydrology, to the extent feasible. The goal of LID is to increase groundwater recharge, enhance water quality, and prevent degradation of downstream natural drainage channels. This goal may be accomplished with creative site planning and with incorporation of localized, naturally functioning BMPs into the project. Implementation of Retention BMPs will reduce the size of additional Hydromodification Control Measures that may be required for a new development or redevelopment project, and, in many circumstances, may be used to satisfy all stormwater management requirements.

1.5 Applicability

The following projects and associated triggers, contained in subpart 4.E.II of Order R4-2010-0108, are subject to the requirements and standards laid out in the 2011 TGM.

Note that some of the project triggers are based on *total altered surface area* and others on *impervious surface area*, which is an intentional requirement in the MS4 Permit.

New Development Projects

Development projects subject to conditioning and approval for the design and implementation of post-construction stormwater management control measures, prior to completion of the project(s), are:

1) All development projects equal to 1 acre or greater of disturbed area that adds more than 10,000 square feet of impervious surface area.

2) Industrial parks with 10,000 square feet or more of total altered surface area.

3) Commercial strip malls with 10,000 square feet or more of impervious surface area.

4) Retail gasoline outlets with 5,000 square feet or more of total altered surface area.

5) Restaurants (Standard Industrial Classification (SIC) of 5812) with 5,000 square feet or more of total altered surface area.

6) Parking lots with 5,000 square feet or more of impervious surface area, or with 25 or more parking spaces.

7) Streets, roads, highways, and freeway construction of 10,000 square feet or more of impervious surface area (see Section 2 for specific requirements).

8) Automotive service facilities (Standard Industrial Classification (SIC) of 5013, 5014, 5511, 5541, 7532-7534 and 7536-7539) of 5,000 square feet or more of total altered surface area.

9) Projects located in or directly adjacent to, or discharging directly to an Environmentally Sensitive Area (ESA), where the development will:

    a. Discharge stormwater runoff that is likely to impact a sensitive biological species or habitat; and

b. Create 2,500 square feet or more of impervious surface area.

10) Single-family hillside homes (see Section 2 for specific requirements).

Redevelopment Projects

Redevelopment projects subject to conditioning and approval for the design and implementation of post-construction stormwater management control measures, prior to completion of the project(s), are redevelopment projects in categories 1 through 10 above that meet the threshold identified below:

- Land-disturbing activity that results in the creation or addition or replacement of 5,000 square feet or more of impervious surface area on an already developed site.

Additionally:

1) Projects where redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was not subject to the post development stormwater quality control requirements of Board Order 00-108, shall mitigate the entire redevelopment project area.

2) Projects where redevelopment results in an alteration to more than fifty percent of impervious surfaces of a previously existing development, and the existing development was subject to the post development stormwater quality control requirements of Board Order 00-108, must mitigate only the altered portion of the redevelopment project area and not the entire project area.

3) Projects where redevelopment results in an alteration of less than fifty percent of impervious surfaces of a previously existing development must mitigate only the altered portion of the redevelopment project area and not the entire project area.

Land-disturbing activity that results in the creation or addition or replacement of less than 5,000 square feet of impervious surface area on an already developed site, or that results in a decrease in impervious area which was subject to the post-development stormwater quality control requirements of Board Order 00-108, is not subject to mitigation unless so directed by the local permitting agency.

Redevelopment does not include routine maintenance activities that are conducted to maintain the original line and grade, hydraulic capacity, or original purpose of the facility or emergency redevelopment activity required to protect public health and safety. Impervious surface replacement, such as the reconstruction of parking lots and roadways, that does not disturb additional area and maintains the original grade and alignment, is considered a routine maintenance activity. Agencies' flood control, drainage, and wet utilities projects that maintain original line and grade or hydraulic capacity are considered routine maintenance. Redevelopment also does not include the repaving of existing roads to maintain original line and grade.

Existing single-family dwelling and accessory structure projects are exempt from the redevelopment requirements unless the project creates, adds, or replaces 10,000 square feet of impervious surface area.

Effective Date

The new development and redevelopment requirements contained in Part 4, Section E of Board Order R4-2010-0108 (the "Order") shall become effective 90 calendar days after the Regional Water Quality Control Board Executive Officer approves the 2011 TGM (the "Effective Date"). After the Effective Date, all applicable projects, except those identified below, must comply with the new development and redevelopment requirements contained in Part 4, Section E of the Order.

The new development and redevelopment requirements contained in Part 4, Section E of the Order shall not apply to the projects described in paragraphs 1 through 5 below. Projects meeting the criteria listed in paragraphs 1 through 5 below shall instead continue to comply with the performance criteria set forth in the 2002 Technical Guidance Manual for Stormwater Quality Control Measures under Board Order 00-108:

1) Projects or phases of projects where the project's applications have been "deemed complete for processing" (or words of equivalent meaning), including projects with ministerial approval, by the applicable local permitting agency in accordance with the local permitting agency's applicable rules prior to the Effective Date; or

2) Projects that are the subject of an approved Development Agreement and/or an adopted Specific Plan; or an application for a Development Agreement and/or Specific Plan where the application for the Development Agreement and/or Specific Plan has been "deemed complete for processing" (or words of equivalent meaning), by the applicable local permitting agency in accordance with the local permitting agency's applicable rules, and thereafter during the term of such Development Agreement and/or Specific Plan unless earlier cancelled or terminated; or

3) All private projects in which, prior to the Effective Date, the private party has completed public improvements; commenced design, obtained financing, and/or participated in the financing of the public improvements; or which requires the private party to reimburse the local agency for public improvements upon the development of such private project; or

4) Local agency projects for which the governing body or their designee has approved initiation of the project design prior to the Effective Date; or

5) A Tentative Map or Vesting Tentative Map deemed complete or approved by the local permitting agency prior to the Effective Date, and subsequently a Revised Map is submitted, the project would be exempt from the 2011 TGM provisions if the revisions substantially conform to original map design, consistent with

Subdivision Map Act requirements. Changes must also comply with local and state law.

The intent of these guidelines is to ensure that projects for which the applications have been deemed "complete" or the applicants have worked with local permitting agency staff to develop a final, or substantially final, drainage concept and site layout that includes water quality treatment based upon the performance criteria set forth in the 2002 Technical Guidance Manual for Stormwater Quality Control Measures prior to the Effective Date, are not required to redesign their proposed projects for purposes of complying with the new development and redevelopment requirements contained in Part 4, Section E of Board Order R4-2010-0108.

In addition, any project, phase of a project, or individual lot within a larger previously-approved project, where the application for such project has been "deemed complete for processing" (or words of equivalent meaning) that does not have a f inal or substantially final drainage concept as determined by the local permitting agency or a site layout that includes water quality treatment must comply with the performance standards set forth in the 2011 TGM.

1.6 Organization of the 2011 TGM

The 2011 TGM is divided into seven sections and nine appendices:

Section 1	Introduction
Section 2	Stormwater Management Standards
Section 3	Site Assessment and BMP Selection
Section 4	Site Design Principles & Techniques
Section 5	Source Control Measures
Section 6	Retention BMPs, Biofiltration BMPs, and Treatment Control Measure Design
Section 7	Operation and Maintenance Planning
Appendix A	Glossary of Terms
Appendix B	Maps: Watersheds Delineation, Existing Urban Areas, Environmentally Sensitive Areas, and 85th Percentile Rainfall Depth
Appendix C	Site Soil Type and Infiltration Testing

Appendix D	BMP Performance Guidance
Appendix E	BMP Sizing Worksheets
Appendix F	Flow Splitter Design
Appendix G	Design Criteria Checklists for Stormwater Runoff BMPs
Appendix H	Stormwater Control Measure Access and Maintenance Agreements
Appendix I	Stormwater Control Measure Maintenance Plan Guidelines and Checklists

2 STORMWATER MANAGEMENT STANDARDS

2.1 Introduction

This section outlines the design process to comply with stormwater control requirements. A flowchart is presented in Figure 2-1 to illustrate a step-by-step process for incorporating these stormwater management control measures.

The selection of appropriate stormwater management control measures should be a collaborative effort between the project proponent and the local permitting agency staff. It is recommended that discussions between project planners, engineers, and local permitting agency staff regarding selection of stormwater management control measures occur very early in the design process.

2.2 Step 1: Determine Project Applicability

New development and redevelopment projects meeting the applicability criteria contained in Section 4.E.II of Order R4-2010-0108 [presented in Section 1.5 of the 2011 TGM] must include control measures specified in the 2011 TGM. These projects should be designed to meet the performance criteria described in the steps below.

Separate requirements exist for three types of projects:

- Projects located within a Redevelopment Project Area Master Plan (RPAMP);
- Single Family Hillside Homes; and
- Roadway Projects.

The requirements for these three project types are described in further detail in the substeps below. Projects that are not applicable are still subject to stormwater agency review, especially for flood drainage requirements. Stormwater management control measures may be required by the governing agency for inapplicable projects, depending on the potential discharge of pollutants in stormwater runoff, impairments in receiving water, or other special conditions that would require increased protection.

Step 1a: Determine RPAMP Eligibility

If a project is located within the boundary of a Redevelopment Project Area Master Plan (RPAMP), the stormwater management requirements in the RPAMP take precedence over the control measures and performance criteria specified in this 2011 TGM. A stormwater agency may apply to the Regional Water Quality Control Board for approval of a RPAMP in consideration of exceptional site constraints that inhibit site-by-site or project-by-project implementation of post-construction requirements.

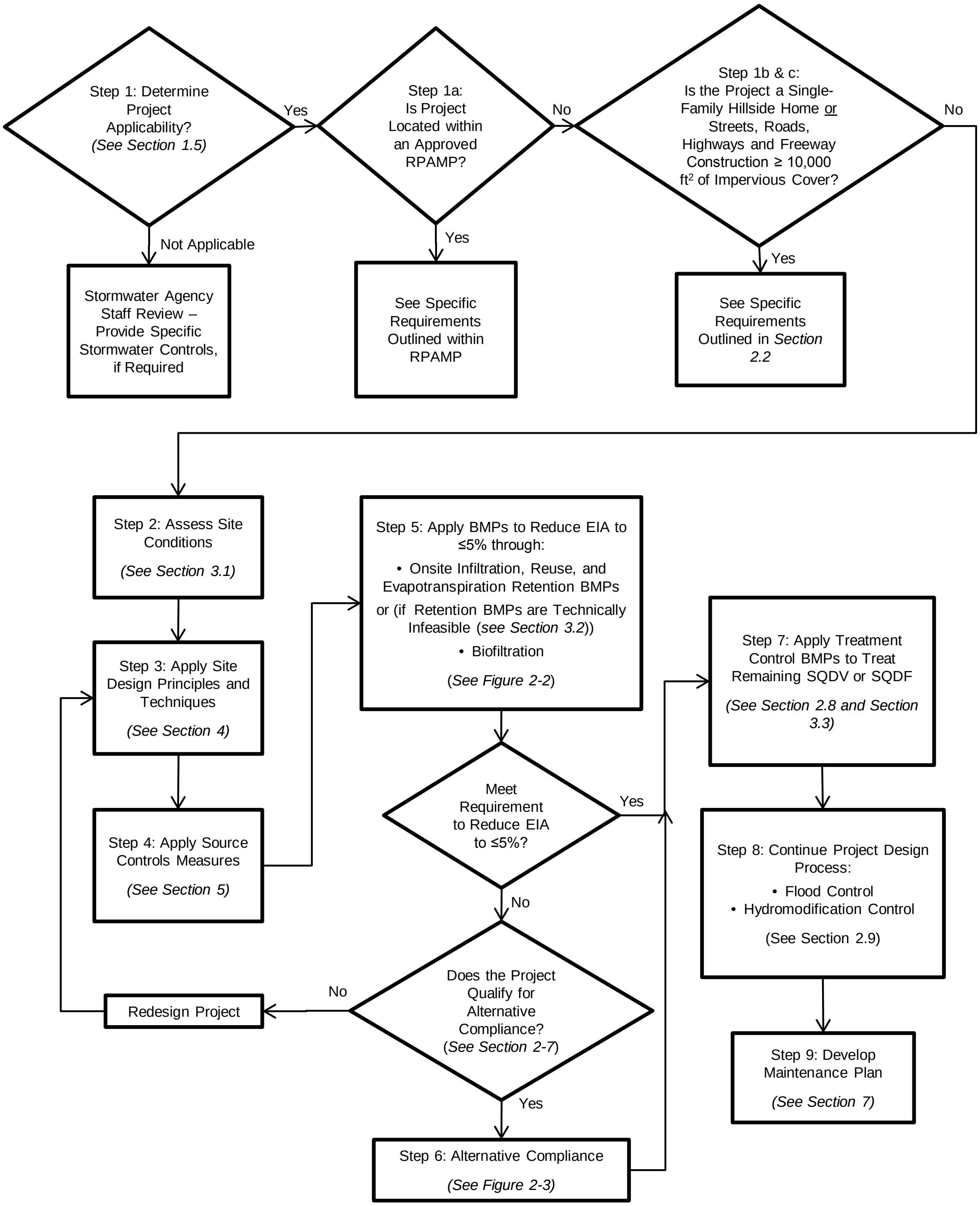


Figure 2-1: Stormwater Management Control Measures Design Decision Flowchart

Step 1b: Single-Family Hillside Homes

Single-family hillside home projects have specific requirements separate from other new development and redevelopment project categories. These requirements only apply to single-family hillside homes that disturb less than 1 acre and that add less than 10,000 square feet of impervious surface area. If the project is equal to 1 acre or greater of disturbed area that adds more than 10,000 square feet of impervious surface area, then project must comply with Steps 2 through 9.

According to Order R4-2010-0108, a hillside is defined as:

> "*Property located in an area with known erosive soil conditions, where the development will result in grading on any slope that is 20% or greater or an area designated by the Municipality under a General Plan or ordinance as a 'hillside area.'*"

The measures presented in this substep comprise the performance standard for single-family hillside home new development and redevelopment projects and apply to the entire lot (additional information on these measures may be found in Section 4 and Section 5).

Conserve Natural Areas

Each project site possesses unique topographic, hydrologic and vegetative features, some of which are more suitable for development than others. Locating development on the least sensitive portion of a site and conserving naturally vegetated areas can minimize environmental impacts in general and stormwater runoff impacts in particular.

The following measures are required and should be included in the lot layout, consistent with applicable General Plan and Local Area Plan policies and if appropriate and feasible with the given site conditions:

1) Concentrate or cluster improvements on the least-sensitive portions of the lot and leave the remaining land in a natural undisturbed state; at a minimum, sensitive portions of the lot should include areas covered under Clean Water Act Section 404 such as riparian areas and wetlands;

2) Limit clearing and grading of native vegetation on the lot to the minimum area needed to build the home, allow access, and provide fire protection; and

3) Maximize trees and other vegetation at the site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought-tolerant plants.

Protect Slopes and Channels

Erosion of slopes and channels can be a major source of sediment and associated pollutants such as nutrients, if not properly protected and stabilized.

Slope Protection

Slope protection practices must conform to local permitting agency erosion and sediment control standards and design requirements. The post-construction design criteria described below are intended to enhance and be consistent with these local standards.

1) Slopes must be protected from erosion by safely conveying runoff from the tops of slopes.

2) Slopes must be vegetated by first considering the use of native or drought-tolerant species.

Channel Protection

The following measures should be implemented to provide erosion protection to unlined receiving streams on the lot. Activities and structures must conform to applicable permitting requirements, standards, and specifications of agencies with jurisdiction (i.e., U.S. Army Corps of Engineers, California Department of Fish and Game, or Regional Water Quality Control Board).

1) Use natural drainage systems to the maximum extent practicable, but minimize runoff discharge to the maximum extent practicable.

2) Stabilize permanent channel crossings.

3) Install energy dissipaters, such as rock riprap, at the outlets of storm drains, culverts, conduits or channels that discharge into unlined channels.

Provide Storm Drain System Stenciling and Signage

Storm drain message markers or placards are required at all storm drain inlets within the project boundary. The signs should be placed in clear sight facing anyone approaching the inlet from either side. All storm drain inlet locations must be identified on the development site map.

Some local agencies within the County have approved storm drain message placards for use. Consult local permitting agency stormwater staff to determine specific requirements for placard types and installation methods.

Divert Roof Runoff and Surface Flows to Vegetated Area(s) or Collection System(s), Unless the Diversion Would Result in Slope Instability

Diverted Roof Runoff
City of Santa Barbara

Disconnecting downspouts divert water from roof gutters to (1) vegetated pervious areas of the site in order to allow for infiltration, storage, evapotranspiration (i.e., evaporation and uptake of water by plants), and treatment, or (2) a rainwater collection system (e.g., a rain barrel or a cistern). Disconnected downspouts differ from conventional downspout systems that provide a direct connection of roof runoff to stormwater conveyance systems (storm drains), which quickly collect and convey stormwater away from the site. "Flow spreading" is a technique used to spread runoff from rooftops, sidewalks, patios, and driveways out over a vegetated pervious area, rather than concentrating and conveying the runoff directly to a stormwater conveyance system.

Dispersion methods include splash blocks, gravel-filled trenches, or other methods which serve to spread runoff over vegetated pervious areas. Sheet flow dispersion is the simplest method and can be used for any impervious or pervious surface that is graded so as to avoid concentrating flows. Because flows are already dispersed as they leave the surface, they only need to traverse through a narrow band of adjacent vegetation for the runoff to be effectively attenuated and treated.

The following requirements apply to runoff diversion:

- Vegetated flowpaths for the diverted flows should be at least 25 feet in length, measured from the diversion location to the downstream property line, structure, steep slope, stream, wetland, or impervious surface. The vegetated flowpath must be covered with well-established lawn or pasture, landscaping with well-established groundcover, or native vegetation with natural groundcover. The groundcover should be dense enough to help disperse and infiltrate flows and to prevent erosion.

- If the vegetated flowpath (measured as defined above) is less than 25 feet, a perforated stub-out connection may be used in lieu of downspout dispersion. A perforated stub-out connection is a length of perforated pipe within a gravel-filled trench that is placed between roof downspouts and a stub-out to the local drainage system. A perforated stub-out may also be used where implementation of downspout dispersion might cause erosion or flooding problems, either onsite or on adjacent lots. This provision might be appropriate, for example, for lots where dispersed flows might pose a potential hazard for lower lying lots or adjacent offsite lots. Location of the connection should be selected to allow a m aximum amount of runoff to infiltrate into the ground (ideally a dry location on the site that is relatively well drained). To facilitate maintenance, the perforated pipe portion of the system should not be located under impervious or heavily compacted (e.g., driveways and parking areas) surfaces. The use of a perforated stub-out in lieu of downspout dispersion may be determined by the Local permitting agency.

- In general, if the ground is sloped away from the foundation and there is adequate vegetation and area for effective dispersion, splash blocks will adequately disperse stormwater runoff. If the ground is fairly level, if the structure includes a basement, or if foundation drains are proposed, splash blocks with downspout extensions may be a better choice because the discharge point is moved away from the foundation. Downspout extensions may include piping to a splash block/discharge point a considerable distance from the downspout, as long as the runoff can travel through a well-vegetated area as described above.
- No erosion or flooding of downstream properties may result.
- Runoff discharged towards steep slopes or landslide hazard areas, including perforated stub-out connections, must be evaluated by a geotechnical engineer or qualified geologist. The discharge point may not be placed on or above slopes greater than 20% or above erosion hazard areas without evaluation by a geotechnical engineer or qualified geologist and jurisdiction approval.
- For sites with septic systems, the discharge point must be down gradient of the drainfield primary and reserve areas. This requirement can be waived by the jurisdiction's permit review staff if site topography clearly prohibits flows from intersecting with the drainfield.

Step 1c: Roadway Projects

Roadway projects have specific requirements separate from other new development and redevelopment project categories. The measures presented in this substep comprise the performance standard for street, roadway, highway, and freeway projects. Section 4.E.II of Order R4-2010-0108 requires street, roadway, highway, and freeway projects that construct 10,000 square feet or more of impervious surface area, to incorporate USEPA guidance regarding *Managing Wet Weather with Green Infrastructure: Green Streets* to the maximum extent practicable.

The following requirements apply to the impervious area within the right-of-way associated with public streets, roads, highways, and freeways projects and the streets that are part of a larger private project. These requirements do not apply to routine maintenance activities that are conducted to maintain original line and grade, hydraulic capacity, original purpose of facility, or emergency redevelopment activity required to protect public health and safety. Impervious surface replacement, such as the reconstruction of parking lots and roadways, which does not disturb additional area and maintains the original grade and alignment, is considered a r outine maintenance activity. Agencies' flood control, drainage, and wet utilities projects that maintain original line and grade or hydraulic capacity are considered routine maintenance. Also, the requirements do not apply to the repaving of existing roads to maintain original line and grade.

Minimum requirements for the impervious area within the right-of-way associated with streets, roads, highways, and freeways are as follows:

1) Provide Retention BMPs or Biofiltration BMPs sized to capture and treat the Stormwater Quality Design Volume (SQDV) or the Stormwater Quality design Flow (SQDF) (see Step 7 for guidance on calculating the SQDV and SQDF).

   Additional Treatment Control Measures may be integrated into roadway projects if they are used in a treatment train approach with Retention BMPs or Biofiltration BMPs to address the pollutants of concern (see Section 3.3).

2) Projects should apply the following measures to the maximum extent practicable and as specified in the local permitting agency's codes:

   - Minimize street width to the appropriate minimum width for maintaining traffic flow and public safety;
   - Use porous pavement or pavers for low traffic roadways, on-street parking, shoulders or sidewalks; and
   - Add tree canopy by planting or preserving trees and shrubs.

2.3 Step 2: Assess Site Conditions

The next step is to collect site information that is critical for the selection and implementation of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. The following information should be documented: topography, soil type and geology, groundwater, geotechnical considerations, offsite drainage, existing utilities, and Environmentally Sensitive Areas. I n addition, soil and infiltration testing should be conducted. Detailed guidance on assessing site conditions can be found in Section 3.1.

2.4 Step 3: Apply Site Design Principles and Techniques

The third step is to apply Site Design Principles & Techniques (see Section 4). The implementation of LID requires an integrated approach to site design and stormwater management. Traditional approaches to stormwater management planning within the site planning process are not likely to achieve the LID performance standard of the MS4 Permit. The use of the site planning techniques presented in Section 4 (Site Design Principles & Techniques) will help generate a more hydrologically functional site, maximize the effectiveness of Retention BMPs, and integrate stormwater management throughout the site.

The following criteria should be considered during the early site planning stages:

- Retention BMPs should be considered as early as possible in the site planning process. Hydrology should be a key principle that is integrated into the initial site assessment planning phases. Where flexibility exists, conceptual drainage plans should attempt to route water to areas suitable for Retention BMPs.
- A multidisciplinary approach at the initial phases of the project is recommended and should include planners, engineers, landscape architects, and architects.
- Individual Retention BMPs should be distributed throughout the project site as feasible and may influence the configuration of roads, buildings and other infrastructure.
- The project must demonstrate disconnection of impervious surface such that the 5% EIA requirement is achieved. If fully meeting the 5% EIA requirement using Retention BMPs is not technically feasible, the project must still utilize Retention BMPs to the maximum extent practicable.
- Flood and hydromodification control should be considered early in the design stages. Even sites with Retention BMPs will still have runoff that occurs during large storm events, but Retention facilities can have flood and hydromodification control benefits. It may be possible to simultaneously address flood and hydromodification control requirements through an integrated water resources management approach.

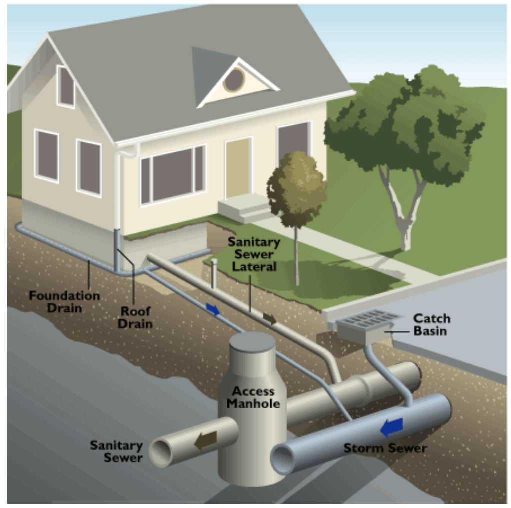
Perhaps the most important aspect of site planning is allowing sufficient space for Retention BMPs in areas that can physically accept runoff. A simple rule of thumb is to allow 3 to 10 percent of the tributary impervious area (depending on how well the soils drain and then allow for more area with less infiltrative soils) for infiltration BMPs and 3 to 5 percent for biofiltration in preliminary design to achieve the 5% Effective Impermeable Area (EIA) standard.

2.5 Step 4: Apply Source Control Measures

All applicable projects must implement applicable Source Control Measures. Source Control Measures are operational practices that reduce potential pollutants at the source. They typically do not require maintenance or significant construction. Guidance on Source Control Measures can be found in Section 5.

2.6 Step 5: Apply BMPs to Reduce EIA to ≤5%

According to Order R4-2010-0108, Applicable projects must reduce Effective Impervious Area (EIA) to less than or equal to five percent (≤5%) of the total project area, unless infeasible. Impervious surfaces are rendered "ineffective" if the design storm volume is fully retained onsite using either infiltration, rainwater harvesting, and/or evapotranspiration Retention BMPs. Biofiltration BMPs may be used to achieve the 5% EIA standard if Retention BMPs are technically infeasible (see Section 3.2). This section and Figure 2-2 describe the process for reducing EIA to ≤5%. Refer to Section 2.7 if Retention BMPs and/or Biofiltration BMPs cannot feasibly be used to meet the 5% EIA standard (see Section 3.2).



Effective Impervious Area
Victoria, BC Capital Regional District

Step 5a: Calculate Allowable EIA

EIA is defined as impervious area that is hydrologically connected via sheet flow over a hardened conveyance or impervious surface without any intervening medium to mitigate flow volume. Connected impervious areas efficiently transport runoff without allowing infiltration. Often in urban areas, runoff from connected impervious surfaces is immediately directed into a stormwater conveyance system where it is further connected and efficiently transported to an outfall (stormwater conveyance system outlet). For example, in this illustration, the rooftop is directly connected via a roof drain and underground solid drain pipe to the storm drain in the street (Note that the sanitary sewer is separate from the storm sewer). The roadway drains to the storm drain through the catch basin. The roof area and roadway area would be considered EIA.

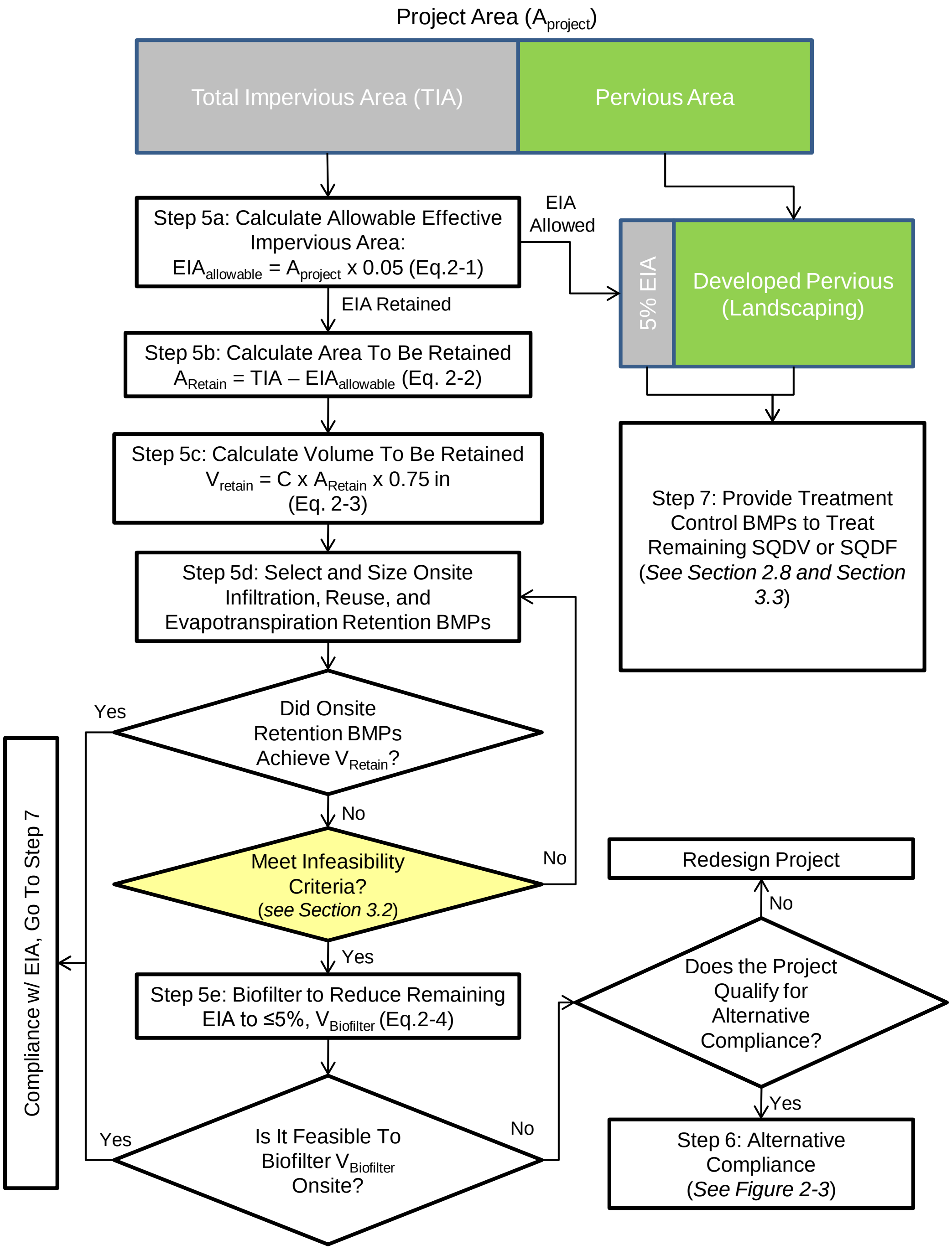


Figure 2-2: Apply BMPs to Reduce EIA to ≤5% Process Flow Chart

"Impervious surface" is a man-made hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under natural conditions prior to development. Common impervious surfaces include, but are not limited to, rooftops, walkways, patios, driveways, parking lots or storage areas, concrete or asphalt paving, compacted gravel roads, packed earthen materials, and oiled, macadam or other surfaces which similarly impede the natural infiltration of stormwater. Open, uncovered retention/detention facilities and exposed bedrock shall not be considered as impervious surfaces for purposes of determining EIA retention volume.

The allowable EIA for a project site should be calculated as follows:

$$EIA_{allowable} = (A_{project})*(\%_{allowable}) \qquad \text{(Equation 2-1)}$$

Where:

$EIA_{allowable}$ = the maximum impervious area from which runoff can be treated and discharged offsite [and not retained onsite] (acres)

$A_{project}$ = the total project area (acres).

"Total project area" (or "gross project area") for new development and redevelopment projects is defined as the disturbed, developed, and undisturbed portions within the project's property (or properties) boundary, at the project scale submitted for first approval. Areas proposed to be permanently dedicated for open space purposes as part of the project are explicitly included in the "total project area." Areas of land precluded from development through a restrictive covenant, conservation easement, or other recorded document for the permanent preservation of open space prior to project submittal shall not be included in the "total project area."

$\%_{allowable}$ = 5 percent

Step 5b: Calculate Impervious Area to be Retained

The impervious area from which runoff must be retained onsite is the total impervious area minus the $EIA_{allowable}$, which should be calculated as follows:

$$A_{Retain} = TIA - EIA_{allowable} = (IMP*A_{project}) - EIA_{allowable} \qquad \text{(Equation 2-2)}$$

Where:

A_{Retain} = the drainage area from which runoff must be retained (acres)

TIA = total impervious area (acres)

$EIA_{allowable}$	=	the maximum impervious area from which runoff can be treated and discharged offsite [and not retained onsite] (acres).
IMP	=	imperviousness of project area (%)/100
$A_{project}$	=	the total project area (acres)

Step 5c: Calculate the Volume to be Retained (SQDV)

All Retention BMPs used to render impervious surfaces "ineffective" should be properly sized to retain the volume of water that results from the water quality design storm. The design storm volume, referred to in the TGM as the Stormwater Quality Design Volume (SQDV) shall be calculated using the following four allowable methodologies:

1) The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or

2) The volume of annual runoff based on unit basin storage water quality volume to achieve 80 percent or more volume treatment; or

3) The volume of runoff produced from a 0.75 inch storm event; or

4) Eighty (80) percent of the average annual runoff volume using an appropriate public domain continuous flow model [such as Storm Water Management Model (SWMM) or Hydrologic Engineering Center – Hydrologic Simulation Program – Fortran (HEC-HSPF)], using the local rainfall record and relevant BMP sizing and design data.

Note: Examples used throughout the 2011 TGM use the 0.75 inch storm event (Methodology #3).

EXAMPLE 2-1: EIA CALCULATION

Given: 10 acre total project area, 55% impervious, 25% landscaped, 20% undisturbed, percent allowable EIA = 5%.

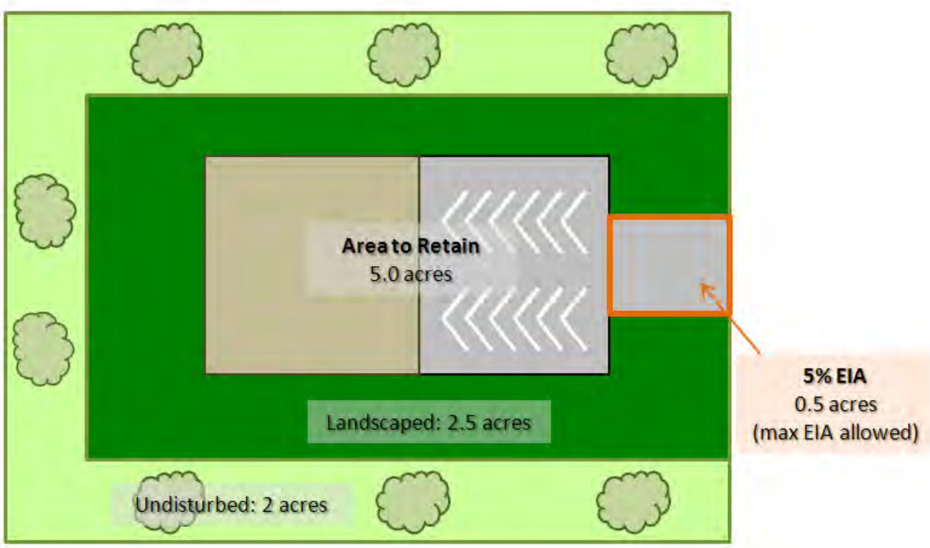
$EIA_{allowable}$ = 10 * 0.05 = 0.5 acres

A_{Retain} = (0.55*10) – 0.5 = 5.0 acres

$A_{treatment}$ = (0.25*10) + 0.5 = 3.0 acres

The maximum EIA allowed for the site is 0.5 acres, from which the generated runoff must be treated prior to discharge, in addition to the runoff from the 2.5 acres landscaped area, up to the design storm volume or flow rate. The runoff volume generated from the remaining 5 acre impervious area (A_{Retain}) must be retained onsite via infiltration, rainwater harvesting, and/or evapotranspiration Retention BMPs.

$A_{treatment}$ equals the EIA allowed for the site plus the landscaped area.



Note: graphic not to scale; for illustration purposes only

The runoff volume that is to be retained onsite should be calculated using Equation 2-3 below:

$$V_{Retain} = C*(0.75/12)*A_{retain} \qquad \text{(Equation 2-3)}$$

Where:

V_{Retain} = the stormwater quality design volume (SQDV) that must be retained onsite (ac-ft)

C	=	runoff coefficient (equals 0.95 for impervious surfaces)
0.75	=	the design rainfall depth (in) [based on SQDV sizing method 3]
A_{Retain}	=	the drainage area from which runoff is retained (acres), calculated using Equation 2-2

EXAMPLE 2-2: RETENTION VOLUME CALCULATION

Given: A_{Retain} = 5.0 acres (from Example 2-1); runoff coefficient (C) = 0.95

$$V_{Retain} = 0.95*(0.75/12)*5.0 \text{ acres} = 0.3 \text{ acre-feet}$$

The project must retain at least 0.3 acre-feet of runoff from impervious surfaces using Retention BMPs.

Step 5d: Select and Size Onsite Retention BMPs to Achieve 5% EIA

The next step is to select and size Retention BMPs, based on the site assessment design, and constraints. Section 3-4 provides guidance on the selection of Retention BMPs. The project must demonstrate disconnection of impervious area such that the 5% EIA requirement is achieved.

Step 5e: Select and Size Biofiltration BMPs to Reduce EIA to ≤5%

Retention BMPs shall be used onsite to the maximum extent practicable. Pretreatment BMPs shall be provided for all infiltration BMPs and other Retention BMPs as needed (see Section 6.1).

New development and redevelopment projects that demonstrate technical infeasibility for reducing EIA to ≤5% using Retention BMPs are eligible to use Biofiltration BMPs to achieve the EIA performance standard.

The project applicant shall demonstrate technical infeasibility by submitting a site-specific analysis conducted and endorsed by a registered professional engineer, geologist, architect, and/or landscape architect. Section 3.2 discusses technical feasibility screening criteria. Projects that cannot demonstrate technical infeasibility shall meet the requirement to reduce EIA to ≤5% using Retention BMPs. Otherwise project applicants must examine other options for meeting the requirements, such as redesigning the site.

Volume-based biofiltration BMPs shall be sized to treat 1.5 times the volume not retained using Retention BMPs.

The onsite biofiltered volume ($V_{Biofilter}$), should be calculated as follows:

$$V_{Biofilter} = (V_{Retain} - V_{Achieved}) * 1.5 \qquad \text{(Equation 2-4)}$$

Where:

$V_{Biofilter}$ = the volume that must be captured and treated in a Biofiltration BMP (ac-ft)

V_{Retain} = the stormwater quality design volume (SQDV) that must be retained (ac-ft) (established in Step 5c)

$V_{Achieved}$ = the volume retained onsite using Retention BMPs (ac-ft)

EXAMPLE 2-3: BIOFILTRATION VOLUME CALCULATION

Given: V_{Retain} = 0.3 ac-ft (from Example 2-2); $V_{Achieved}$ = 0.25 ac-ft

$$V_{Biofilter} = (0.3 - 0.25) * 1.5 = 0.075 \text{ ac-ft}$$

If the project applicant has demonstrated technical infeasibility, the remaining EIA requirement may be met by biofiltering 1.5 times the remaining V_{Retain}. In this case, the Biofiltration BMP must be sized to treat 0.075 ac-ft.

If the project applicant has demonstrated technical infeasibility, the remaining EIA requirement may also be satisfied with flow-based Biofiltration BMPs. Flow-based Biofiltration BMPs shall be sized for the remaining drainage area from which runoff must be retained (A_{Retain}) using the methodology described in Section 2.8, Stormwater Quality Design Flow, with a rainfall intensity that varies with time of concentration for the catchment tributary to the flow-based Biofiltration BMP, according to Table 2-1.

Table 2-1: Flow-Based Biofiltration BMP Design Intensity for 150% Sizing

Time of Concentration, minutes	Design Intensity for 150% Sizing, in/hr
30	0.24
20	0.25
15	0.28
10	0.31
5	0.35

Time of concentration should be determined using the methodology provided in the Ventura County Hydrology Manual.

2.7 Step 6: Alternative Compliance

Certain new development and redevelopment project types are eligible for alternative compliance measures if onsite Retention BMPs and/or Biofiltration BMPs cannot feasibly be used to meet the 5% EIA standard (see Section 3.2). Such projects include:

1) Redevelopment projects (as defined in Section 1.5).

2) Infill projects. Infill projects meet the following conditions:

   a. The project is consistent with applicable general plan designation, and all applicable general plan policies, and applicable zoning designation and regulations;

   b. The proposed development occurs on a project site of no more than five acres substantially surrounded by urban uses;

   c. The project site has no value as habitat for endangered, rare, or threatened species;

   d. Approval of the project would not result in any significant effects relating to traffic, noise, air quality, or water quality; and

   e. The site can be adequately served by all required utilities and public services (modified from State Guidelines § 15332).

3) Smart Growth projects. Smart Growth projects are defined as new development and redevelopment projects that occur within existing urban areas[2] (see maps in Appendix B) designed to achieve the majority of the following principles[3]:

   a. Create a range of housing opportunities and choices;

   b. Create walkable neighborhoods;

   c. Mix land uses;

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[2] Existing urban areas and corresponding maps in Appendix B are based on the cities' City Urban Restriction Boundaries (CURB) lines and in the case of the unincorporated County, the Existing Community designation. These boundaries are a growth management tool intended to channel growth and protect agricultural and open-space land. The 2011 TGM utilizes existing urban areas (as defined in Appendix B) to provide parameters around eligibility for alternative compliance in two areas: 1) Smart Growth and 2) low income housing projects.

[3] Adapted from the Smart Growth Network's Smart Growth Principles in cooperation with the U.S. Environmental Protection Agency.

d. Preserve open space, natural beauty, and critical areas;

   i. Farmland preservation may also be considered for projects occurring outside existing urban areas (as defined by the Appendix B maps).

e. Provide a variety of transportation choices;

   i. Includes transit oriented development (development located within an average 2,000 foot walk to a bus or train station).[4]

f. Strengthen and direct development towards existing communities (as defined by Appendix B maps); and

g. Take advantage of compact building design.

The City or County Planning Division in which a project is proposed will ultimately determine whether a project meets these Smart Growth criteria.

4) Pedestrian/bike trail projects:

- ✓ Located along side of a road and
- ✓ Where right-of-way width is inadequate for the implementation of Retention and/or Biofiltration BMPs.

5) Agency flood control, drainage, and wet utilities projects:

- ✓ Located within waterbody and is therefore not increasing functional impervious cover; or
- ✓ Located on top of a narrow flood control feature (such as a levee) and space is unavailable for the implementation of Retention and/or Biofiltration BMPs; or
- ✓ Where the integrity of the flood control feature (such as a dam or levee) may be compromised through Retention and/or Biofiltration BMPs (e.g., infiltration of stormwater is not appropriate in a levee).

6) Historical preservation projects:

- ✓ Where the extent of the designated preservation area restricts the amount of land available for the implementation of Retention BMPs.

[4] Calthorpe, P. (1993), "The next American metropolis: Ecology, community, and the American dream", New York: Princeton Architectural Press.

7) Low income housing projects that occur within existing urban areas (as defined by the maps provided in Appendix B):

   - ✓ Where density requirements restrict the amount of land available for the implementation of Retention BMPs and/or
   - ✓ Where project financing constraints restrict the amount of land available for the implementation of Retention BMPs.

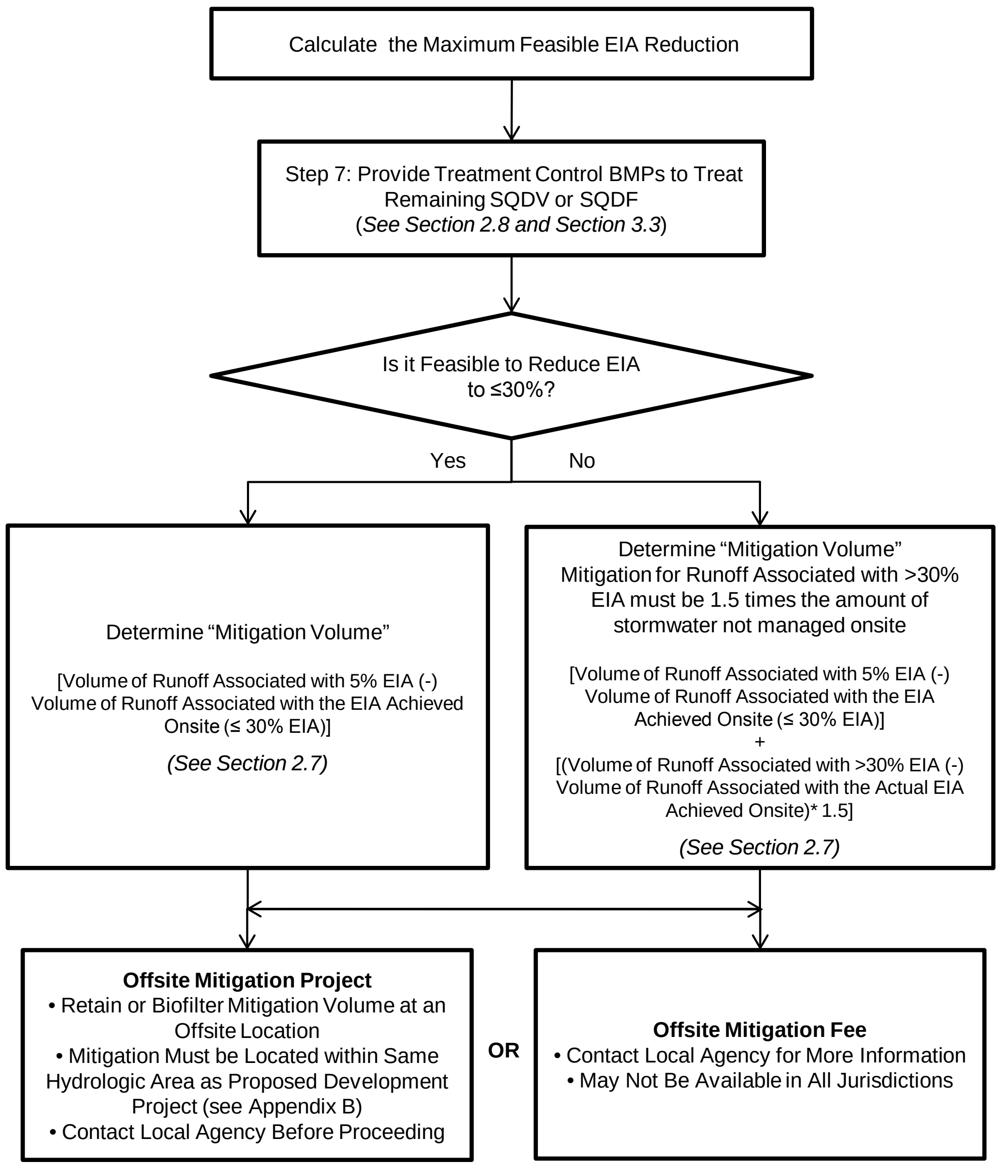


Figure 2-3: Alternative Stormwater Management Control Measures Compliance Decision Flow Chart

Projects in these categories must demonstrate that full compliance with the 5% EIA standard using Retention BMPs and Biofiltration BMPs is infeasible prior to moving to the alternative compliance flowchart (Figure 2-3) and selecting an offsite mitigation alternative. Section 3.2 provides infeasibility criteria.

Stormwater runoff from impervious surfaces and developed pervious surfaces that is not fully retained onsite (up to the SQDV) shall be mitigated using Treatment Control Measures [Chapter 6] selected per the BMP selection process outlined in Section 3.3, in addition to offsite alternative compliance measures.

Alternative compliance may be met through two options:

- Offsite mitigation project; or
- Offsite mitigation fee.

In either case, the Project applicant must contact the local approval agency before proceeding with Alternative Compliance.

Mitigation Volume

Projects requesting alternative compliance must demonstration that EIA has been reduced to the maximum extent practicable. Additionally, the SQDV or SQDF from all directly connected impervious area and the developed pervious project area must be captured and treated within the project site.

Alternative compliance options will be based on the “mitigation volume.” The mitigation volume is the difference between the volume of runoff associated with 5% EIA and the volume of runoff associated with the actual EIA achieved onsite less than or equal to 30% (≤30%) EIA. The offsite mitigation requirement for EIA in excess of 30% (>30%) is 1.5 times the amount of stormwater not managed onsite.

Projects Feasible to Reduce EIA to ≤ 30%

1) Determine the volume of runoff that is retained and biofiltered onsite ($V_{Ret/Bio}$), using Equation 2-5 below:

$$V_{Ret/Bio} = (V_{Achieved} + (V_{Biofiltered}/1.5)) \quad \text{(Equation 2-5)}$$

Where:

$V_{Ret/Bio}$ = the total volume of runoff retained and/or biofiltered onsite using Retention and Biofiltration BMPs

$V_{Achieved}$ = the runoff volume retained onsite using Retention BMPs as calculated in Equation 2-4

$V_{Biofiltered}$ = the runoff volume biofiltered onsite

2) Determine the Mitigation Volume ($V_{Mitigation}$), using Equation 2-6 below:

$$V_{Mitigation} = V_{Retain} - V_{Ret/Bio} \quad \text{(Equation 2-6)}$$

Where:

$V_{Mitigation}$ = the volume of runoff that must be mitigated offsite

V_{Retain} = the SQDV that must be retained onsite per the 5% EIA requirement calculated in Equation 2-3

$V_{Ret/Bio}$ = the total volume of runoff retained and/or biofiltered onsite using Retention and Biofiltration BMPs calculated in Equation 2-5

EXAMPLE 2-4: ≤30% EIA OFFSITE MITIGATION VOLUME CALCULATION

Given: V_{Retain} = 0.3 ac-ft (from Example 2-2); $V_{Retained}$ = 0.25 ac-ft; $V_{Biofiltered}$ = 0.06 ac-ft

1) Calculate volume of runoff retained and biofiltered onsite ($V_{Ret/Bio}$).

$V_{Ret/BioBio}$ = 0.25 + (0.06/1.5) = 0.29 ac-ft [See Equation 2-5]

2) Calculate Mitigation Volume: ($V_{Mitigation}$):

$V_{Mitigation}$ = 0.3– 0.29 = 0.01 acre-feet [See Equation 2-6]

The required offsite mitigation volume is 0.01 ac-ft.

In addition, the SQDV or SQDF from the EIA (0.5 acres) and the developed pervious area (10 acres *25% = 2.5 acres) must be captured and treated in an ap proved Treatment Control Measure.

SQDV (acre-feet) = C*(0.75/12)*3 acres

OR

SQDF (cfs) = C * 0.20 in/hr * 3 acres

Note: Per Order R4-2010-0108, several options exist to determine the SQDV and SQDF. Examples used throughout the 2011 TGM use the 0.75 inch storm event (SQDV Methodology #3) for the SQDV and 0.2 inches per hour intensity for the SQDF (SQDF Methodology #1). For these examples, the 10-acre project site is assumed to be in a location where the 85th percentile storm event is equal to 0.75 inches.

Projects with EIA > 30%

For the scenario where the effective impervious area of the project is greater than 30% due to infeasibility, the runoff volume associated with the effective impervious area up to 30% must be mitigated offsite at a one-to-one ratio and the runoff volume associated with the effective impervious area greater than 30% must be mitigated off-site at 1.5 times the volume.

1) Determine the area of the impervious portion of the drainage area from which runoff is retained or biofiltered at 30% EIA ($A_{30\%EIA}$), using Equation 2-7 below:

$$A_{30\%EIA} = (IMP*A_{project}) - (30\%*A_{project}) \quad \text{(Equation 2-7)}$$

Where:

$A_{30\%EIA}$	=	the impervious portion of the drainage area from which runoff would have been retained or biofiltered at 30% EIA (acres)
IMP	=	total imperviousness of project area (%)/100
$A_{project}$	=	the total project area (acres)

2) Determine the total volume that would have been retained or biofiltered onsite at 30% EIA ($V_{30\%EIA}$), using Equation 2-8 below:

$$V_{30\%EIA} = C*(0.75/12)*A_{30\%EIA} \qquad \text{(Equation 2-8)}$$

Where:

$V_{30\%EIA}$	=	the stormwater quality design volume (SQDV) retained or biofiltered at 30% EIA (note: for the purposes of this calculation, the biofiltered volume does not include the 1.5 multiplier)
C	=	runoff coefficient [equals 0.95 for impervious surfaces]
0.75	=	the design rainfall depth (in) [based on SQDV sizing method 3]
$A_{30\%EIA}$	=	the impervious area from which runoff would have been retained or biofiltered at 30% EIA (acres) [See Equation 2-7]

3) Determine the impervious area from which runoff is actually retained ($A_{ActualEIA}$). This is the total amount of impervious area that drains to properly sized Retention or Biofiltration BMPs.

$$A_{ActualEIA} = (IMP*A_{project}) - (EIA\%*A_{project}) \qquad \text{(Equation 2-9)}$$

Where:

$A_{ActualEIA}$	=	the impervious portion of the drainage area from which runoff is retained or biofiltered using the actual EIA achieved on-site (acres)
IMP	=	total imperviousness of project area (%)/100
$A_{project}$	=	the total project area (acres)
EIA%	=	percent EIA actually achieved on-site

4) Determine the volume that is actually retained onsite ($V_{ActualEIA}$), using Equation 2-10 below:

$$V_{ActualEIA} = C*(0.75/12)*A_{AcutalEIA} \quad \text{(Equation 2-10)}$$

Where:

$V_{AcutalEIA}$ = the stormwater quality design volume (SQDV) that is retained and/or biofiltered onsite C = runoff coefficient [equals 0.95 for impervious surfaces]

0.75 = the design rainfall depth (in) [based on SQDV sizing method 3]

$A_{ActualEIA}$ = the area associated with the Actual EIA achieved onsite, (i.e., the area from which runoff is retained or biofiltered (acres) [See # 3 above]

Determine the Mitigation Volume for 30% EIA using Equation 2-11 below:

$$V_{Mitigation30\%} = V_{Retain} - V_{30\%EIA} \quad \text{(Equation 2-11)}$$

Where:

$V_{Mitigation30\%}$ = the mitigation volume for Project site with 30% EIA

V_{Retain} = the SQDV that must be retained onsite per the 5% EIA requirement, calculated using Equation 2-3

$V_{30\%EIA}$ = the runoff that would have been retained and/or biofiltered at 30% EIA (note: for the purposes of this calculation, the biofiltered volume does not include the 1.5 multiplier), calculated using Equation 2-8

Determine the Mitigation Volume for >30% (EIA $V_{Mitigation>30\%}$), using Equation 2-12 below:

$$V_{Mitigation>30\%} = (V_{30\%EIA} - V_{ActualEIA})*1.5 \quad \text{(Equation 2-12)}$$

Where:

$V_{Mitigation>30\%}$ = the mitigation volume for >30% EIA

$V_{30\%EIA}$ = the stormwater quality design volume (SQDV) retained or biofiltered at 30% EIA (note: for the purposes of this calculation, the biofiltered volume does not include the 1.5 multiplier)

$V_{ActualEIA}$ = the stormwater quality design volume (SQDV) that is actually retained and/or biofiltered onsite, calculated using Equation 2-9

Determine the Total Mitigation Volume ($V_{MitigationTotal}$), using Equation 2-13 below:

$$V_{MitigationTotal} = V_{Mitigation>30\%} + V_{Mitigation30\%} \quad \text{(Equation 2-13)}$$

Where:

$V_{MitigationTotal}$ = the total mitigation volume for 30% EIA

$V_{Mitigation>30\%}$ = the mitigation volume for >30% EIA, calculated using Equation 2-11

$V_{Mitigation30\%}$ = the mitigation volume for 30% EIA calculated using Equation 2-10.

EXAMPLE 2-5: >30% EIA OFFSITE MITIGATION CALCULATION

Given: 40% EIA; 10 acre total project area, 55% impervious, 25% landscaped, 20% undisturbed; runoff coefficient (C) = 0.95; V_{Retain} = 0.3 ac-ft

1) Determine impervious area retained or biofiltered onsite at 30% EIA
$A_{30\%EIA} = ((55/100)*10) - ((30/100)*10) = 2.5$ acres [See Equation 2-7]

2) Determine the volume that is retained or biofiltered onsite at 30% EIA
$V_{30\%EIA} = 0.95*(0.75/12)*2.5 = 0.15$ ac-ft [See Equation 2-8]

3) Determine the impervious area from which runoff is actually retained
$A_{ActualEIA} = ((55/100)*10) - ((40/100)*10) = 1.5$ acres [See Equation 2-9]

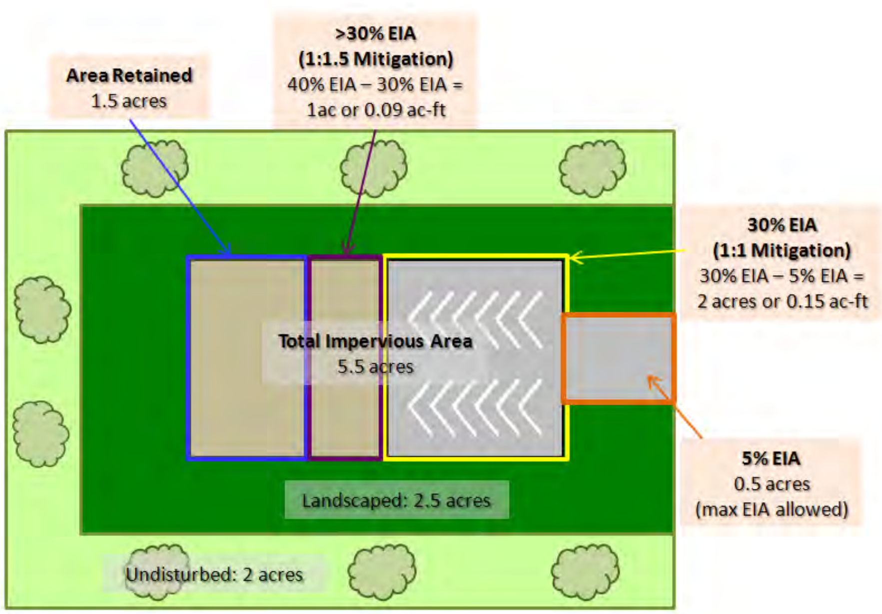
4) Determine the volume that is actually retained or biofiltered onsite
$V_{ActualEIA} = 0.95*(0.75/12)*1.5 = 0.09$ ac-ft [See Equation 2-10]

5) Determine Mitigation Volume for 30% EIA
$V_{Mitigation30\%} = 0.3 - 0.15 = 0.15$ ac-ft [See Equation 2-11]

6) Determine Mitigation Volume for >30%
$V_{Mitigation>30\%} = (0.15-0.09) *1.5 = 0.09$ ac-ft [See Equation 2-12]

7) Determine the Total Mitigation Volume
$V_{MitigationTotal} = 0.15 + 0.09 = 0.24$ ac-ft [See Equation 2-13]

The required offsite mitigation volume is 0.24 ac-ft



Selecting Offsite Mitigation Projects

Project applicants may identify offsite mitigation projects. Project applicants are responsible for completing offsite mitigation projects that will achieve equivalent volume and pollutant load reduction using Retention and/or Biofiltration BMPs sized for the mitigation volume. Offsite mitigation projects must adhere to the following criteria:

- Offsite mitigation projects must be located within the same hydrologic area (see map in Appendix B)
- Offsite mitigation projects must be completed as soon as possible and at the latest, within 4 years of the certificate of occupancy for the original project.

Examples of Offsite Mitigation Projects

Mitigation projects should target urbanized areas that were developed without stormwater mitigation. All projects must be approved by the local permitting agency and must adhere to the BMP Selection Criteria presented in Section 3.3 of the 2011 TGM. Potential project types may include:

- Convert a convex parking lot landscaped island into a depressed bioretention area designed to retain parking lot runoff.
- Convert a traditionally-paved parking lot into porous pavement.
- Modify an existing detention pond into a retention pond.
- Install bioretention in bump-outs, in parkways, or in roadway medians.
- Install bioretention in sidewalk areas to infiltrate roof, sidewalk, and/or roadway runoff. Sidewalks must be wide enough to permit foot traffic around bioretention area.
- Incorporate infiltration BMPs into landscaped areas that collect runoff from impervious surfaces.
- Regional BMPs.

Offsite Mitigation Fee

In some cases, Alternative Compliance may be achieved through an Offsite Mitigation Fee. A l ist of offsite mitigation projects available for funding will be identified by the Approval Agencies. Applicants should contact their local Approval Agency for more information. The Offsite Mitigation Fee may not be available in all jurisdictions.

2.8 Step 7: Apply Treatment Control Measures

Stormwater runoff from EIA and developed pervious surfaces shall be mitigated using Retention BMPs, Biofiltration BMPs, or Treatment Control Measures [Chapter 6] selected per the BMP selection process outlined in Section 3.3. Biofiltration BMPs and Treatment Control Measures may be sized to meet the Stormwater Quality Design Volume (SQDV) or the Stormwater Quality Design Flow (SQDF). Treatment Control Measures should be designed in adherence with the guidance provided in Section 6 of the 2011 TGM in order to assure a level of pollutant removal comparable to those listed in Attachment "C" of Order R4-2010-0108 (also provided in Appendix D.1).

Projects that are eligible for Offsite Mitigation must still provide treatment for all impervious surfaces and developed pervious areas using Treatment Control Measures sized to meet the SQDV or SQDF on site. Treatment Control Measures must be selected per the BMP selection process outlined in Section 3.3.

Stormwater Quality Design Volume (SQDV)

Volume-based Treatment Control Measures must be sized to capture and treat the runoff volume from the water quality design storm. The SQDV shall be calculated using the following four allowable methodologies:

1) The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or

2) The volume of annual runoff based on unit basin storage water quality volume to achieve 80 percent or more volume treatment; or

3) The volume of runoff produced from a 0.75 inch storm event; or

4) Eighty (80) percent of the average annual runoff volume using an appropriate public domain continuous flow model [such as Storm Water Management Model (SWMM) or Hydrologic Engineering Center – Hydrologic Simulation Program – Fortran (HEC-HSPF)], using the local rainfall record and relevant BMP sizing and design data.

The allowable design storm calculation methodology for Treatment Control Measures, per Order R4-2010-0108, is determined by the total project disturbed land area, as summarized in Table 2-2 below.

Table 2-2: Allowed Design Storm Methodology Based on Project Size

Project Size (Disturbed Land Area[1])	Allowed Design Storm Methodology
Less than 5 acres	(1), (2), (3), or (4)
5 acres - 50 acres	(1), (2), or (4)
More than 50 acres	(4)

[1] "Disturbed Area" means any area that is altered as a result of land disturbance, such as clearing, grading, grubbing, stockpiling or excavation.

Instructions for calculating the SQDV based on method (3), the volume of runoff produced from a 0.75 inch storm event, are provided below. Instructions for calculating the SQDV for methods (1), (2), and (4) are provided in Appendix E. Note that Biofiltration BMPs must be sized to treat 1.5 times the volume not retained using Retention BMPs as indicated in Step 5e.

Calculation Procedure

1) Determine the area from which runoff must be retained or captured and treated ($A_{project}$).

2) Determine the runoff coefficient (C), using Equation 2-13 below:

$$C = 0.95*imp + C_p (1-imp) \qquad \text{(Equation 2-13)}$$

Where:

C = runoff coefficient (equals 0.95 for impervious surfaces)

imp = impervious fraction of watershed

C_p = pervious runoff coefficient, determined based on soil type using table below [see Ventura County Hydrology Manual (2006)]:

Table 2-3: Ventura Soil Type Pervious Runoff Coefficients

Ventura Soil Type (Soil Number)	C_p value
1	0.15
2	0.10
3	0.10
4	0.05
5	0.05
6	0
7	0

3) Determine the stormwater runoff design volume (SQDV), using Equation 2-14 below:

$$SQDV = C*(0.75/12)*A_{project} \qquad \text{(Equation 2-14)}$$

Where:

SQDV	=	the stormwater quality design volume (acre-feet)
C	=	runoff coefficient, calculated by Equation 2-13
0.75	=	the design rainfall depth (in) [based on sizing method (3)]Atrib
$A_{project}$	=	drainage area of the tributary catchment (acres)

Stormwater Quality Design Flow (SQDF)

For the purposes of the 2011 TGM, instructions for calculating the SQDF based on method (1), the flow of runoff produced from a rainfall event equal to at least 0.2 inches per hour intensity, are provided below. Instructions for calculating the SQDF for methods (2), and (3) are provided in Appendix E. Note that flow-based Biofiltration BMPs used to achieve 5% EIA must be sized per the design intensity specified in Table 2-1.

Calculation Procedure

1) Determine the drainage area from which the flow-based BMP will be receiving runoff ($A_{project}$).

2) Calculate the runoff coefficient (C), using Equation 2-13.

3) Calculate the SQDF using Equation 2-15 below:

$$SQDF = C*I*A_{project} \quad \text{(Equation 2-15)}$$

Where:

SQDF	=	flow in cubic feet per second (cfs)
C	=	runoff coefficient, calculated by Equation 2-13 above
I	=	average rainfall intensity (inches/hour) for a duration equal to the time of concentration of the watershed [equal to 0.2 in/hr for method (1); see also Table 2-1:]
$A_{project}$	=	drainage area of the tributary catchment (acres)

2.9 Step 8: Continue Project Design Process: Flood Control and Hydromodification Requirements

The project applicant should continue with the design process to address additional requirements including flood control and hydromodification control criteria.

Step 8a: Flood Control Requirements

Applicants shall comply with Ventura County and local approval agency regulations on floodplain and floodway management.

Step 8b: Hydromodification (Flow/Volume/Duration) Control Criteria

Projects meeting the applicability criteria contained in Section 4.E.II of Order R4-2010-0108 (presented in Section 1.5 of the 2011 TGM) are required to implement hydrologic control measures to prevent accelerated erosion and to protect stream habitat in downstream natural drainage systems. Natural drainage systems are defined as unlined or unimproved (not engineered) creeks, streams, rivers and their tributaries.

Exemptions

The following new development and redevelopment projects are exempt from the hydromodification control criteria:

1) Single-family structures, unless such projects disturb one acre or more of land or create, add, or replace 10,000 square feet or more of impervious surface area.

2) All projects that disturb less than one acre.

3) Projects that are replacement, maintenance, or repair of an Agency's existing flood control facility, storm drain, or transportation network.

4) Redevelopment projects in existing urban areas [see maps in Appendix B] that do not increase the effective impervious area or decrease the infiltration capacity of pervious areas compared to the pre-developed condition.

5) Projects that have any increased discharge directly or via a storm drain to a sump, lake, area under tidal influence, into a waterway that has a 100-year peak flow (Q100) of 25,000 cubic feet per second (cfs) or more, or other receiving water that is not susceptible to hydromodification impacts.

6) Projects that discharge directly or via a storm drain into concrete or improved (not natural) channels (e.g., rip rap, sackcrete, etc.), which, in turn, discharge into receiving water that is not susceptible to hydromodification impacts (as in #5 above).

Hydromodification Control Measures

The purpose of Hydromodification Control Measures is to minimize changes in post-development stormwater runoff discharge rates, velocities, and durations by maintaining within a certain tolerance, the project's pre-developed stormwater runoff flow rates and durations.

Hydromodification Control Measures may include onsite, subregional, or regional Hydromodification Control Measures, Retention BMPs, or stream restoration measures. Preference must be given to onsite Retention BMPs and Hydromodification Control Measures. In-stream restoration measures may not adversely affect the beneficial uses of natural drainage systems.

The Southern California Stormwater Monitoring Coalition (SMC) is developing a regional methodology to eliminate or mitigate the adverse impacts of hydromodification as a result of urbanization, including hydromodification assessment and management tools. The Program will develop and implement watershed-specific Hydromodification Control Plans (HCPs) after the completion of the SMC study. Until the completion of the HCPs, the Interim Hydromodification Control Criteria, described below, apply to applicable, non-exempt new development and redevelopment projects.

Interim Hydromodification Control Criteria

1) Projects disturbing less than 50 acres must comply with the Stormwater Management Standards contained in the 2011 TGM (i.e., a combination of Retention BMPs, Biofiltration BMPs, and/or Treatment Control Measures).

2) Projects disturbing 50 acres or greater must develop and implement a Hydromodification Analysis Study (HAS) that demonstrates that post development conditions are expected to approximate the pre-developed erosive

effect of sediment transporting flows in receiving waters. The HAS must lead to the incorporation of project design features intended to approximate, to the extent feasible, an Erosion Potential value of 1, or any alternative value that can be shown to be protective of the natural drainage systems from erosion, incision, and sedimentation that can occur as a result of flow increases from impervious surfaces and damage stream habitat in natural drainage systems. The methodology for calculating Erosion Potential is provided in Appendix E of Order R4-2010-0108. Project proponents must work with their local permitting authority to ensure that the HAS is correctly prepared.

2.10 Step 9: Develop Maintenance Plan

The Ventura Countywide Stormwater Quality Management Program (Program) requires the submittal of a M aintenance Plan and execution of a M aintenance Agreement with the owner/operator of any stormwater control that requires maintenance including Site Design Principles and Techniques (Section 4); Source Control Measures (Section 5; and Retention BMPs, Biofiltration BMPs, and Treatment Control Measures (Section 6). Maintenance Plans must include guidelines for how and when inspection and maintenance should occur for each control. Section 7 and Appendices H and I provide additional information and guidance on compliance with maintenance requirements.

3 SITE ASSESSMENT AND BMP SELECTION

3.1 Assessing Site Conditions and Other Constraints

Assessing a site's potential for implementation of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures requires both the review of existing information and the collection of site-specific measurements. Available information regarding site layout and slope, soil type, geotechnical conditions, and local groundwater conditions should be reviewed as discussed below. In addition, soil and infiltration testing should be conducted to determine if stormwater infiltration is feasible and to determine the appropriate design infiltration rates for infiltration-based treatment BMPs.

Site Conditions

Topography

The site's topography should be assessed to evaluate surface drainage and topographic high and low points, as well as to identify the presence of steep slopes that qualify as Hillside Locations. All of these conditions have an impact on what type of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures will be most beneficial for a given project site. Stormwater infiltration is more effective on level or gently sloping sites. Flows on slopes steeper than 15% may runoff as surface flows, rather than infiltrate into the ground. On hillsides, infiltrated runoff may daylight or resurface a short distance downslope, which could cause slope instability depending on the soil or geologic conditions. See the Geotechnical Considerations section below.

Soil Type and Geology

The site's soil types and geologic conditions should be determined to evaluate the site's ability to infiltrate stormwater and to identify suitable, as well as unsuitable, locations for infiltration-based BMPs (e.g., infiltration basins and trenches, bioretention without an underdrain, permeable pavement, and drywells). Using the Soil Survey completed by the Soil Conservation Service (SCS) (now identified as the Natural Resource Conservation Service [NRCS]) of the U. S. Department of Agriculture in April 1970, soils in Ventura County were grouped into seven hydrologically homogeneous families [see Ventura County Hydrology Manual (2006); also see Appendix B]. Two families were assigned to each of the NRCS Hydrologic Soil Groups A, B, and C; while only one family was considered appropriate for NRCS Hydrologic Soil Group D [for further information, see http://soils.usda.gov/]:

- Group A soils are typically sands, loamy sands, or sandy loams. Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep and well to excessively drained sands or gravels and have a high rate of water transmission. Ventura County soil numbers 6 and 7 are Group A soils.

- Group B soils are typically silty loams or loams. They have a moderate infiltration rate when thoroughly wetted and consist chiefly of moderately deep to deep and moderately well to well drained soils with moderately fine to moderately coarse texture. Ventura County soil numbers 4 and 5 are Group B soils.

- Group C soils are typically sandy clay loams. They have low infiltration rates when thoroughly wetted, consist chiefly of soils with a layer that impedes downward movement of water, and/or have moderately fine to fine soil structure. Ventura County soil numbers 2 and 3 are Group C soils.

- Group D soils are typically clay loams, silty clay loams, sandy clays, silty clays, or clays. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with high swelling potential, permanent high water table, claypan or clay layer at or near the surface, and/or shallow soils over nearly impervious material. Ventura County soil number 1 is a Group D soil.

Infiltration-based BMPs should be feasible in areas mapped with Ventura County Soil Numbers 4 through 7. If site-specific data is available, then soils with infiltration rates of 0.5 in/hr or greater are considered feasible for infiltration. Infiltration-based BMPs should not be designed for sites mapped with Ventura County Soil Numbers 1 through 3 (unless site specific testing is performed and shows an i nfiltration rate greater than 0.5 in/hr) or with site-specific infiltration rates less than 0.5 in/hr.

Locations where soils are mapped with Ventura Hydrology Manual Soil Number 3, or where a site-specific analyses show that the soils have an infiltration rate of 0.3 to 0.5 inches per hour, and no other infiltration-related infeasibility criteria apply, shall use a Bioinfiltration BMP (or Rainwater Harvesting). Bioinfiltration is an adaption of the Bioretention with an Underdrain BMP in which the underdrain is raised above the gravel storage layer in order to promote infiltration but allow release of biotreated runoff to the storm drain when infiltration capacity is reached.

Early identification of soil types throughout the project footprint can reduce the number of test pit investigations and infiltration tests needed. Early identification reduces the number of potential test sites to locations with those that are most likely to be amenable to infiltration. Guidance for conducting test pit investigations and infiltration tests is provided in Appendix C.

Project applicants should review available geologic or geotechnical reports on local geology to identify relevant features such as depth to bedrock, rock type, lithology, faults, and hydrostratigraphic or confining units. These geologic investigations may also identify shallow water tables and past groundwater issues that are important for BMP design (see below).

Groundwater Considerations

Site groundwater conditions should be considered prior to Retention BMP, Biofiltration BMP, and Treatment Control Measure siting, selection, sizing, and design. The depth to groundwater beneath the project during the wet season may preclude infiltration, since five feet of separation to the seasonal high ground water level and mounded groundwater level is required. Depth to seasonal high groundwater level shall be estimated as the average of the annual minima (i.e., the shallowest recorded measurements in each water year, defined as October 1 through September 30) for all years on record. If groundwater level data are not available or not considered to be representative, seasonal high groundwater depth can be determined by redoximorphic analytical methods combined with temporary groundwater monitoring for November 1 through April 1 at the proposed project site.

In areas with known groundwater pollution, infiltration may need to be avoided, as it could contribute to the movement or dispersion of groundwater contamination. Areas with known groundwater impacts include sites listed by the Los Angeles Regional Water Quality Control Board's Leaking Underground Storage Tanks (LUST) program and Site Cleanup Program (SCP). The California State Water Resources Control Board maintains a database of registered contaminated sites through their 'Geotracker' Program. Registered contaminated sites can be identified in the project vicinity when the site address is typed into the "map cleanup sites" field.

Mobilization of groundwater contaminants may also be of concern where contamination from natural sources is prevalent (e.g., marine sediments, selenium rich groundwater, to the extent that data is available). Infiltration on sites with contaminated soils or groundwater that could be mobilized or exacerbated by infiltration is not allowed, unless a site-specific analysis determines the infiltration would be beneficial. A site-specific analysis may be conducted where groundwater pollutant mobilization is a concern to allow for infiltration-based BMPs.

Research conducted on the effects of stormwater infiltration on groundwater by Pitt et al. (1994) indicate that the potential for contamination due to infiltration is dependent on a number of factors, including the local hydrogeology and the chemical characteristics of the pollutants of concern. Chemical characteristics that influence the potential for groundwater impacts include high mobility (low absorption potential), high solubility fractions, and abundance of pollutants in urban runoff. As a class of constituents, trace metals tend to adsorb onto soil particles and are filtered out by the soils. This has been confirmed by extensive data collected beneath stormwater detention/retention ponds in Fresno (conducted as part of the Nationwide Urban Runoff Program (Brown & Caldwell, 1984)) that showed that trace metals tended to be adsorbed in the upper few feet in the bottom sediments. Bacteria are also filtered out by soils. More mobile and soluble pollutants, such as chloride and nitrate, have a greater potential for impacting groundwater.

Where soils have very high infiltration rates, groundwater quality may be impacted by infiltration BMPs. Prior to the use of infiltration basins and subsurface infiltration BMPs in areas with high infiltration rates, consult with the local

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regulatory agencies to identify if unconfined aquifers are located beneath the project to determine the appropriateness of infiltration-based BMPs. In areas underlain by unconfined aquifers with designated beneficial groundwater uses (e.g. drinking water supply), the application of infiltration BMPs should be limited to those that provide significant pretreatment to ensure groundwater is protected from pollutants of concern.

Geotechnical Considerations

Water infiltration can cause geotechnical issues, including: (1) settlement through collapsible soil, (2) expansive soil movement, (3) slope instability, and (4) increased liquefaction hazard. Stormwater infiltration temporarily raises the groundwater level near the infiltration facility, such that the potential geotechnical conditions are likely to be of greatest significance near the infiltration area and decrease with distance. A geotechnical investigation should be performed for the infiltration facility to identify potential geotechnical issues and geological hazards that may result from infiltration.

In general, infiltration-based BMPs must be set back from building foundations or steep slopes. Increased water pressure in soil pores reduces soil strength. Decreased soil strength can make foundations more susceptible to settlement and slopes more susceptible to failure. Recommendations for each site should be determined by a licensed geotechnical engineer based on soils boring data, drainage patterns, and the current requirements for stormwater treatment. Implementing the geotechnical engineer's requirements is essential to prevent damage from increased subsurface water pressure on surrounding properties, public infrastructure, sloped banks, and even mudslides.

Collapsible Soil

Typically, collapsible soil is observed in sediments that are loosely deposited, separated by coatings or particles of clay or carbonate, and subject to saturation. Stormwater infiltration will result in a temporary rise in the groundwater elevation. This rise in groundwater could change the soil structure by dissolving or deteriorating the intergranular contacts between the sand particles, resulting in a sudden collapse, referred to as hydrocollapse. This collapse phenomenon generally occurs during the first saturation episode after deposition of the soil, and repeated cycles of saturation are not likely to result in additional collapse. It is important to evaluate the potential for hydrocollapse during the geotechnical investigation.

The magnitude of hydrocollapse is proportional to the thickness of the soil column where infiltration is occurring. In most instances, the magnitude of hydrocollapse will be small. Regardless, the geotechnical engineer should evaluate the potential effects of hydrocollapse from large infiltration facilities on nearby structures and roadways. Typically, a network of surface settlement monuments is installed around the infiltration site, along adjacent roadways, and in neighboring developments to evaluate if hydrocollapse has occurred. These monuments are typically monitored prior to infiltrating stormwater, monthly during the first year of operation of the facility, then yearly thereafter for a period of approximately five years.

Expansive Soil

Expansive soil is generally defined as soil or rock material that has a potential for shrinking or swelling under changing moisture conditions. Expansive soils contain clay minerals that expand in volume when water is introduced and shrink when the water is removed or the material is dried. When expansive soil is present near the ground surface, a rise in groundwater from infiltration activities can introduce moisture and cause these soils to swell. Conversely, as the groundwater surface falls after infiltration, these soils will shrink in response to the loss of moisture in the soil structure. The effects of expansive soil movement (swelling and shrinking) will be greatest on near surface structures such as shallow foundations, roadways, and concrete walks. Basements or below-grade parking structures can also be affected as additional loads are applied to the basement walls from the large swelling pressures generated by soil expansion. A geotechnical investigation should identify if expandable materials are present near the proposed infiltration facility, and if they are, evaluate if the infiltration will result in wetting of these materials. See Appendix B, Map B-14 (expansive soil potential map).

Slopes

Slopes near the infiltration facility can be affected by the temporary rise in groundwater. The presence of a water surface near a slope can substantially reduce the stability of the slope from a dry condition. A groundwater mounding analysis should be performed to evaluate the rise in groundwater around the facility. If the computed rise in groundwater approaches nearby slopes, then a separate slope stability evaluation should be performed to evaluate the implications of the temporary groundwater surface. The geotechnical and groundwater mounding evaluations should identify the duration of the elevated groundwater and assign factors of safety consistent with the duration (e.g., temporary or long-term conditions).

Liquefaction

Seismically-induced soil liquefaction is a phenomenon in which saturated granular materials, typically possessing low to medium density, undergo matrix rearrangement, develop high pore water pressure, and lose shear strength due to cyclic ground motions induced by earthquakes. This rearrangement and strength loss is followed by a reduction in bulk volume. Manifestation of soil liquefaction can include loss of bearing capacity for foundations, surface settlements, and tilting in level ground. Soil liquefaction can also result in instabilities and lateral spreading in embankments and areas of sloping ground.

Saturation of the subsurface soils above the existing groundwater table may occur as a result of stormwater infiltration. A groundwater mounding analysis should also evaluate the duration of mounding, as a lengthy duration or long-term rise in groundwater will need to be considered in the evaluation of liquefaction. If the granular soils are sufficiently dense, it is unlikely that liquefaction will be of concern, regardless of the groundwater mounding. If analyses indicate that the potential for liquefaction may be increased from stormwater infiltration, then the analyses will need to evaluate the liquefaction-induced settlement of structures, lateral spreading, and other surface manifestations. See Appendix B, Map B-14 (liquefaction potential map).

Managing Offsite Drainage

Locations and sources of offsite run-on onto the site should be identified early in the design process. Offsite drainage should be considered when determining appropriate BMPs so that drainage can be managed. Concentrated flows from offsite drainage may cause extensive erosion, if not properly conveyed through or around the project site or otherwise managed. By identifying the locations and sources of offsite drainage, the volume of water running onto the site may be estimated and factored into the siting and sizing of onsite BMPs. Vegetated swales or storm drains may be used to intercept, divert, and convey offsite drainage through or around a site to prevent flooding or erosion that might otherwise occur.

Existing Utilities

Existing utility lines that are onsite will limit the possible locations of certain BMPs. For example, infiltration BMPs should not be located near utility lines where the increased amount of water could damage the utilities. Stormwater should be directed away from existing underground utilities. Project designs that require the relocation of existing utilities should be avoided, if possible.

Environmentally Sensitive Areas

The presence of Environmentally Sensitive Areas (ESAs) may limit the siting of certain BMPs. ESA’s are typically delineated by and fall under the regulatory oversight of state or federal agencies such as the U.S. Army Corp of Engineers (USACE), California Department of Fish and Game, U.S. Fish and Wildlife Service, or the California Environmental Protection Agency. BMPs should be selected and sited to avoid adversely affecting an ESA. The Ventura County ESA map (ESA as defined in Order R4-2010-0108) is provided in Appendix B or may be obtained from the local permitting authority.

3.2 Technical Feasibility Screening

To use biofiltration BMPs and alternative compliance measures, the project applicant should demonstrate that compliance with the requirement to reduce EIA to ≤5% using Retention BMPs is technically infeasible by submitting a site-specific hydrologic and/or design analysis conducted and endorsed by a registered professional engineer and/or geologist. Projects seeking to use alternative compliance measures must demonstrate EIA has been reduced to the maximum extent practicable. Project applicants should contact their local Approval Agency to determine if additional infeasibility criteria apply. Technical infeasibility may result from conditions including the following:

1) Locations where seasonal high groundwater or mounded groundwater beneath an infiltration BMP is within 5 feet of the bottom of the infiltration BMP.

2) Locations on the project site where soils are mapped with Ventura Hydrology Manual Soil Numbers 1-2 or site-specific analyses show that the soils have an infiltration rate less than 0.3 inches per hour. Locations where soils are mapped with Ventura Hydrology Manual Soil Number 3, or where a site-specific analyses show that the soils have an infiltration rate of 0.3 to 0.5 inches per hour, and no other infiltration-related infeasibility criteria apply, shall use a Bioinfiltration BMP or Rainwater Harvesting (if feasible) to achieve the 5% EIA requirement.

3) Locations on the project site within 100 feet of a groundwater well used for drinking water, non-potable wells, drain fields, and springs; locations less than 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project; and locations less than eight feet from building foundations or an alternative setback established by the geotechnical expert for the project.

4) Locations where pollutant mobilization is a documented concern, unless a site-specific analysis determines that infiltration would not be detrimental. Portions of brownfield development sites may be eligible for alternative compliance where pollutant mobilization is a concern.

5) Locations with potential geotechnical hazards established by the geotechnical professional for the project.

6) Projects with high-risk areas such as service/gas stations, truck stops, and heavy industrial sites, unless a site-specific evaluation demonstrates that:

   - Treatment is provided to address pollutants of concern, and/or

   - High risks areas are isolated from stormwater runoff or infiltration areas with little chance of spill migration.

7) Locations where reduction of surface runoff may potentially impair beneficial uses of the receiving water as documented in a site-specific study (e.g., California Environmental Quality Act (CEQA) analysis) or watershed plan.

8) Location where an increase in infiltration over natural conditions could potentially cause impairments to downstream beneficial uses, such as change of seasonality of ephemeral washes, as confirmed through a site-specific study.

9) Green roofs are not required to be considered for all project locations and types; this evapotranspiration BMP is considered optional subject to the approval of the permitting authority.

10) Projects that do not provide sufficient demand for harvested stormwater such that the system provides 80% capture with a 72 hour drawdown time considering all "allowable and reliable demand."

    a. Allowable and reliable demand is defined as the rate of use of harvested water under average wet season conditions (November through March), from sources meeting the following criteria:

        - The use is permitted by building codes and health codes without requiring disinfection and fine filtration.

        - The use is reliable on a seasonal basis, such that the lowest weekly demand on an average annual basis is no less than 2/7th of the wet season average. *Intent: Under worst-case conditions, the demand should still be sufficient to use the entire tank volume within a week.*

        - Where a reliable use is present on the site that is not permitted by building codes and/or health codes, a variance has been sought to allow use without disinfection and fine filtration.

        - The use does not conflict with mandatory use of reclaimed water. It is assumed that uses do not conflict unless water balance calculations are provided to demonstrate the contrary.

        - The estimated use rates are consistent with requirements for low water use landscaping requirements under local and statewide ordinance (including California Assembly Bill 1881).

11) BMPs that are not allowable per current federal, state or local codes are considered infeasible. Local codes will be updated by mid-2012 as required in Order R4-2010-0108 (Provision III.D).

12) The following project types where the density and/or nature of the project would create significant difficulty for compliance with the requirement to reduce EIA to ≤5%:

    a. Redevelopment projects (as defined in Section1.5).

    b. Infill projects that meet the following conditions:

        i. The project is consistent with applicable general plan designation, and all applicable general plan policies, and applicable zoning designation and regulations;

ii. The proposed development occurs on a project site of no more than five acres substantially surrounded by urban uses;

iii. The project site has no value as habitat for endangered, rare, or threatened species;

iv. Approval of the project would not result in any significant effects relating to traffic, noise, air quality, or water quality; and

v. The site can be adequately served by all required utilities and public services (modified from State Guidelines § 15332).

c. Smart Growth projects, which are defined as new development and redevelopment projects that occur within existing urban areas (see maps in Appendix B) designed to achieve the majority of the following principles :

i. Create a range of housing opportunities and choices;

ii. Create walkable neighborhoods;

iii. Mix land uses;

iv. Preserve open space, natural beauty, and critical areas;

1. Farmland preservation may also be considered for projects occurring outside existing urban areas (as defined by the Appendix B maps).

v. Provide a variety of transportation choices;

vi. Includes transit oriented development (development located within an average 2,000 foot walk to a bus or train station).

vii. Strengthen and direct development towards existing communities (as defined by Appendix B maps); and

viii. Take advantage of compact building design.

The City or County Planning Division in which a project is proposed will ultimately determine whether a project meets these Smart Growth criteria.

13) Pedestrian/bike trail projects:

- ✓ Located along side of a road and
- ✓ Where right-of-way width is inadequate for the implementation of Retention and/or Biofiltration BMPs.

14) Agency flood control, drainage, and wet utilities projects:

- ✓ Located within waterbody and is therefore not increasing functional impervious cover; or
- ✓ Located on top of a narrow flood control feature (such as a levee) and space is unavailable for the implementation of Retention and/or Biofiltration BMPs; or
- ✓ Where the integrity of the flood control feature (such as a dam or levee) may be compromised through Retention and/or Biofiltration BMPs (e.g., infiltration of stormwater is not appropriate in a levee).

15) Historical preservation projects:

- ✓ Where the extent of the designated preservation area restricts the amount of land available for the implementation of Retention BMPs.

16) Low income housing projects that occur within existing urban areas (as defined by the maps provided in Appendix B):

- ✓ Where density requirements restrict the amount of land available for the implementation of Retention BMPs and/or
- ✓ Where project financing constraints restrict the amount of land available for the implementation of Retention BMPs.

Determining Maximum Volume Feasibly Infiltrated and/or Biofiltered

Site conditions and constraints may make it infeasible to fully retain stormwater to achieve ≤ 5% EIA using Retention BMPs. In such cases, stormwater runoff must be retained to the maximum extent practicable and then the remaining volume must be multiplied by 1.5 and biofiltered to the maximum extent practicable. If SQDV still remains, it may be addressed in an alternative compliance program. This section provides narrative and numeric criteria for determining the "maximized" volume for Infiltration BMPs and Biofiltration BMPs. The term "maximized" refers to the volume that is determined, on a case-by-case basis, to be consistent with the maximum extent practicable standard.

Criteria for Maximizing Infiltration Volume

Volume can be considered to be maximized in infiltration BMPs when all of the following conditions are met, or when adjustments to the site/BMP plan to meet any one of these criteria results in achievement of the ≤5% EIA performance standard:

1) BMPs are designed to the maximum depth allowed by design standards, but are not required to exceed the depth that infiltrates within 48 hours at the design percolation rate. *Explanation: Deeper BMPs provide more volume per footprint*

area, therefore it is more feasible to retain stormwater in deeper BMPs than shallower BMPs. However, because of the nature of sequential storms in Southern California, the volume provided in excess of that which drains within 48 hours provides significantly diminishing value.

2) All practicable methods are employed to enhance the design percolation rate, including:

    - Use of soil amendments to native soil below infiltration BMPs, and
    - Provision of pretreatment to reduce the allowable factor of safety, and
    - Additional site investigation to reduce uncertainty in infiltration rate and allow the use of a lower factor of safety.

3) Good site practices have been integrated to provide the maximum pervious area feasible for infiltration BMPs, and infiltration BMPs have been configured to make use of this area. Table 3-1 provides recommended percentages of a site, by project type, that should be feasible to dedicate to infiltration BMPs (where technically feasible) within pervious areas. If the project has not provided this portion of the project site for infiltration BMPs (where technically feasible), an attempt should be made to improve site design to provide more pervious area until it is either infeasible to provide more pervious area or EIA is reduced to ≤5%. The minimum percent of parking lot pavement area considered feasible to dedicate to permeable pavement (where technically feasible) is 20%; this does not apply to parking lots that anticipate heavy truck traffic such as truck stops and heavy industrial areas. The criteria provided in Table 3-1 are guidance; each project will be individually evaluated by the local permitting authority to determine if good site practices have been integrated into the project to provide the maximum pervious area feasible for siting infiltration BMPs.

Criteria for Maximizing Biofiltration Volume

Biofiltration BMPs can be used downstream of a R etention BMP that has been "maximized" (e.g., a planter box treating overflow from a cistern) or can be designed to provide both "maximized" retention and "maximized" biofiltration in the same BMP (e.g., a bioretention area with an underdrain, where retention volume is provided in a gravel layer or other subsurface reservoir below the underdrain).

Volume can be considered to be maximized in Biofiltration BMPs when all of the following conditions are met, or when adjustments to the site design and BMP plan to meet any one of these criteria results in achievement of the ≤5% EIA performance standard:

1) Drain time and/or treatment rate of the Biofiltration BMP is consistent with design guidance contained in Section 6 of the 2011 TGM.

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2) Good site practices have been integrated to provide the maximum area feasible for Biofiltration BMPs, and BMPs have been configured to make use of this area. Table 3-1 provides recommended percentages of a site that are feasible to be dedicated to Biofiltration BMPs by project type. If the project has not provided these portions of the project site for siting Biofiltration BMPs, an attempt should be made to improve site design to provide more area until it is either infeasible to provide more area or EIA is reduced to ≤5%. The criteria provided in Table 3-1 are guidance; each project will be individually evaluated by the local permitting authority to determine if good site practices have been integrated into the project to provide the maximum pervious area feasible for siting Biofiltration BMPs.

If a Biofiltration BMP also includes a retention component (e.g., storage volume in a swale in amended soil below the surface discharge elevation or storage below the underdrain of a bioretention area), the maximized retention volume is determined as the volume of water that can be infiltrated or evapotranspired within 48 hours after the Biofiltration BMP has emptied. This criterion should be used to establish the depth of the retention layer (i.e., the depth of amended soil below the swale or the size of the storage below underdrains in the bioretention area).

Table 3-1: Recommended Criteria for Percent of Site Feasible to Dedicate to BMPs

Project Type		Percent of Site[1]
New Development	SF/MF Residential < 7 du/ac	10
	SF/MF Residential 7 – 18 du/ac	7
	SF/MF Residential > 18 du/ac	5
	Mixed Use, Commercial, Institutional/Industrial w/ FAR < 1.0	10
	Mixed Use, Commercial, Institutional/Industrial w/ FAR 1.0 – 2.0	7
	Mixed Use, Commercial, Institutional/Industrial w/ FAR > 2.0	5
	Podium (parking under > 75% of project)	3
	Projects with zoning allowing development to lot lines	2
	Transit Oriented Development	5
	Parking	5

Project Type		Percent of Site[1]
Redevelopment	SF/MF Residential < 7 du/ac	5
	SF/MF Residential 7 – 18 du/ac	4
	SF/MF Residential > 18 du/ac	3
	Mixed Use, Commercial, Institutional/Industrial w/ FAR < 1.0	5
	Mixed Use, Commercial, Institutional/Industrial w/ FAR 1.0 – 2.0	4
	Mixed Use, Commercial, Institutional/Industrial w/ FAR > 2.0	3
	Podium (parking under > 75% of project)	2
	Projects with zoning allowing development to lot lines	1
	Transit Oriented Development	3
	Projects in Historic Districts	3

Key: SF = Single Family, MF = Multi Family, du/ac = dwelling units per acre, FAR = Floor Area Ratio = ratio of gross floor area of building to gross lot area.

[1] If subsurface BMPs are used, dedicated area may have other surface land uses which do not structurally impact the subsurface BMP (see INF-6: Proprietary Infiltration).

3.3 Treatment Control Measure Selection Guidance

Treatment Control Measure selection criteria contained in Order R4-2010-0108 include the following:

- Treatment Control Measures shall be selected based on the primary class of pollutants likely to be discharged from the project (e.g., metals from an auto repair shop).
- For projects that discharge to an impaired waterbody and whose discharges contain the pollutant causing impairment, the project shall select Treatment Control Measures from the top three performing BMP categories, or alternative BMPs that are designed to meet or exceed the performance of the highest performing BMP, for the pollutant causing impairment.

Primary Class of Pollutants

Pollutants in stormwater runoff are typically related to land use activities, which means that the proposed project's site uses provide some indication of the pollutants that will be generated in the site's runoff. Table 3-2 identifies pollutants of concern based on typical land use activities that may be present on a project site.

Table 3-2: Land Uses and Associated Pollutants

Class of Pollutant	Potential Land Use and Activities Sources
Sediment (TSS and Turbidity)	Streets, driveways, roads, landscaped areas, construction activities, soil erosion (channels and slopes)
Nutrients	Landscape fertilizers, atmospheric deposition, automobile exhaust, soil erosion, animal waste, detergents
Metals/Metalloids	Automobiles, bridges, atmospheric deposition, industrial areas, soil erosion, metal surfaces, combustion processes
Pesticides	Landscaped areas, roadsides, utility right-of-ways
Organic Materials/ Oxygen Demanding Substances	Landscaped areas, animal wastes, industrial wastes
Oil and Grease/ Organics Associated with Petroleum	Roads, driveways, parking lots, vehicle maintenance areas, gas stations, automobile emissions, restaurants
Bacteria and Viruses	Lawns, roads, leaky sanitary sewer lines, sanitary sewer cross-connections, animal waste (domestic and wild), septic systems, homeless encampments, sediments/biofilms in stormwater conveyance system
Trash and Debris (Gross Solids and Floatables)	Commercial areas, roadways, schools, trash receptacles/storage/disposal

Adapted from US EPA, 1999 (Preliminary Data Summary of Urban Stormwater BMPs)

Impaired Waterbodies

When designated beneficial uses of a particular receiving water body are being compromised by water quality for a specific or multiple pollutants, Section 303(d) of the CWA requires identifying and listing that water body as "impaired".

Table 3-3 below lists the categories of pollutants and specific pollutants that are included on the 2010 303(d) list for Ventura County. Project proponents should consult the most recent 303(d) list to identify whether the project's receiving waterbody is listed as impaired. The most recent 303(d) list is located on the State Water Resources Control Board website (click on water issues/programs/water quality assessment).

Table 3-3: Ventura County 2010 303(d)-listed Water Quality Pollutants

Class of Pollutant	Specific Pollutants		
Sediment (TSS and Turbidity)	Sedimentation/Siltation		
Nutrients	Ammonia Nitrate and Nitrite Nitrate Nitrogen	Organic Enrichment/ Low Dissolved Oxygen	Algae Eutrophic
Metals/Metalloids	Boron Copper Copper, Dissolved	Lead Mercury Nickel	Selenium Zinc
Pesticides	ChemA (tissue) Chlordane Chlordane (tissue & sediment) Chlordane (tissue) Chlorpyrifos Chlorpyrifos (tissue) DDT DDT (sediment) DDT (tissue & sediment)	DDT (tissue) Diazinon Dieldrin Dieldrin (tissue) Organophosphorous Pesticides Toxaphene Toxaphene (tissue & sediment) Toxaphene (tissue)	
Trash and Debris (Gross Solids and Floatables)	Trash and Debris		
Other Organics	PCBs		
Bacteria and Viruses	Coliform Bacteria	Indicator Bacteria	
Salinity	Chloride		
Toxicity	Sediment Toxicity	Toxicity	
Miscellaneous	pH	Scum/Foam - unnatural	Sulfates

Once the classes of pollutants likely to be discharged from the project have been identified for projects that do not discharge to an impaired waterbody, any Treatment Control Measures listed in Table 3-4 that addresses the primary pollutant class may be selected. If more than one pollutant class is identified, then sediment shall be the primary pollutant class.

For projects that discharge to an impaired waterbody and whose discharges contain the pollutant causing impairment, the project shall select Treatment Control Measures from the top three BMPs listed for that class of pollutant in Table 3-4, or alternative BMPs that are designed to meet or exceed the performance of the highest performing Treatment Control Measure, for the pollutant causing impairment. Many receiving water impairments are due to legacy pollutants from past land use activities (e.g., DDT from historical farming or PCBs from historical industrial activities), where the primary sources are contaminated soils and sediment. F or these pollutants, site clean-up, erosion and sediment controls during construction, slope stabilization measures, and placement of impervious surfaces will address the legacy pollutants.

Table 3-4: Treatment Control Measures for Addressing Pollutants of Concern

Class of Pollutant	Recommended BMPs (in Order of Performance)
Sediment	1. Retention BMPs (Infiltration, Rainwater Harvesting, and Evapotranspiration BMPs) 2. Any of the following BMPs(equivalent performance): a. Biofiltration BMPs b. Wet Detention Basin c. Constructed Wetland d. Sand Filter/Cartridge Media Filter 3. Dry Extended Detention Basin
Metals / Metalloids	1. Retention BMPs (Infiltration, Rainwater Harvesting, and Evapotranspiration BMPs) 2. Any of the following BMPs (equivalent performance): a. Constructed Wetland b. Biofiltration BMPs c. Wet Detention Basin d. Sand Filter/Cartridge Media Filter 3. Dry Extended Detention Basin
Nutrients[1]	1. Retention BMPs (Infiltration, Rainwater Harvesting, and Evapotranspiration BMPs) 2. Any of the following BMPs (equivalent performance): a. Bioinfiltration b. Wet Detention Basin c. Constructed Wetland 3. Any of the following BMPs (equivalent performance): a. Biofiltration BMPs 4. Any of the following (equivalent performance): a. Sand Filter/Cartridge Media Filter b. Dry Extended Detention Basin
Pesticides[2]	1. Source controls, erosion controls 2. Retention BMPs (Infiltration, Rainwater Harvesting, and Evapotranspiration BMPs) 3. Any of the following BMPs (equivalent performance): a. Biofiltration BMPs b. Wet Detention Basin c. Constructed Wetland d. Sand Filter/Cartridge Media Filter 4. Dry Extended Detention Basin

Class of Pollutant	Recommended BMPs (in Order of Performance)
Pathogens	1. Retention BMPs (Infiltration, Rainwater Harvesting, and Evapotranspiration BMPs) 2. Any of the following BMPs (equivalent performance): a. Bioretention with Underdrain b. Wet Detention Basins c. Proprietary Biofiltration 3. Sand Filter/Cartridge Media Filter
Trash and Debris	1. Gross Solids Removal BMPs (should be combined with a Retention BMP, Biofiltration BMP, or Treatment Control Measure) 2. Any Retention BMP, Biofiltration BMP, or Treatment Control Measure designed to incorporate a trash capture device (e.g., a trash screen)

[1]Performance is based on removal of nitrogen compounds. For performance of BMPs in removing phosphorous, see sediment pollutant class as they are largely associated with particulates.
[2]Performance data is not available for this pollutant class, but as they are largely associated with particulates, BMP selection should be similar to the sediment pollutant class.

An analysis of Biofiltration BMP and Treatment Control Measure performance from the ASCE International Stormwater BMP Database [1999-2008] is provided in Appendix D. These performance data summaries are occasionally revised. Updated analyses of Biofiltration BMP and Treatment Control Measure performance may be found on the ASCE International Stormwater BMP Database website. The 2011 TGM assumes that BMPs adhering to the design guidance provided in Section 6 will have a level of pollutant removal performance comparable to those listed in Attachment C in Order R4-2010-0108 (also provided in Appendix D.1).

Proprietary BMPs should meet or exceed the performance standards listed in Attachment C in Order R4-2010-0108 and provided in Appendix D.

The data contained in the Stormwater BMP Database indicate that wet detention basins, constructed wetlands, sand filters, and biofilters are among the best performing BMPs for the typical pollutants of concern in urban runoff. This conclusion is consistent with the treatment processes typically provided by these BMP types (e.g., filtration, sedimentation, adsorption, and biological processes).

Wet detention basins (wetponds) and constructed wetlands are attractive solutions both from a treatment process and observed performance perspective. However, these systems require significant base flow to maintain their permanent pools and to avoid creating stagnant conditions and vector concerns. Therefore, these BMPs are often infeasible in locations where water conservation during dry weather is a significant concern. If a regional Treatment Control Measure is desired, infiltration basins and dry extended detention basins may be more feasible in Ventura County. However, these BMPs may need additional treatment train components (e.g., pre- or post-treatment) to adequately address the entire list of pollutants of concern and provide reliable and consistent performance, in addition to significant space requirements. BMP designs for each pollutant category that incorporate dense vegetation and promote extended contact with or filtration through soils are encouraged, consistent with the BMP selection prioritization requirements in Order R4-2010-0108.

Consideration of Site-Specific Conditions

Ultimately, Retention BMPs, Biofiltration BMPs, and Treatment Control Measures have to be constructed at a physical location and site-specific conditions should be considered during the BMP selection process. Site constraints such as steep slopes, poor draining soils, high ground water tables, unstable or contaminated soils and several other factors can preclude the implementation of certain kinds of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures or design options. Therefore, site-specific conditions must be considered when selecting specific BMPs or Treatment Control Measures to implement. Once candidate BMPs or Treatment Control Measures have been chosen, the selection process should consider the site assessment results for soil characteristics, slopes, groundwater proximity, etc. Table 3-5 below provides general guidance for designers regarding site limitations for the different Retention BMPs, Biofiltration BMPs, and Treatment Control Measures.

Table 3-6 below provides general guidance for designers regarding capital and operation costs for the different Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. BMP costs can also be estimated using the Water Environment Research Foundation (WERF) BMP and LID Whole Life Cost Models. These models are set of spreadsheet tools that help users identify and combine capital costs and ongoing maintenance expenditures in order to estimate whole life costs for stormwater management. The models provide a framework for calculating capital and long-term maintenance costs of individual Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. Models are included for retention ponds, extended detention basins, vegetated swales, permeable pavement, green roofs, large commercial cisterns, and bioretention. Online PDF of user's guide and spreadsheet tools are located here: http://www.werf.org/AM/Template.cfm?Section=Research_Profile&Template=/CustomSource/Research/PublicationProfile.cfm&id=SW2R08.

Table 3-5: BMP Site Suitability Considerations

Important Note to Users: This table should be used to provide general BMP comparisons only and should not replace an evaluation performed by a qualified water quality professional.

BMP	Site Suitability Considerations			
	Tributary Area (Acres) [1]	Site Slope (%)	Depth to Seasonally High or Mounded Groundwater (ft)	Soil Number
Infiltration BMPs: INF-1: Infiltration Basin INF-2: Infiltration Trench INF-3: Bioretention INF-4: Drywell INF-6: Proprietary Infiltration	< 5	< 7[2]	> 5	Not suitable in Soil Numbers 1, 2, and 3 unless percolation testing shows the infiltration rate is greater than 0.5 in/hr
INF-5: Permeable Pavement	< 5	< 5[2,5]	> 2 with underdrains; > 5 without underdrains	Underdrains should be provided for Soil Numbers 1, 2, and 3
ET-1: Green Roof	Equal to roof tributary area	N/A	N/A	N/A
BIO-1: Bioretention with Underdrain	< 5	< 15; planter boxes are generally more suitable for steep slopes[2,3]	> 2 with underdrains; > 5 without underdrains	Underdrains should be provided for Soil Numbers 1, 2, and 3
BIO-2: Planter Box	< 1	< 15[4]	> 2	Any
BIO-3: Vegetated Swale	< 5	< 10 site slope; 0.5 to 6 longitudinal slope of swale [2,3]	> 2 with underdrains; > 5 without underdrains	Any[3]

BMP	Site Suitability Considerations			
	Tributary Area (Acres) [1]	Site Slope (%)	Depth to Seasonally High or Mounded Groundwater (ft)	Soil Number
BIO-4: Vegetated Filter Strip	< 2	< 4 site slope; 2 to 6 longitudinal slope of strip[2]	> 2	Any
BIO-5: Proprietary Biotreatment Devices	The site suitability requirements for specific proprietary devices must be provided by the manufacturer and should be verified by independent sources or assessed by a qualified water quality professional.			
TCM-4: Sand Filter	< 10	< 15[4]	> 2	Any
TCM-5: Cartridge Media Filters	The site suitability requirements for specific proprietary devices must be provided by the manufacturer and should be verified by independent sources or assessed by a qualified water quality professional.			
PT-1: Hydrodynamic Devices	The site suitability requirements for specific proprietary devices must be provided by the manufacturer and should be verified by independent sources or assessed by a qualified water quality professional.			
PT-2: Catch Basin Inserts				

[1] Tributary area is the area of the site draining to the BMP. Tributary areas provided here should be used as a general guideline only. Tributary areas can be larger or smaller as appropriate.

[2] If site slope exceeds that specified or if the system is within 200 ft from the top of a hazardous slope or landslide area (on the uphill side), a geotechnical investigation analysis and report addressing slope stability shall be prepared by a licensed civil engineer. In addition, for swales, if the longitudinal slope exceeds 6%, check dams should be provided.

[3] If system is located within 50 feet of a sensitive steep slope (on the uphill side), within 10 feet from a structure, has a longitudinal slope less than 1.5% (swales), or has poorly drained soils (e.g., silts and clays), underdrains should be incorporated.

[4] If system is fully contained, includes an underdrain system, and overflows to a stormwater conveyance system, then slopes can exceed 15%.

[5] If a gravel base is used for storage of runoff: (1) slopes should be restricted to 0.5% (steeper grades reduce storage capacity) and (2) underdrains should be used if within 50 feet of a sensitive steep slope.

[6] Setbacks apply to systems without underdrains.

Table 3-6: BMP Cost Considerations

BMP Type	Relative Expense[4] (cost/ac-ft[1] or cost/cfs[2])	Construction Costs (per cubic feet)[3,4]	Typical Cost[3]		Annual Maintenance Cost (% of Construction)[3,4]	Notes
			($/BMP)	Application		
Infiltration Trench	Not included	$4- $50	$45,000	5-ac Commercial Site (65% Impervious)	5%-20%	
Infiltration Basin	$	$1.30 - $18	$15,000	5-ac Commercial Site (65% Impervious)	1% -10%	
Bioretention	Not included	$3- $5.30	$60,000	5-ac Commercial Site (65% Impervious)	5%- 7%	Cost of plants varies. Maintenance costs comparable to cost of typical landscaping.
Swale	$$	$0.25-$0.50	$3,500	5-ac Residential Site (35% Impervious)	5%- 7%	
Filter Strip	$$	$0.00- $1.30	$0- $9,000	5-ac Residential Site (35% Impervious)	$350/ acre/ year (about $0.01/square foot/ year)	
Extended Detention Basin	$$$	$0.50- $1.00	Not included		3 to 6%	Costs vary widely. One 0.3 ac-ft basin was recorded to have cost $160,000[5] $3,132 Annual maintenance costs for per Caltrans[5]
Wet Ponds	$$$	$0.50- $1.00	Not included		3 to 6%	$17,000 Annual maintenance costs for one Caltrans pond[5]
Constructed Wetland	$$$$	$0.60 – $1.25	$125,000	50-Acre Residential Site (35% Impervious)	2%	
Sand Filter	$$$$	$3 - $6	$35,000- $70,000	5-Acre Commercial Site (65% Impervious)		

1 Volume based BMPs

2 Flow based BMPs

3 EPA, 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. Part D, Cost and Benefits Analysis. http://water.epa.gov/scitech/wastetech/guide/stormwater/index.cfm#report

4 CASQA, 2003. New Development and Redevelopment Handbook

5 Figures from Caltrans studies cited in CASQA BMP Handbook.

4 SITE DESIGN PRINCIPLES AND TECHNIQUES

4.1 Introduction

The primary objective of the Site Design Principles and Techniques is to reduce the hydrologic and water quality impacts associated with land development. The benefits derived from this approach include**:**

- Reduced size of downstream Treatment Control Measures and conveyance systems;
- Reduced pollutant loading to onsite Treatment Control Measures and receiving streams; and
- Reduced hydraulic impact on receiving streams.

Site Design Principles and Techniques include the following design features and considerations:

- Site planning;
- Protect and restore natural areas;
- Minimize land disturbance;
- Minimize impervious cover;
- Apply Low Impact Development best management practices (LID BMPs) at various scales: and
- Implement Integrated Water Resource Management Practices.

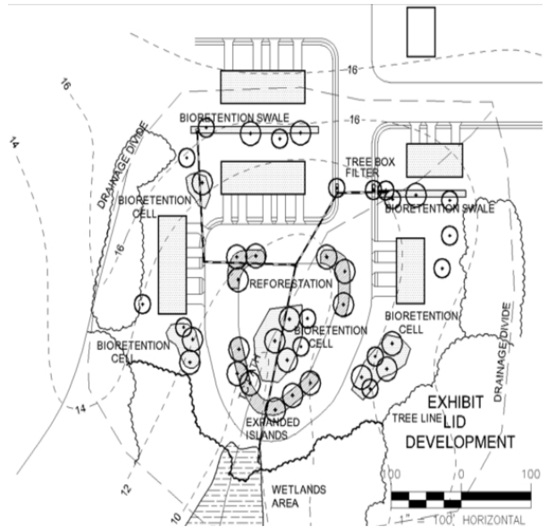
The Site Design Principles and Techniques described in this section are required to be considered for all new development and redevelopment projects subject to conditioning and approval for the design and implementation of post-construction stormwater management control measures (as defined in Section 1.5). They are not required if the project proponent demonstrates to the satisfaction of the City or County that the particular measures are not applicable to the proposed project, or the project site conditions make it infeasible to implement the site design control measure in question. The applicability of specific controls outlined within this section should be confirmed with the local government.

Detailed descriptions and design criteria for each of the Site Design Principles and Techniques are presented in the following section.

4.2 Site Planning

Purpose

LID requires a holistic approach to site design and stormwater management. As such, planners, developers, architects, and engineers should reconsider conventional approaches to stormwater management. The use of site planning techniques presented here will generate a more hydrologically functional site, help to maximize the effectiveness of Retention BMPs, and integrate stormwater management throughout the site.



LID BMPs Integrated within Site Planning Process

Low Impact Development Center, Inc.

Design Criteria

The following criteria should be considered during the early site planning stages:

1) Retention BMPs should be considered as early as possible in the site planning process. Hydrology should be an o rganizing principle that is integrated into the initial site assessment planning phases.

2) Project applicants should anticipate and plan for the space requirements of Retention and Biofiltration BMPs. Table 4-1 provides general rules of thumb for BMP space requirements.

3) Site planning should use a multidisciplinary approach that includes planners, engineers, landscape architects, and architects at the initial phases of the project.

4) Individual Retention BMPs should be distributed throughout the project site and may influence the configuration of roads, buildings, and other infrastructure.

5) The project must demonstrate disconnection of impervious surface such that the 5% EIA requirement is achieved. If fully meeting the 5% EIA requirement using Retention BMPs is not technically feasible, the project must still utilize Retention BMPs to the maximum extent practicable.

6) Consider flood control early in the design stages. Even sites with Retention BMPs will still have runoff that occurs during large storm events. Look for opportunities to simultaneously address flood control requirements and the requirement to reduce EIA to ≤5% presented in Section 2.

7) Consider the use of alternative building materials instead of conventional materials for new construction and renovation. Several studies have indicated that metal used as roofing material, flashing, or gutters can leach metals into the environment. Avoid the use of roofing, gutters, and trim made of copper and galvanized (zinc) roofs, gutters, chain link fences and siding.

8) Consider 2010 Green Building Code requirements during the site planning stages.

Table 4-1: Rule of Thumb Space Requirements for BMPs[5]

BMP Type	% of Contributing Drainage Area
Infiltration	3 to 10
Rainwater Harvesting (Cistern)	0 to 10
Evapotranspiration (Green Roof)	1 to 1 ratio of impervious cover treated
Biofiltration	3 to 5
Dry Extended Detention Basin	1 to 3
Wet Detention Basin	1 to 3
Sand Filters	0 to 5
Cartridge Media Filter	0 to 5

[5] Modified from Schueler, T., D. Hirschman, M. Novotney, and J. Zielinski. 2007. Urban Stormwater Retrofit Practices. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

4.3 Protect and Restore Natural Areas

Purpose

Each project site possesses unique topographic, hydrologic and vegetative features, some of which are more suitable for development than others. Sensitive areas that should be protected and/or restored include streams and their buffers, floodplains, wetlands, steep slopes, and high permeability soils. Additionally, slopes can be a major source of sediment and should be properly protected and stabilized.

Locating development on the least sensitive portion of a s ite and conserving naturally vegetated areas can minimize environmental impacts in general and stormwater runoff impacts in particular.

Stream Buffer

Larry Walker Associates

Design Criteria

If applicable and feasible for the given site conditions, the following site design features or elements are required and should be included in the project site layout, consistent with applicable General Plan and Local Area Plan policies:

1) Identify and cordon off streams and their buffers, floodplains, wetlands, and steep slopes.
2) Reserve areas with high permeability soils for either open space or Infiltration BMPs.
3) Incorporate existing trees into site layout.
4) Identify areas that may be restored or revegetated either during or post-construction.
5) Identify and avoid and/or stabilize areas susceptible to erosion and sediment loss.
6) Concentrate or cluster development on the least-sensitive portions of a site, while leaving the remaining land in a natural undisturbed state.
7) Slopes must be protected from erosion by safely conveying runoff from the tops of slopes.
    - Slopes should be vegetated by first considering use of native or drought-tolerant species.

- Slope protection practices must conform to local permitting agency erosion and sediment control standards and design standards. The design criteria described in this section are intended to enhance and be consistent with these local standards.

8) Limit clearing and grading of native vegetation at the project site to the minimum amount needed to build lots, allow access, and provide fire protection.

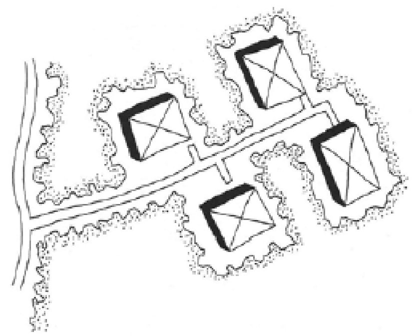
9) Maintain existing topography and existing drainage divides to encourage dispersed flow.

10) Maximize trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native and/or drought-tolerant plants.

11) Promote natural vegetation by using parking lot islands and other landscaped areas. Integrate vegetated BMPs within parking lot islands and landscaped areas.

4.4 Minimize Land Disturbance

Purpose



Minimized Clearing and Grading

Greenfield et al., 1991

This control works to protect water quality by preserving some of the natural hydrologic function of the site. By designing a site layout to preserve the natural hydrology and drainageways on the site, it reduces the need for grading the disturbance of vegetation and soils (GSMM, 2001). By siting buildings and impervious surfaces away from steep slopes, drainageways, and floodplains, it limits the amount of grading, clearing and distance and reduces the hydrologic impact. This site design principle has most applicability in greenfield settings, but opportunities may exist in redevelopment and infill projects.

Existing soils may contain organic material and soil biota that are ideal for storing and infiltrating stormwater. Clearing, grading, and heavy equipment can remove and compact existing soils and, therefore, limit their infiltrative capacity. The design criteria presented below are not intended to supersede compaction requirements associated with building codes.

Design Criteria

1) Delineate and flag the development envelope for the site. Delineating and flagging the development envelope includes a clear indication of the development envelope on the site plan and physical demarcation in the field which can be accomplished using temporary orange construction fencing or flagging. The development envelope can be established by identifying the minimum area needed to build lots; allow access and provide fire protection; and protect and buffer sensitive features such as streams, floodplains, steep slopes and wetlands. Concentrate buildings and paved areas on the least permeable soils, with the least intact habitats.

2) Plan clearing and grading to minimize the compaction of infiltrative soils.

3) Restrict equipment access and storage of construction equipment to the development envelope.

4) Restrict storage of construction equipment within the development envelope.

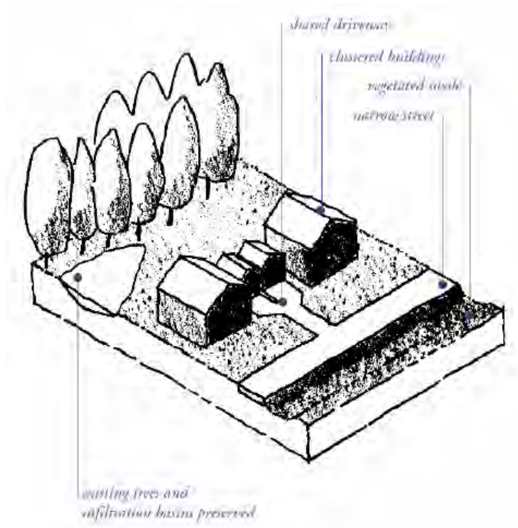
5) Avoid the removal of existing trees and valuable vegetation, as feasible.

6) Consider soil amendments to restore permeability and organic content especially for infill and redevelopment projects to avoid soil disturbance.

4.5 Minimize Impervious Cover

Purpose

The potential for the discharge of pollutants in stormwater runoff from a project site increases as the percentage of impervious area within the project site increases because impervious areas increase the volume and rate of runoff flow. Pollutants deposited on impervious areas tend to be easily mobilized and transported by surface water runoff. Minimizing impervious area through site design is an important means of minimizing stormwater pollutants of concern. In addition to the environmental and aesthetic benefits, a highly pervious site may allow reduction in the size of downstream conveyance and treatment systems, yielding savings in development costs. Reducing impervious area is the most cost effective way of minimizing the effective impervious area (EIA) requirement.



Impervious Cover Minimization

BASMAA, Start at the Source

Design Criteria

Local permitting agency building and fire codes and ordinances determine some aspects of site design. These design strategies are intended to enhance and be consistent with these local codes and ordinances. Minimizing impervious surfaces at every possible opportunity requires integration of many small strategies. Suggested strategies for minimizing impervious surfaces through site design include the following:

1) Use minimum allowable roadway cross sections, driveway lengths, and parking stall widths and lengths.

2) Minimize or eliminate the use of curbs and gutters, and maximize the use of Retention BMPs, where slope and density permit.

3) Use two-track/ribbon alleyways/driveways or shared driveways.

4) Include landscape islands in cul-de-sac streets. Consider alternatives to cul-de-sacs to increase connectivity.

5) Reduce the footprints of building and parking lots. Building footprints may be reduced by building taller.

6) Use permeable pavement to accommodate overflow parking (if overflow parking is needed).

7) Cluster buildings and paved areas to maximize pervious area.

8) Maximize tree preservation or tree planting.

9) Avoid compacting or paving over soils with high infiltration rates (see Minimize Land Disturbance).

10) Use pervious pavement materials where appropriate, such as modular paving blocks, turf blocks, porous concrete and asphalt, brick, and gravel or cobbles.

11) Use grass-lined channels or surface swales to convey runoff instead of paved gutters (see Vegetated Swale in Section 6).

12) Build more compactly in infill and redevelopment site to avoid disturbing natural and agricultural lands. Per capita impacts can be significantly reduced by building more compactly in infill and redevelopment areas.

4.6 Apply LID at Various Scales

Purpose

LID is a decentralized approach to stormwater management that works to mimic the natural hydrology of the site by retaining rainfall onsite. In order to realize the full benefits of water quality protection and runoff volume reduction, LID should be integrated and considered at the regional and watershed scale and the site scale.

Design Criteria

Regional/Watershed

1) Consider Density: Low density development has a greater water resource impact than compact growth on a w atershed scale. Higher density development uses less land and produces less impervious cover per capita than low density development (USEPA, 2006). Developments should consider higher densities, but should still adhere to density levels as specified within local zoning requirements.

2) Identify and Preserve Contiguous Open Space: Large contiguous areas of open space can act as a flood control, have an ecological benefit, serve as a buffer for streams and rivers, and provide recreational opportunities (EPA, 2004). Applicants should look for opportunities to link open space preservation with regional open space preservation efforts (such as Save Open Space and Agricultural Resources).

3) Make use of Previously Developed Sites: Redevelopment of existing sites replace impervious cover with impervious cover, reduces the need for greenfield development, and makes use of existing infrastructure.

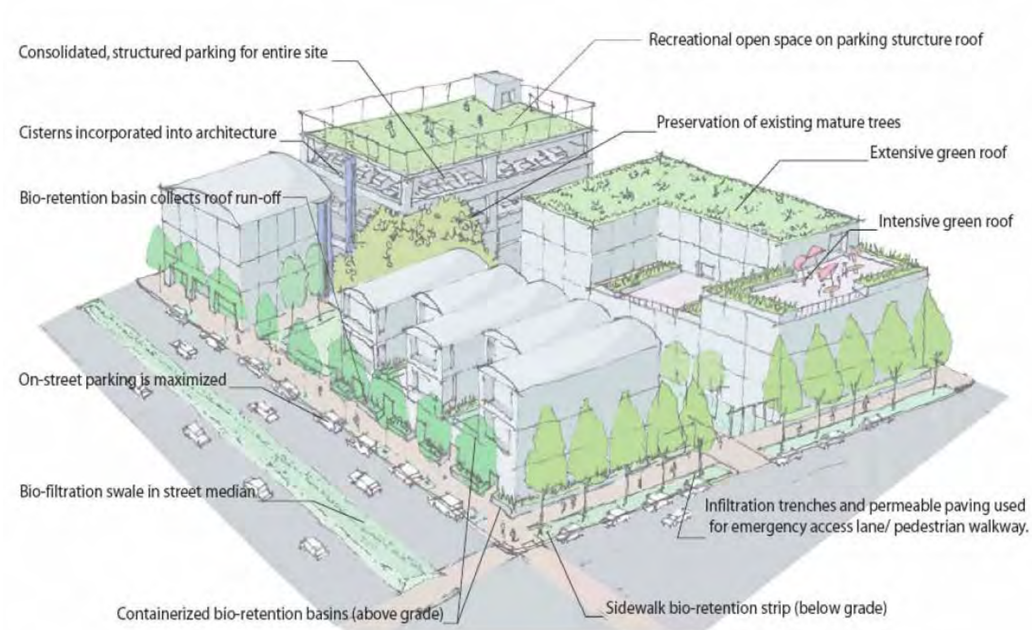
4) Locate Compact Development within Close Proximity to Mass Transit: This maximizes transportation choices, reduces the number of automobile trips, and lessens the water quality impacts associated with transportation and low-density sprawl.

Site

The following design criteria should be considered at the site level in addition to the principles and techniques discussed earlier in this section (e.g., Minimize Impervious Cover).

1) Maintain and Restore Natural Flowpaths for Runoff: Site buildings and impervious surfaces away from steep slopes, drainageways, and floodplains to reduce the amount of necessary clearing and grading and maintain the pre-development hydrology's time of concentration.

2) Maximize Use of Existing Impervious Cover: Assess and take advantage of opportunities to use existing impervious surfaces at the site level to reduce runoff at a watershed scale.



LID BMPs Considered at Various Scales

C. Anderson, Sustainable Urbanism

3) Design Public Spaces and Common Areas to Minimize Stormwater Runoff: Public spaces and common areas can serve as community gathering places but are often composed of impervious cover (e.g., courtyards primarily made up of concrete) (EPA, 2004). Design public spaces and common areas to accommodate both people and stormwater management.

4) Compact Project Design: Compact project design reduces the amount of impervious cover per capita, increases walkability, and decreases water quality impacts associated with transportation. Concentrating development on one portion of the site reduces the amount of lawn, provides more opportunities to preserve open space, and maintains and restores natural flow paths. Additionally, compact design can reduce street and driveway length and as a result, can help to reduce the imperviousness associated with development.

5) Encourage Use of Multiple Modes of Transportation: In addition to density and compact design, additional aspects of site design may encourage the use of multiple modes of transportation:

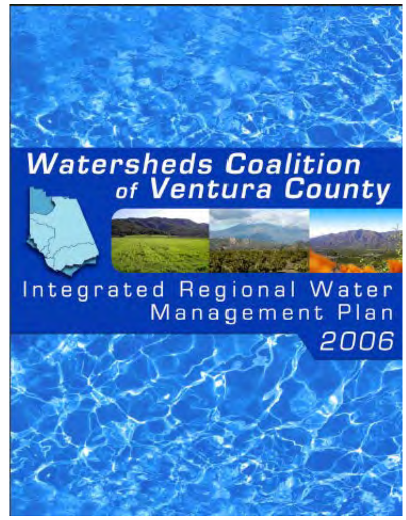
- Bicycle and pedestrian-friendly streets;
- Well connected sidewalks and streets; and
- Mixed uses that encourage walking.

4.7 Implement Integrated Water Resource Management Practices

Purpose

Integrated Water Resource Management (IWRM) is a process which promotes the coordinated development and management of water, land, and related resources. Order R4-2010-0108 promotes the use of IWRM to help guide the selection of BMPs that conserve water, recharge groundwater, provide recreational opportunities and serve as multiple purpose parks and preserve open space.

Many of the concepts of IWRM are documented in the County's Integrated Regional Water Management Plan (IRWMP). The IRWMP is the product of an intensive stakeholder process and addresses multiple water resource management goals including improved water supply reliability, water recycling, water conservation, recreation and access, flood control, wetlands enhancement and creation, and environmental and habitat protection (Watershed Coalition of Ventura County, 2006).



Integrated Regional Water Management Plan

Ventura County

Design Criteria

The goals of the 2011 TGM and the new development and redevelopment requirements contained within Order R4-2010-0108, complement the goals of the IRWMP. Development projects should strive to select BMPs that meet the following multiple objectives (Watershed Coalition of Ventura County, 2006):

1) Conserve and Augment Water Supplies: Identify and evaluate the opportunities to recharge groundwater and increase water use efficiency. This can be accomplished through infiltration of stormwater runoff and selection of drought-tolerant landscaping.

2) Protect People, Property and the Environment from Adverse Flooding Impacts: Identify opportunities to utilize BMPs that provide both water quality and water quantity benefits. Provide and maintain setbacks from streams and rivers.

3) Protect and Restore Habitat and Ecosystems in Watersheds: Implement the practices identified in Protect and Restore Natural Areas to integrate habitat and stormwater goals. Landscaping selection for stormwater management practices may also further encourage and attract wildlife.

4) Provide Water-related Recreational, Public Access and Educational Opportunities: Integrate recreation and stormwater management by creating multi-functional BMPs and designing courtyards and open spaces that accommodate both people and stormwater runoff. Consider providing educational signs for BMPs located in public spaces, where appropriate.

5 SOURCE CONTROL MEASURES

5.1 Introduction

Source Control Measures are low-technology practices designed to prevent pollutants from contacting stormwater runoff and prevent discharge of contaminated runoff to the storm drainage system. This section addresses site-specific, structural-type Source Control Measures consisting of specific design features or elements. Non-structural type Source Control Measures; such as good housekeeping and employee training, are not included in the 2011 TGM. The project applicant can consult the California Industrial Best Management Practice Manual for this type of practice (SWQTF, 1993). The governing stormwater agency may require additional Source Control Measures not included in the 2011 TGM for specific pollutants, activities, or land uses.

This section describes control measures for specific types of sites or activities that have been identified as potential significant sources of pollutants in stormwater. Each of the measures specified in this section should be implemented in conjunction with appropriate non-structural Source Control Measures to optimize pollution prevention.

The measures addressed in this section apply to both stormwater and non-stormwater discharges. Non-stormwater discharges are the discharge of any substance, such as process wastewater, to the storm drainage system or water body that is not composed entirely of stormwater. Stormwater that is mixed or commingled with other non-stormwater flows is considered non-stormwater. Discharges of stormwater and non-stormwater to the storm drainage system or a water body may be subject to local, state, or federal permitting prior to discharge. The appropriate agency should be contacted prior to any discharge. Discuss the matter with the stormwater staff if you are uncertain as to which agency should be contacted.

Some of the measures presented in this section require connection to the sanitary sewer system. It is prohibited to connect and discharge to the sanitary sewer system without prior approval or obtaining the required permits. Contact the stormwater staff of the governing agency about obtaining sanitary sewer permits within Ventura County. Discharges of certain types of flows to the sanitary sewer system may be cost prohibitive. The designer is urged to contact the appropriate agency prior to completing site and equipment design of the facility.

5.2 Description

Table 5-1 summarizes site-specific Source Control Measures and associated design features specified for various sites and activities. Fact Sheets are presented in this section for each source control measure. These sheets include design criteria established by the Approval Agencies to ensure effective implementation of the required Source Control Measures:

Table 5-1: Summary of Site-Specific Source Control Measure Design Features

Site-Specific Source Control Measure [1]	DESIGN FEATURE OR ELEMENT					
	Signs, placards, stencils	Surfacing (compatible, impervious)	Covers, screens	Grading/berming to prevent run-on	Grading/berming to provide secondary containment	Sanitary sewer connection	Emergency Storm Drain Seal
Storm Drain Message and Signage (S-1)	X						
Outdoor Material Storage Area Design (S-2)		X	X	X	X		X
Outdoor Trash Storage and Waste Handling Area Design (S-3)		X	X	X		X	
Outdoor Loading/Unloading Dock Area Design (S-4)		X	X	X	X		
Outdoor Repair/Maintenance Bay Design (S-5)		X	X	X	X		X
Outdoor Vehicle/Equipment/ Accessory Washing Area Design (S-6)		X	X	X	X	X	X
Fueling Area Design (S-7)		X	X	X	X		X
Parking Lot Design [2]							

1 Refer to Fact Sheets in Section 6 for detailed information and design criteria and Appendix E for BMP sizing worksheets

2 Requirements for proper design of parking lots are covered by requirements for General Site Design Principles and Techniques (see Section 4) and Treatment Control Measures (see Section 6).

5.3 Site-Specific Source Control Measures

S-1: Storm Drain Message and Signage

Purpose

Waste materials dumped into storm drain inlets can have severe impacts on receiving and ground waters. Posting notices regarding discharge prohibitions at storm drain inlets can prevent waste dumping. This Fact Sheet contains details on the installation of storm drain messages at storm drain inlets located in new or redeveloped commercial, industrial, and residential sites.

Design Criteria

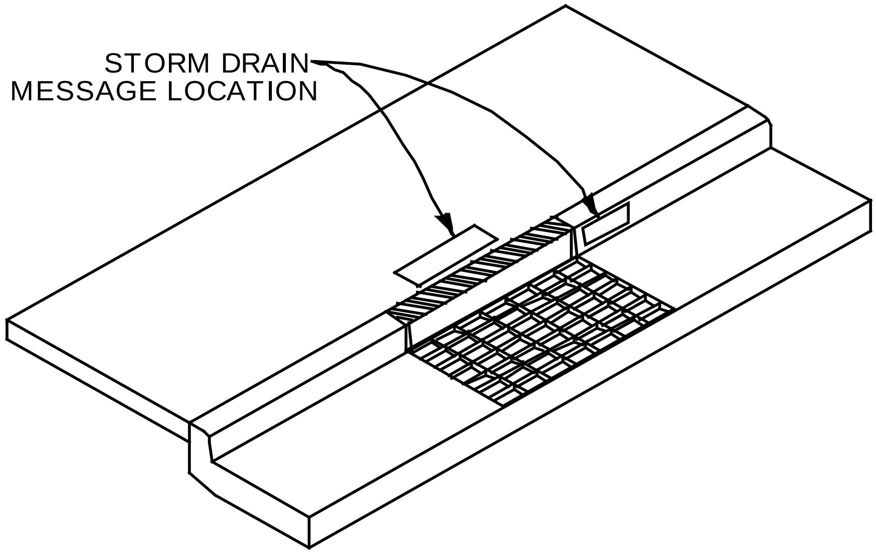
Storm drain messages have become a popular method of alerting the public to the effects of and the prohibitions against waste disposal into the storm drain system. The signs are typically stenciled or affixed near the storm drain inlet. The message simply informs the public that dumping of wastes into storm drain inlets is prohibited and/or the drain discharges to a receiving water.

Storm drain message markers or placards are required at all storm drain inlets within the boundary of the development project. The marker should be placed in clear sight facing anyone approaching the inlet from either side (see Figure 5-1). All storm drain inlet locations must be identified on the development site map.

Some local agencies within the County have approved storm drain message placards for use. Signs with language and/or graphical icons, which prohibit illegal dumping, should be posted at designated public access points along channels and streams within a project area. Consult local permitting agency stormwater staff to determine specific requirements for placard types and installation methods.

Maintenance Requirements

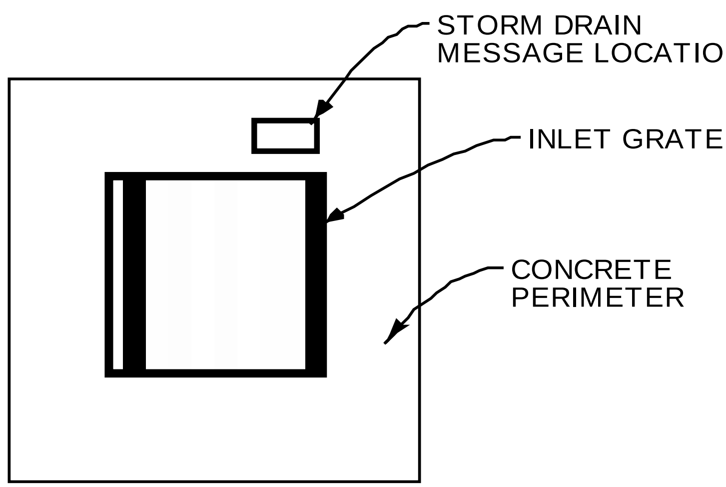
Legibility of markers and signs should be maintained. If required by the agency with jurisdiction over the project, the owner/operator or homeowner's association shall enter into a Maintenance Agreement with the agency or record a deed restriction upon the property title to maintain the legibility of placards and signs.



CURB TYPE INLET

NOTES:

1. STORM DRAIN MESSAGE SHALL BE APPLIED IN SUCH A WAY AS TO PROVIDE A CLEAR, LEGIBLE IMAGE.
2. STORM DRAIN MESSAGE SHALL BE PERMANENTLY APPLIED DURING THE CONSTRUCTION OF THE CURB AND GUTTER USING A METHOD APPROVED BY THE LOCAL AGENCY.



AREA TYPE INLET

Figure 5-1: Storm Drain Message Location

S-2: Outdoor Material Storage Area Design

Purpose

Materials that are stored outdoors could become sources of pollutants in stormwater runoff if not handled or stored properly. Materials could be in the form of raw products, by-products, finished products, and waste products. The type of pollutants associated with the materials will vary depending on the type of commercial or industrial activity.

Some materials are more of a concern than others. Toxic and hazardous materials must be prevented from coming in contact with stormwater. Non-toxic or non-hazardous materials do not have to be prevented from stormwater contact, but cannot be allowed to runoff with the stormwater. These materials may have toxic effects on receiving waters. Accumulated material on an impervious surface could result in significant debris and sediment being discharged with stormwater runoff causing a significant impact on the rivers or streams that receive the runoff.

Materials may be stored in a variety of ways, including bulk piles, containers, shelving, stacking, and tanks. Stormwater contamination may be prevented by eliminating the possibility of stormwater contact with the material storage areas either through diversion, cover, or capture of the stormwater. Control measures may also include minimizing the storage area. Control measures are site-specific and must meet local permitting agency requirements.

Design Criteria

Design requirements for material storage areas are governed by Building and Fire Codes and by current City or County ordinances and zoning requirements. Source Control Measures described in the Fact Sheet are intended to enhance and be consistent with these code and ordinance requirements. The following design features should be incorporated into the design of a material storage area when storing materials outside could contribute significant pollutants to the storm drain.

Table 5-2: Design Criteria for Outdoor Material Storage Area Design

Source Control Design Feature	Design Criteria
Surfacing	• Construct the storage area base with a material impervious to leaks and spills.
Covers	• Install a cover that extends beyond the storage area, or use a manufactured storage shed for small containers.
Grading/Containment	• Minimize the storage area. • Slope the storage area towards a dead-end sump to contain spills. • Grade or berm storage areas to prevent run-on from surrounding areas. • Direct runoff from downspouts/roofs away from storage areas.

Accumulated Stormwater and Non-stormwater

Stormwater and non-stormwater will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

S-3: Outdoor Trash Storage Area Design

Purpose

Stormwater runoff from areas where trash is stored or disposed of can be polluted. In addition, loose trash and debris can be easily transported by water or wind into nearby storm drain inlets, channels, and/or creeks. Waste handling operations may be sources of stormwater pollution and include dumpsters, litter control, and waste piles. This fact sheet contains details on the specific measures required to prevent or reduce pollutants in stormwater runoff associated with trash storage and handling.

Design Criteria

Design requirements for waste handling areas are governed by Building and Fire Codes, and by current local permitting agency ordinances and zoning requirements. The design criteria described in the Fact Sheet are meant to enhance and be consistent with these code and ordinance requirements. Hazardous waste should be handled in accordance with legal requirements established in Title 22, California Code of Regulations.

Wastes from commercial and industrial sites are typically hauled by either public or commercial carriers that may have design or access requirements for waste storage areas. The design criteria listed below are recommendations and are not intended to be in conflict with requirements established by the waste hauler. The waste hauler should be contacted prior to the design of your site trash collection area to obtain established and accepted guidelines for designing trash collection areas. Conflicts or issues should be discussed with the local permitting agency.

The following trash storage area design controls were developed to enhance the local permitting agency codes and ordinances and should be implemented depending on the type of waste and the type of containment.

Table 5-3: Design Criteria for Outdoor Trash Storage Areas

Source Control Design Feature	Design Criteria
Surfacing	• Construct the storage area base with a material impervious to leaks and spills.
Screens/Covers	• Install a screen or wall around trash storage area to prevent offsite transport of loose trash. • Use lined bins or dumpsters to reduce leaking of liquid wastes. • Use water-proof lids on bins/dumpsters or provide a roof to cover enclosure (local permitting agency discretion) to prevent rainfall from entering containers.
Grading/Contouring	• Berm or grade the waste handling area to prevent run-on of stormwater. • Do not locate storm drains in immediate vicinity of the trash storage area.
Signs	• Post signs on all dumpsters informing users that hazardous materials are not to be disposed of therein.

Maintenance Requirements

The owner/operator must maintain the integrity of structural elements that are subject to damage (e.g. screens, covers and signs). Maintenance Agreements between the local permitting agency and the owner/operator may be required. Some agencies will require maintenance deed restrictions to be recorded of the property title. If required by the local permitting agency, Maintenance Agreements or deed restrictions must be executed by the owner/operator before improvement plans are approved. Refer to Appendix G and H for further guidance regarding Maintenance Plan Agreements.

S-4: Outdoor Loading/Unloading Dock Area Design

Purpose

Materials spilled, leaked, or lost during loading or unloading may collect on impervious surfaces or in the soil and be carried away by runoff or when the area is cleaned. Rainfall may also wash pollutants from machinery used to load or unload materials. Depressed loading docks (truck wells) are contained areas that can accumulate stormwater runoff. Discharge of spills or contaminated stormwater to the storm drain system is prohibited. This Fact Sheet contains details on specific measures recommended to prevent or reduce pollutants in stormwater runoff from outdoor loading or unloading areas.

Design Criteria

Design requirements for outdoor loading and unloading of materials are governed by Building and Fire Codes, and by current local permitting agency ordinances and zoning requirements. Source Control Measures described in this Fact Sheet are meant to enhance and be consistent with these code and ordinance requirements. Companies may have their own design or access requirements for loading docks. The design criteria listed below are not intended to be in conflict with requirements established by individual companies. Conflicts or issues should be discussed with the local permitting agency.

The following design criteria should be followed when developing construction plans for material loading and unloading areas:

Table 5-4: Design Criteria for Outdoor Loading/ Unloading Areas

Source Control Design Feature	Design Criteria
Surfacing	• Construct floor surfaces with materials that are compatible with materials being handled in the loading/unloading area.
Covers	• Cover loading/unloading areas to a distance of at least 3 feet beyond the loading dock or install a seal or door skirt to be used for all material transfers between the trailer and the building.
Grading/Contouring	• Grade or berm storage the areas to prevent run-on from surrounding areas. • Direct runoff from downspouts/roofs away from loading areas.
Emergency Storm Drain Seal	• Do not locate storm drains in the loading dock area. Direct connections to storm drains from depressed loading docks are prohibited. • Provide means, such as isolation valves, drain plugs, or drain covers, to prevent spills or contaminated stormwater from entering the storm drainage system.

Accumulated Stormwater and Non-stormwater

Stormwater and non-stormwater will accumulate in containment areas and sumps with impervious surfaces, such as depressed loading docks. C ontaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

S-5: Outdoor Repair/Maintenance Bay Design

Purpose

Activities that can contaminate stormwater include engine repair, service, and parking (i.e. leaking engines or parts). Oil and grease, solvents, car battery acid, coolant and gasoline from the repair/maintenance bays can severely impact stormwater if allowed to come into contact with stormwater runoff. This Fact Sheet contains details on the specific measures required to prevent or reduce pollutants in stormwater runoff from vehicle and equipment maintenance and repair areas.

Design Criteria

Design requirements for vehicle maintenance and repair areas are governed by Building and Fire Codes, and by current local permitting agency ordinances, and zoning requirements. The design criteria described in this Fact Sheet are meant to enhance and be consistent with these code requirements.

The following design criteria are required for vehicle and equipment maintenance, and repair. All wash water, hazardous and toxic wastes must be prevented from entering the storm drainage system.

Source Control Design Feature	Design Criteria
Surfacing	• Construct the vehicle maintenance/repair floor area with Portland cement concrete.
Covers	• Cover or berm areas where vehicle parts with fluids are stored. • Cover or enclose all vehicle maintenance/repair areas.
Grading/ Contouring	• Berm or grade the maintenance/repair area to prevent run-on and runoff of stormwater or runoff of spills. • Direct runoff from downspouts/roofs away from maintenance/repair areas. • Grade the maintenance/repair area to drain to a dead-end sump for collection of all wash water, leaks and spills. Direct connection of maintenance/repair area to storm drain system is prohibited. • Do not locate storm drains in the immediate vicinity of the maintenance/repair area.
Emergency Storm Drain Seal	• Provide means, such as isolation valves, drain plugs, or drain covers, to prevent spills or contaminated stormwater from entering the storm drainage system.

Accumulated Stormwater and Non-stormwater

Stormwater and non-stormwater will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

S-6: Outdoor Vehicle/Equipment/Accessory Washing Area Design

Purpose

Washing vehicles and equipment in areas where wash water flows onto the ground can pollute stormwater. Wash waters are not allowed in the storm drain system. They can contain high concentrations of oil and grease, solvents, phosphates and high suspended solids loads. Sources of washing contamination include outside vehicle/equipment cleaning or wash water discharge to the ground. This Fact Sheet contains details on the specific measures required to prevent or reduce pollutants in stormwater runoff from vehicle and equipment washing areas.

Design Criteria

Design requirements for vehicle maintenance and repair areas are governed by Building and Fire Codes, and by current local permitting agency ordinances, and zoning requirements. The design criteria described in this Fact Sheet are meant to enhance and be consistent with these code requirements.

The following design criteria are required for vehicle and equipment washing areas. All hazardous and toxic wastes must be prevented from entering the storm drain system.

Source Control Design Feature	Design Criteria
Surfacing	• Construct the vehicle/equipment wash area floors with Portland cement concrete.
Covers	• Provide a cover that extends over the entire wash area.
Grading/ Contouring	• Berm or grade the maintenance/repair area to prevent run-on and runoff of stormwater or runoff of spills. • Grade or berm the wash area to contain the wash water within the covered area and direct the wash water to treatment and recycle or pretreatment and proper connection to the sanitary sewer system. Obtain approval from the governing agency before discharging to the sanitary sewer. • Direct runoff from downspouts/roofs away from wash areas. • Do not locate storm drains in the immediate vicinity of the wash area.
Emergency Storm Drain Seal	• Provide means, such as isolation valves, drain plugs, or drain covers, to prevent spills or contaminated stormwater from entering the storm drainage system.

Accumulated Stormwater and Non-stormwater

Stormwater and non-stormwater will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

S-7: Fueling Area Design

Purpose

Spills at vehicle and equipment fueling areas can be a significant source of pollution because fuels contain toxic materials and heavy metals that are not easily removed by stormwater treatment devices. When stormwater mixes with fuel spilled or leaked onto the ground, it becomes polluted by petroleum-based materials that are harmful to humans, fish, and wildlife. This could occur at large industrial sites or at small commercial sites such as gas stations and convenience stores. This Fact Sheet contains details on specific measures required to prevent or reduce pollutants in stormwater runoff from vehicle and equipment fueling areas, including retail gas stations.

Design Criteria

Design requirements for fueling areas are governed by Building and Fire Codes and by current local permitting agency ordinances and zoning requirements. The design requirements described in this Fact Sheet are meant to enhance and be consistent with these code and ordinance requirements.

Source Control Design Feature	Design Criteria
Surfacing	• Fuel dispensing areas must be paved with Portland cement concrete. The fuel dispensing area is defined as extending 6.5 feet from the corner of each fuel dispenser or the length at which the hose and nozzle assemble may be operated plus 1 foot, whichever is less. The paving around the fuel dispensing area may exceed the minimum dimensions of the "fuel dispensing area" stated above. • Use asphalt sealant to protect asphalt paved areas surrounding the fueling area.
Covers	• The fuel dispensing area must be covered [1], and the cover's minimum dimensions must be equal to or greater than the area within the grade break or the fuel dispensing area, as defined above. The cover must not drain onto the fuel dispensing area.
Grading/ Contouring	• The fuel dispensing area should have a 2% to 4% slope to prevent ponding and must be separated from the rest of the site by a grade break that prevents run-on of stormwater to the extent practicable. • Grade the fueling area to drain toward a dead-end sump. • Direct runoff from downspouts/roofs away from fueling areas. • Do not locate storm drains in the immediate vicinity of the fueling area.

Source Control Design Feature	Design Criteria
Emergency Storm Drain Seal	• Provide means, such as isolation valves, drain plugs, or drain covers, to prevent spills or contaminated stormwater from entering the storm drainage system.

1. If fueling large equipment or vehicles that would prohibit the use of covers or roofs, the fueling island should be designed to sufficiently accommodate the larger vehicles and equipment and to prevent run-on and runoff of stormwater. Grade to direct stormwater to a dead-end sump.

Accumulated Stormwater and Non-stormwater

Stormwater and non-stormwater will accumulate in containment areas and sumps with impervious surfaces. Contaminated accumulated water must be disposed of in accordance with applicable laws and cannot be discharged directly to the storm drain or sanitary sewer system without the appropriate permit.

S-8: Proof of Control Measure Maintenance

Purpose

Continued effectiveness of control measures specified in the 2011 TGM depends on diligent ongoing inspection and maintenance. To ensure that such maintenance is provided, the local permitting agency will require both a Maintenance Agreement and a Maintenance Plan from the owner/operator of stormwater control measures.

Maintenance Agreement

Onsite Treatment Control Measures are to be maintained by the owner/operator. Maintenance Agreements between the governing agency and the owner/operator may be required. A Maintenance Agreement with the governing agency must be executed by the owner/operator before occupancy of the project is approved. A sample Maintenance Agreement form is provided in Appendix H.

Maintenance Plan

A post-construction Maintenance Plan shall be prepared and made available at the governing agency's request. The Maintenance Plan should address items such as:

- Operation plan and schedule, including a site map;
- Maintenance and cleaning activities and schedule;
- Equipment and resource requirements necessary to operate and maintain facility; and
- Responsible party for operation and maintenance.

Additional guidelines for Maintenance Plans are provided in Appendix I.

6 STORMWATER BMP DESIGN

6.1 Introduction

Retention BMPs, Biofiltration BMPs, and Treatment Control Measures are required to augment Site Design Principles and Techniques and Source Control Measures to reduce pollution from stormwater discharges to the maximum extent practicable. Retention BMPs are engineered facilities that are designed to retain surface runoff on the project site. Biofiltration BMPs are vegetated stormwater BMPs that remove pollutants by filtering stormwater through vegetation and soils. Treatment Control Measures are engineered BMPs that provide a r eduction of pollutant loads and concentrations in stormwater runoff. The type(s) of Retention BMPs and Biofiltration BMPs to be implemented depends on site suitability factors discussed in this chapter. The type of Treatment Control Measure(s) to be implemented at a site depends on a number of factors including: type of pollutants in the stormwater runoff, quantity of stormwater runoff to be treated, project site conditions, receiving water conditions, and state industrial permit requirements, where applicable. Land requirements and costs to design, construct, and maintain Treatment Control Measures vary by type.

Unlike flood control measures that are designed to handle peak flows, stormwater Retention BMPs, Biofiltration BMPs, and Treatment Control Measures are designed to retain or treat the more frequent, lower-flow storm events, or the first flush runoff from larger storm events (typically referred to as the first flush events). Small, frequent storm events represent most of the total average annual rainfall for the area. It's the volume from such small events, referred to as the Stormwater Quality Design Volume (SQDV), that is targeted for retention onsite in Retention BMPs. Biofiltration BMPs and Treatment Control Measures can be sized to capture either the SQDV or the Stormwater Quality Design Flow (SQDF). Calculation methods for the SQDV and the SQDF are presented in Section 2 and Appendix E.

6.2 General Considerations

Retention BMPs, Biofiltration BMPs, and Treatment Control Measures are designed to remove pollutants contained in stormwater runoff. The pollutants of concern, depending on the watershed, may include trash, debris, and sediment; metals such as copper, lead, and zinc; nutrients such as nitrogen and phosphorous; certain bacteria and viruses; mineral salts such as chloride; and organic chemicals such as petroleum hydrocarbons and pesticides. Pollutant removal methods include sedimentation/settling, filtration, plant uptake, ion exchange, adsorption, and microbially-mediated decomposition. Floatable pollutants such as oil, debris, and scum can be removed with separator structures. Retention BMPs, Biofiltration BMPs, and some Treatment Control Measures are also designed to reduce runoff volume, thereby reducing pollutant loading to receiving waters. Retention BMP, Biofiltration BMPs, and Treatment Control Measure types and common terms used in stormwater treatment are discussed below.

Maintenance Responsibility

Unless otherwise agreed to by the governing stormwater agency, the landowner, site operator, or homeowner's association is responsible for the operation and maintenance of the Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. Failure to properly operate and maintain the measures could result in reduced treatment of stormwater runoff or a concentrated loading of pollutants to the storm drain system. To protect against failure, a Maintenance Plan must be developed and implemented for all Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. Guidelines for maintenance plans are provided in Appendix I of the 2011 TGM. The Plan must be made available at the agency's request. In addition, a maintenance agreement with the governing agency may be required. The example maintenance agreements are included in Appendix H.

In addition to maintenance, the governing agency may require water quality monitoring agreements for any of the Retention BMPs, Biofiltration BMPs, or Treatment Control Measures recommended in the 2011 TGM. Monitoring may be conducted by the site operator, the agency, or both. Monitoring may be required for a period of time to help the agency evaluate the effectiveness of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures in reducing pollutants in stormwater runoff.

Pretreatment

Pretreatment must be provided for filtration and infiltration facilities and other facilities whose function could be adversely affected by sediment or other pollutants. Pretreatment may also be provided for water quality detention basins and other Treatment Control Measures to facilitate the routine removal of sediment, trash, and debris, and to increase the longevity of the downstream BMPs.

Pretreatment may be provided by presettling basins or forebays (small detention basins), vegetated swales, filter strips, and hydrodynamic separators. Source control activities, described in Chapter 5, minimize the introduction of pollutants into stormwater runoff and also help to protect filtration and infiltration facilities. Effort should be made early in the site planning stages to minimize runoff from impervious areas by grading toward landscaped areas, disconnecting downspouts, and using pervious conveyances prior to discharging to the storm drain system. These site design practices can reduce the size and maintenance burden of downstream, end-of-pipe BMPs.

Oil/Water Separation

Oil/water separators remove floating oil from the water surface. There are two general types of separators: American Petroleum Institute (API) separators and coalescing plate (CP) separators. Both types use physical mechanisms to remove high concentrations of floating and dispersed oil. Oil/water separators are not suitable for the relatively low concentrations of petroleum hydrocarbons present in typical urban runoff, and should only be used in locations where higher concentrations of oil are expected to occur, such as retail fuel facilities, high volume roads, and petroleum-related industrial facilities. Oil/water separators must be located off-line from the primary conveyance system, as they function at low flow conditions and will wash out in high flow conditions. Other oil control devices/facilities that may be used for pretreatment of slightly elevated concentrations of oil (i.e., typical of high use commercial parking lots) include catch basin inserts, hydrodynamic devices, and linear sand filters. Oil control devices/facilities should always be placed upstream of other treatment facilities and as close to the oil source as possible.

Infiltration

Infiltration refers to the use of the filtration, adsorption, and biological decomposition properties of soils to remove pollutants prior to the intentional routing of runoff to the subsurface for groundwater recharge. Infiltration BMPs are a type of Retention BMP and include infiltration basins, infiltration trenches, bioretention without an underdrain, dry wells, permeable pavement, and proprietary infiltration devices. Infiltration can provide multiple benefits including pollutant removal, hydromodification control, groundwater recharge, and flood control. However, conditions that can limit the use of infiltration include soil properties and potential adverse impacts on groundwater quality. A geotechnical investigation must be conducted when evaluating infiltration to determine the suitability of the site soil in adequately addressing groundwater protection. This may include an i n-situ percolation test, per the guidance provided in Appendix C, and the determination of minimum depth to groundwater. The minimum separation to seasonal high groundwater or estimated mounded groundwater is five feet. Depth to seasonal high groundwater level shall be estimated as the average of the annual minima (i.e., the shallowest recorded measurements in each water year, defined as October 1 through September 30) for all years on record. If groundwater level data are not available or not considered to be representative, seasonal high groundwater depth can be determined by redoximorphic analytical methods combined with temporary groundwater monitoring for November 1 through April 1 at the proposed project site.

Soils should have sufficient organic content and sorption capacity to remove certain pollutants, but must be coarse enough to infiltrate runoff in a reasonable amount of time (e.g., < 72 hours for above-ground ponded water to prevent vector breeding). Examples of suitable soils are silty and sandy loams. Coarser soils, such as gravelly sands, have limited organic content and high permeability and therefore present a potential risk to groundwater from certain pollutants, especially in areas of shallow groundwater. Prior to the use of infiltration BMPs, consult with the local permitting agency to identify if vulnerable unconfined aquifers are located beneath the project to determine the appropriateness of these BMPs. In an area identified as an unconfined aquifer, the application of infiltration BMPs should include significant pretreatment to ensure groundwater is protected from pollutants of concern.

Infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk. Infiltration BMPs may be placed in high-risk areas if a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.

In addition, infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project. Adequate spacing (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

Infiltration is not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines the infiltration would not be detrimental. A site-specific analysis shall be prepared where pollutant mobilization (e.g., naturally-derived groundwater pollutants) is a concern. Projects must consider the potential for mobilization of groundwater contamination from natural sources as a result of stormwater infiltration (e.g., marine sediments, selenium-rich groundwater) to the extent that data is available.

Incidental infiltration that occurs in other types of Biofiltration BMPs and Treatment Control Measures, such as dry extended detention basins, vegetation swales, filter strips, and bioretention areas with underdrains, pose little risk to groundwater quality as treatment is provided in the BMP prior to infiltration.

Biofiltration BMPs

Biofiltration BMPs use vegetation and soils or other filtration media for runoff treatment. As runoff passes through the vegetation and filtration media, the combined effects of filtration, adsorption, and biological uptake remove pollutants. In biofiltration BMPs, pore spaces and organic material in the soils help to retain water in the form of soil moisture and to promote the pollutant adsorption (e.g., dissolved metals and petroleum hydrocarbons) into the soil matrix. Plants use soil moisture, promote the drying of the soil through transpiration, and uptake pollutants in their roots and leaves. Plants with extensive root systems also help to maintain filtration rates. Vegetation also decreases the velocity of flow and allows for particulates to settle.

Treatment Control Measures

Filtration

Various media, such as sand, perlite, zeolite, compost, and activated carbon, can be used in filtration BMPs to effectively remove total suspended solids (TSS) and associated pollutants such as organics (hydrocarbons and pesticides) and particulate metals. Filtration systems can be configured in the form of horizontal beds, trenches, or lastly, cartridge systems in underground vaults or catch basins.

Wetpools

A wetpool is a permanent pool of water incorporated into a wetpond or stormwater wetland BMP. Wetpools provide runoff treatment by allowing settling of particulates (sedimentation) by biological uptake and by vegetative filtration (if vegetation is present). Wetpool BMPs may be single-purpose facilities, providing only runoff treatment, or they may also provide flow control by providing additional detention storage with the use of a multi-stage outlet structure. If combined with detention, the wetpool volume can often be stacked under the detention volume with little further loss of development area.

"On-line" and "Off-line" Facilities

The location and configuration of control facilities can vary depending on the desired function. For example, drop structures or grade control may be located in a drainage channel so as to stabilize a channel for hydromodification control purposes. Such facilities are referred to as "in-stream" controls. Retention BMPs, Biofiltration BMPs, and Treatment Control Measures may not be located in-stream. Retention BMPs, Biofiltration BMPs, and Treatment Control Measures cannot be located in Waters of the US, but rather must be located upland to retain or treat runoff prior to discharge into Waters of the US.

If a Retention BMP, Biofiltration BMP, or Treatment Control Measure facility is designed such that all the runoff passes through the facility, the facility is called an "on-line" system. However, care must be taken to limit the resuspension of previously captured pollutants or damage to BMP performance during high flows. If, on the other hand, the facility only receives flows less than or equal to the stormwater quality design flow (SQDF), the facility is called an "off-line" system. Off-line systems therefore require a flow splitter or equivalent device. Generally treatment performance is better for off-line facilities because a larger percentage of the runoff is treated. Figure 6-1 illustrates the difference between on-line, off-line, and in-stream controls.

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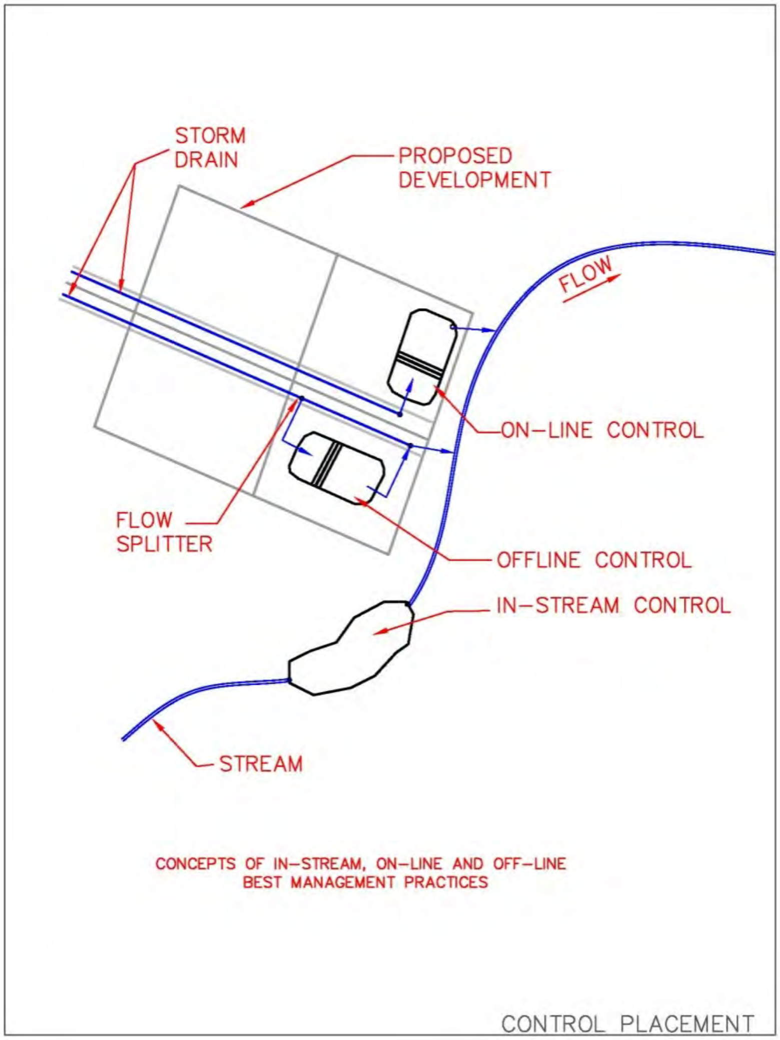


Figure 6-1: Differences between On-line, Off-line, and In-stream Control Measures

6.3 Retention BMP, Biofiltration BMP, and Treatment Control Measure Fact Sheets

This section provides fact sheets with recommended criteria for the design and implementation of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures. The siting, design, and maintenance requirements in the fact sheets are intended to ensure optimal performance of the measures. Alternative designs may be approved by the local permitting authority based on site specific conditions if equivalent pollutant removal performance is provided.

The 2011 TGM also contains calculation worksheets to aid in the design of these BMPs in Appendix E. New BMPs that are equivalent to those included in the 2011 TGM are acceptable based on approval of the local permitting agency.

Fact sheets are provided for the Retention BMPs, Biofiltration BMPs, and Treatment Control Measures listed below:

Retention BMPs

Infiltration BMPs

INF-1: Infiltration Basin
INF-2: Infiltration Trench
INF-3: Bioretention
INF-4: Drywell
INF-5: Permeable Pavement
INF-6: Proprietary Infiltration

Rainwater Harvesting BMPs

RWH-1: Rainwater Harvesting

Evapotranspiration BMPs

ET-1: Green Roof
ET-2: Hydrologic Source Controls

Biofiltration BMPs

BIO-1: Bioretention with Underdrain
BIO-2: Planter Box
BIO-3: Vegetated Swale
BIO-4: Vegetated Filter Strip
BIO-5: Proprietary Biotreatment

Treatment Control Measures

TCM-1: Dry Extended Detention Basin
TCM-2: Wet Detention Basin
TCM-3: Constructed Wetland
TCM-4: Sand Filter (if vegetated, this is considered a Biofiltration BMP)
TCM-5: Cartridge Media Filter

Pretreatment/Gross Solids Removal BMPs

PT-1: Hydrodynamic Device
PT-2: Catch Basin Insert

INF-1: Infiltration Basin

An infiltration basin consists of an earthen basin constructed in naturally pervious soils (Type A or B soils) with a flat bottom and provided with an inlet structure to dissipate energy of incoming flow and an emergency spillway to control excess flows. An optional relief underdrain may be provided to drain the basin if standing water conditions occur. A forebay settling basin or separate Treatment Control Measure must be provided as pretreatment. An infiltration basin functions by retaining the SQDV in the basin and allowing the retained runoff to percolate into the underlying native soils over a specified period of time. The bottoms of infiltration basins are typically vegetated with dry-land grasses or irrigated turf grass. A typical layout of an infiltration basin system is shown in Figure 6-2.

Infiltration Basin in a Fresno, CA Park, Before and After a Rain Event

Photo Credit: Geosyntec Consultants

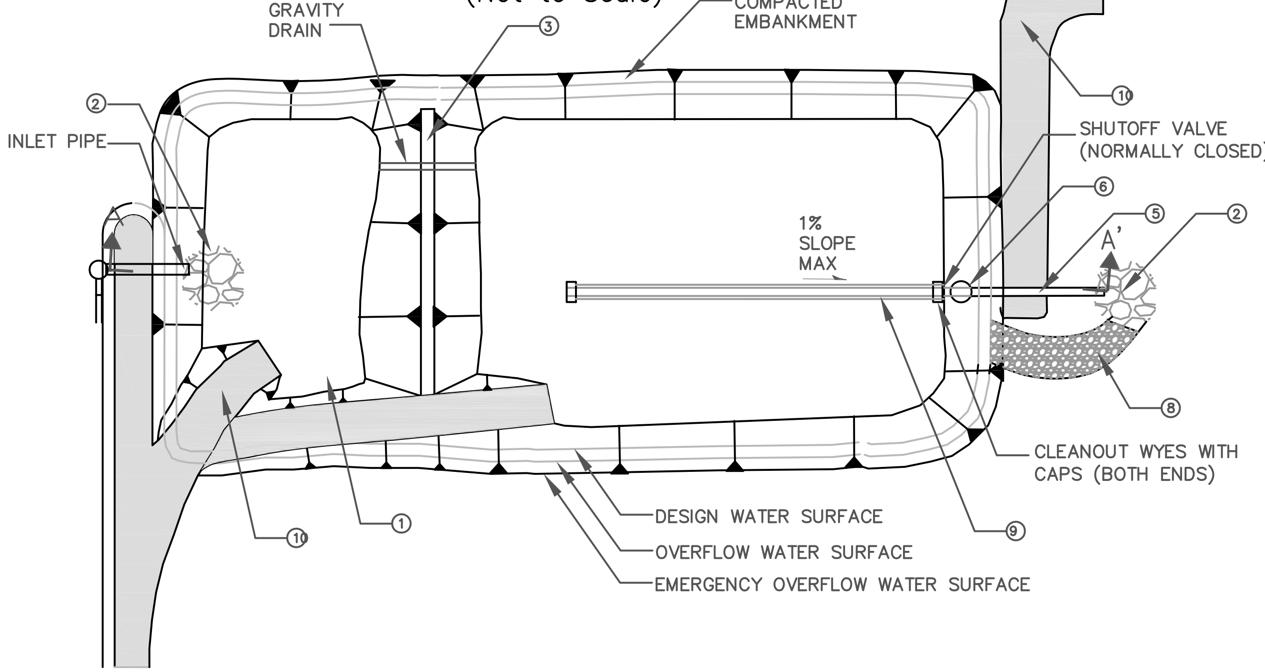
Application

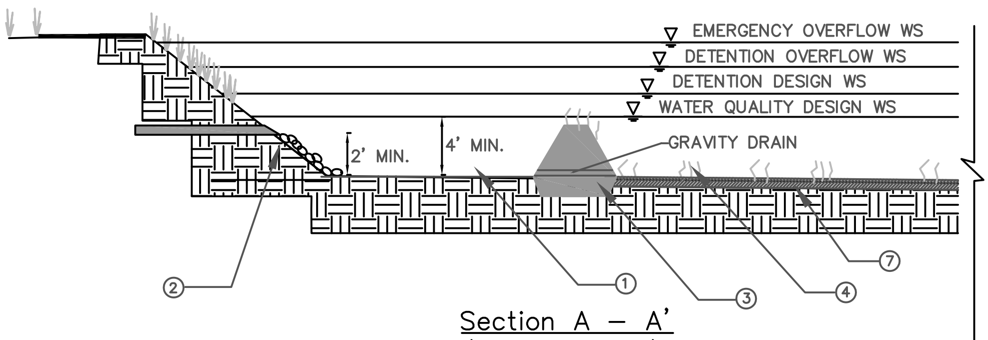
- Mixed-use and commercial
- Roads and parking lots
- Parks and open spaces
- Single and multi-family residential
- Can integrate with parks

Routine Maintenance

- Removal trash, debris, and sediment at inlet and outlets
- Wet weather inspection to ensure drain time
- Remove weeds
- Inspect for mosquito breeding

Plan View
(Not to Scale)





Section A – A'
(Not to Scale)

NOTES:

1. UPSTREAM PRETREATMENT SHALL BE PROVIDED. SEDIMENT FOREBAY WITH VOLUME EQUAL TO 25% OF TOTAL INFILTRATION BASIN VOLUME MAY BE USED IN LIEU OF UPSTREAM PRETREATMENT. DEPTH SHALL BE 4' MIN TO 8' MAX PLUS AN ADDITIONAL 1 FOOT MIN SEDIMENT STORAGE DEPTH.
2. RIP RAP APRON OR OTHER ENERGY DISSIPATION.
3. EXTEND EARTHEN BERM ACROSS ENTIRE WIDTH OF THE INFILTRATION BASIN.
4. INFILTRATION BASIN BOTTOM AND SIDE SLOPES SHALL BE PLANTED WITH DROUGHT TOLERANT VEGETATION. DEEP ROOTED VEGETATION PREFERRED FOR BASIN BOTTOM. NO TOPSOIL SHALL BE ADDED TO INFILTRATION BASIN BED.
5. SIZE OUTLET PIPE TO PASS 100–YEAR PEAK FLOW FOR ON–LINE INFILTRATION BASINS AND WATER QUALITY PEAK FLOW FOR OFF–LINE INFILTRATION BASINS.
6. WATER QUALITY OUTLET STRUCTURE. SEE FIGURE 7–2 AND FIGURE 7–3 FOR DETAILS.
7. OVER EXCAVATE BASIN BOTTOM 1 FOOT. RE–PLACE EXCAVATED MATERIAL UNIFORMLY WITHOUT COMPACTION. AMENDING EXCAVATED MATERIAL WITH 2" – 4" OF COARSE SAND IS RECOMMENDED FOR SOILS WITH BORDER LINE INFILTRATION CAPACITY.
8. INSTALL EMERGENCY OVERFLOW SPILLWAY AS NEEDED. SEE FIGURE 2–4 FOR DETAILS
9. INSTALL OPTIONAL 6" MINIMUM DIAMETER PERFORATED PIPE UNDERDRAIN. INSTALL AT 0.5% MINIMUM SLOPE.
10. MAINTENANCE RAMP SHOULD PROVIDE ACCESS TO BOTH THE FIRST CELL AND MAIN BASIN.

Geosyntec consultants

Figure 6-2: Infiltration Basin

Limitations

The following limitations should be considered before choosing to use an infiltration basin:

- Native soil infiltration rate - permeability of soils at the infiltration basin location must be at least 0.5 inches per hour.
- Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration basin and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.
- Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.
- Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback at least eight feet from building foundations or have an alternative setback established by the geotechnical expert for the project.
- Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer to ensure groundwater is protected for pollutants of concern.
- Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater, where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines the infiltration would be beneficial.
- High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.
- High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.

Additional Control Functions

Infiltration basins can be designed for flow control by providing storage capacity in excess of that provided by infiltration and incorporating outlet controls. The additional storage and outlet structure should be provided per the requirements outlined in the Dry Extended Detention Basins section of the 2011 TGM. Note that the selected outlet structure should not be designed to drain the design volume intended for infiltration and should be similar to outlet structures that maintain a permanent pool (see Section 6.10.2 – Wet Retention Basins).

Multi-Use Opportunities

Infiltration basins may be integrated into the design of a park or playfield. Recreational multi-use facilities should be inspected after every storm and may require a greater maintenance frequency than dedicated infiltration basins to ensure aesthetics and public safety are not compromised. Any planned multi-use facility must obtain approval by the affected City and County departments.

Design Criteria

The main challenge associated with infiltration basins is preventing system clogging and subsequent infiltration inhibition. Infiltration basins should be designed according to the requirements listed in Table 6-1 and outlined in the section below. Detailed design procedures and an example are included in Appendix E.

Table 6-1: Infiltration Basin Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2.3 and Appendix E for calculating SQDV
Design drawdown time	hr	12 - 72 (See Appendix D, Section D.2)
Bottom basin Elevation	feet	5 feet above seasonally high groundwater table or mounded groundwater
Setbacks	feet	100 feet from wells, fields, and springs; 20 feet downslope of 100 feet upslope of foundations; Geotechnical expert should establish the setback requirement from building foundations that must be ≥ 8 ft.
Pretreatment	-	Sedimentation forebay or any Treatment Control Measure shall be provided as pretreatment for all tributary surfaces other than roofs.

Design Parameter	Unit	Design Criteria
Design percolation rate (P_{design})	in/hr	Measured percolation rate must be corrected based onsite suitability assessment and design related considerations described in this fact sheet.
Facility geometry	-	Forebay (if applicable): 25% of facility volume; flat bottom slope
Freeboard (minimum)	ft	1.0
Inlet/ Outlet erosion control	-	Energy dissipater to reduce velocity
Overflow device	-	Required if system is on-line

Geotechnical Considerations

An extensive geotechnical site investigation must be undertaken early in the site planning process to verify site suitability for the installation of infiltration facilities, due to the potential to contaminate groundwater, cause slope instability, impact surrounding structures, and have insufficient infiltration capacity.. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration facility. See Appendix C for guidance on infiltration testing.

The project designer must demonstrate through infiltration testing, soil logs, and the written opinion of a licensed civil engineer that sufficiently permeable soils exist onsite to allow the construction of a properly functioning infiltration facility.

1) Infiltration facilities require a minimum soil infiltration rate of 0.5 inches/hour. Pretreatment is required in all instances.

2) Groundwater separation must be at least 5 feet from the basin bottom to the measured Seasonal High Groundwater Elevation or estimated high groundwater mounding elevation. Groundwater levels measurements must be made during the time when water level is expected to be at a maximum (i.e., toward the end of the wet season).

3) Potential BMP sites with a slope greater than 25% (4:1) should be excluded. A geotechnical analysis and report addressing slope stability are required if located within 50 feet of slopes greater than 15%.

Soil Assessment and Site Geotechnical Investigation Reports

The soil assessment report should:

- State whether the site is suitable for the proposed infiltration basin;

- Recommend a design percolation rate (see "*Step 2: Determine The Design Percolation Rate*" below);
- Identify the seasonally high depth to groundwater table surface elevation;
- Provide a good understanding of how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water; and
- If a geotechnical investigation and report are required, the report should:
    - Provide a written opinion by a professional civil engineer describing whether the infiltration basin will compromise slope stability; and
    - Identify potential impacts to nearby structural foundations.

Setbacks

1) Infiltration facilities shall be setback a minimum of 100 feet from proposed or existing potable wells, non-potable wells, septic drain fields, and springs.
2) Infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.
3) The geotechnical expert shall establish the setback requirement from building foundations that must be ≥ 8 ft.

Pretreatment

Pretreatment is required for infiltration basins in order to reduce the sediment load entering the facility and maintain the infiltration rate of the facility. Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice; easing the long-term maintenance burden. Pretreatment is important for most all structural stormwater BMPs, but it is particularly important for infiltration BMPs. To ensure that pretreatment mechanisms are effective, designers should incorporate sediment reduction practices. Sediment reduction BMPs may include vegetated swales, vegetated filter strips, sedimentation basins or forebays, sedimentation manholes and hydrodynamic separation devices. The use of at least two pretreatment devices is highly recommended for infiltration basins.

For design specification of selected pretreatment devices, refer to:

- BIO-3: Vegetated swales
- BIO-4: Vegetated filter strips
- TCM-4: Sand filters

- TCM-5: Cartridge media filters
- PT-1: Hydrodynamic separation device

Sizing Criteria

As with sand filters, infiltration facilities can be sized using one of two methods: a simple sizing method or a routing modeling method. With either method the SQDV volume must be completely infiltrated within 12 to 72 hours (see Appendix D, Section D.2 for a discussion on drawdown time and BMP performance). The simple sizing procedures provided below can be used for either infiltration basins or infiltration trenches (see INF-2: Infiltration Trench). For the routing modeling method, refer to TCM-4 Sand Filters.

Step 1: Calculate the Design Volume

Infiltration facilities shall be sized to capture and infiltrate the SQDV volume (see Section 2 and Appendix E) with a 12 to 72 hour drawdown time (see Appendix D, Section D.2).

Step 2: Determine the Design Percolation Rate

The percolation rate will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the infiltrative layer. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For infiltration trenches, the design percolation rate discussed here is the percolation rate of the underlying soils and not the percolation rate of the filter media bed (refer to the "Geometry and Sizing" section of INF-2 for the recommended composition of the filter media bed for infiltration trenches).

Considerations for Design Percolation Rate Corrections

Suitability assessment related considerations include (Table 6-2):

- Soil assessment methods – the site assessment extent (e.g., number of borings, test pits, etc.) and the measurement method used to estimate the short-term infiltration rate.
- Predominant soil texture/percent fines – soil texture and the percent fines can greatly influence the potential for clogging.
- Site soil variability – site with spatially heterogeneous soils (vertically or horizontally), as determined from site investigations, are more difficult to estimate average properties resulting in a higher level of uncertainty associated with initial estimates.

- Depth to seasonal high groundwater/impervious layer – groundwater mounding may become an issue during excessively wet conditions where shallow aquifers or shallow clay lenses are present.

Table 6-2: Suitability Assessment Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Assessment methods	Use of soil survey maps or simple texture analysis to estimate short-term infiltration rates	Direct measurement of ≥ 20 percent of infiltration area with localized infiltration measurement methods (e.g., infiltrometer)	Direct measurement of ≥ 50 percent of infiltration area with localized infiltration measurement methods or Use of extensive test pit infiltration measurement methods
Ventura Hydrology Manual soil number (measured infiltration rate)	3 (f = 0.5 – 0.64)	4 or 5 (f = 0.65 –0.91)	6 or 7 (f = 0.92 or higher)
Site soil variability	Highly variable soils indicated from site assessment or limited soil borings collected during site assessment	Soil borings/test pits indicate moderately homogeneous soils	Multiple soil borings/test pits indicate relatively homogeneous soils
Depth to groundwater/ impervious layer	<10 ft below facility bottom	10-30 ft below facility bottom	>30 below facility bottom

Localized infiltration testing refers to methods such as the double ring infiltrometer test (ASTM D3385-88), which measure infiltration rates over an area less than 10 sq-ft and do not attempt to account for soil heterogeneity. Extensive infiltration testing refers to methods that include excavating a significant portion of the proposed infiltration area, filling the excavation with water, and monitoring drawdown. In all cases, testing should be conducted in the area of the proposed BMP where, based on geotechnical data, soils appear least likely to support infiltration.

Design related considerations include (Table 6-3):

- Size of area tributary to facility – all things being equal, both physical and economic risk factors related to infiltration facilities increase with an increase in the tributary area served. Therefore facilities serving larger tributary areas should use more restrictive adjustment factors.

- Level of pretreatment/expected influent sediment loads – credit should be given for good pretreatment by allowing less restrictive factors to account for the reduced probability of clogging from high sediment loading. Also, facilities designed to capture runoff from relatively clean surfaces such as rooftops are likely to see low sediment loads and therefore should be allowed to apply less restrictive safety factors.

- Redundancy – facilities that consist of multiple subsystems operating in parallel such that parts of the system remains functional when other parts fail and/or bypass, should be rewarded for the built-in redundancy with less restrictive correction and safety factors. For example, if bypass flows would be at least partially treated by another BMP, the risk of discharging untreated runoff in the event of clogging the primary facility is reduced. A bioretention facility that overflows to a landscaped area is another example. Compaction during construction – proper construction oversight is needed during construction to ensure that the bottoms of infiltration facility are not overly compacted. Facilities that do not commit to proper construction practices and oversight should have to use more restrictive correction and safety factors.

Table 6-3: Design Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Tributary area size	Greater than 10 acres.	Greater than 2 acres but less than 10 acres.	2 acres or less.
Level of pre-treatment/ expected influent sediment loads	Pre-treatment from gross solids removal devices only, such as hydrodynamic separators, racks and screens, AND tributary area includes landscaped areas, steep slopes, high traffic areas, or any other areas expected to produce high sediment, trash, or debris loads.	Good pre-treatment with BMPs that mitigate coarse sediments such as vegetated swales AND influent sediment loads from the tributary area are expected to be relatively low (e.g., low traffic, mild slopes, disconnected impervious areas, etc.).	Excellent pre-treatment with BMPs that mitigate fine sediments such as bioretention or media filtration OR sedimentation or facility only treats runoff from relatively clean surfaces, such as rooftops.
Redundancy of treatment	No redundancy in BMP treatment train.	Medium redundancy, other BMPs available in treatment train to maintain at least 50% of function of facility in event of failure.	High redundancy, multiple components capable of operating independently and in parallel, maintaining at least 90% of facility functionality in event of failure.
Compaction during construction	Construction of facility on a compacted site or elevated probability of unintended/ indirect compaction.	Medium probability of unintended/ indirect compaction.	Heavy equipment actively prohibited from infiltration areas during construction and low probability of unintended/ indirect compaction.

Adjust the measured short-term infiltration rate using a weighted average of several safety factors using the worksheet shown in Table 6-4 below. The design percolation rate would be determined as follows:

- For each consideration shown in Table 6-2 and Table 6-3 above, determine whether the consideration is a high, medium, or low concern.
- For all high concerns, assign a factor value of 3, for medium concerns, assign a factor value of 2, and for low concerns assign a factor value of 1.
- Multiply each of the factors by the corresponding weight to get a product.

- Sum the products within each factor category to obtain a safety factor for each.
- Multiply the two safety factors together to get the final combined safety factor. If the combined safety factor is less than 2, then use 2 as the safety factor.
- Divide the measured short-term infiltration rate by the combined safety factor to obtain the adjusted design percolation rate for use in sizing the infiltration facility.

Table 6-4: Infiltration Facility Safety Factor Determination Worksheet

Factor Category		Factor Description	Assigned Weight (w)	Factor Value (v)	Product (p) p = w x v
A	Suitability Assessment	Soil assessment methods	0.25		
		Predominant soil texture	0.25		
		Site soil variability	0.25		
		Depth to groundwater / impervious layer	0.25		
		Suitability Assessment Safety Factor, $S_A = \Sigma p$			
B	Design	Tributary area size	0.25		
		Level of pre-treatment/ expected sediment loads	0.25		
		Redundancy	0.25		
		Compaction during construction	0.25		
		Design Safety Factor, $S_B = \Sigma p$			
Combined Safety Factor = S_A x S_B					

Note: The minimum combined adjustment factor shall not be less than 2.0 and the maximum combined adjustment factor shall not exceed 9.

Step 3: Calculate the surface area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus (for infiltration trenches) the void spaces based on the computed porosity of the filter media (normally about 32%).

1) Determine the maximum depth of runoff that can be infiltrated within the required drain time (d_{max}) as follows:

$$d_{\max} = \frac{P_{design}}{12} t \qquad \text{(Equation 6-1)}$$

Where:

d_{max}	=	the maximum depth of water that can be infiltrated within the required drain time (ft)
P_{design}	=	design percolation rate of underlying soils (in/hr)
t	=	required drain time (hrs)

2) Choose the ponding depth (d_p) and/or trench depth (d_t) such that:

$$d_{\max} \geq d_p$$ For Infiltration Basins (Equation 6-2)

$$d_{\max} \geq n_t d_t + d_p$$ For Infiltration Trenches (Equation 6-3)

Where:

d_{max}	=	the maximum depth of water that can be infiltrated within the required drain time (ft)
d_p	=	ponding depth (ft)
n_t	=	trench fill aggregate porosity (unitless)
d_t	=	depth of trench fill (ft)

3) Calculate infiltrating surface area (filter bottom area) required:

$$A = \frac{SQDV}{((TP_{design}/12) + d_p)}$$ For Infiltration Basins (Equation 6-4)

$$A = \frac{SQDV}{((\ TP_{design}/12\ ) + n_t d_t + d_p)}$$ For Infiltration Trenches (Equation 6-5)

Where:

$SQDV$	=	stormwater quality design volume (ft^3)
n_t	=	trench fill aggregate porosity (unitless)
P_{design}	=	design percolation rate (in/hr)
d_p	=	ponding depth (ft)
d_t	=	depth of trench fill (ft)
T	=	fill time (time to fill to max ponding depth with water) (hrs) [use 2 hours for most designs]

Geometry and Sizing

1) Infiltration basins should be designed and constructed with the flattest bottom slope possible to promote uniform ponding and infiltration across the facility.

2) A sediment forebay is required unless adequate pretreatment is provided in a separate pretreatment unit (e.g., vegetated swale, filter strip, hydrodynamic device) to reduce sediment loads entering the infiltration basin. The sediment forebay, if present, should have a volume equal to 25% of the total infiltration basin volume.

3) The forebay should be designed with a minimum length to width ratio of 2:1 and should completely drain to the main basin through an 8-inch minimum low-flow outlet within 10 minutes.

4) All inlets should enter the sediment forebay. If there are multiple inlets, the length-to-width ratio should be based on the average flowpath length for all inlets.

5) Design embankments to conform to requirements of the State of California Division of Safety of Dams, if the basin dimensions cause it to fall under that agency's jurisdiction.

Drainage

1) The bottom of the infiltration bed should be native soil, over-excavated to at least one foot in depth, and replaced uniformly without compaction. Amending the excavated soil with 2-4 inches (~15-30%) of coarse sand is recommended.

2) The hydraulic conductivity of the subsurface layers should be sufficient to ensure a maximum 72-hr drawdown time. An observation well shall be incorporated to allow observation of drain time.

3) For infiltration basins, an underdrain should be installed within the bottom layer to provide drainage in case of standing water. The underdrain should be operated by opening a valve, which should be closed during normal operation. Cleanouts should be provided for the underdrain. See Sand Filter Section VEG-8 for specifications for underdrains.

Emergency Overflow

1) There should be an overflow route for stormwater flows that overtop the facility or in case the infiltration facility becomes clogged.

2) The overflow channel should be able to safely convey flows from the peak design storm to the downstream stormwater conveyance system or other acceptable discharge point.

3) Spillway and overflow structures should be designed in accordance with applicable standards of the Ventura County Flood Control District or local jurisdiction.

Vegetation

1) A thick mat of drought tolerant grass should be established on the basin floor and side-slopes following construction. Grasses can help prevent erosion and increase evapotranspiration and their roots discourage compaction helping to maintain the surface infiltration rates. Additionally, the active growing vegetation can help break up surface layers that accumulate fine particulates.

2) Grass may need to be irrigated during establishment.

3) For infiltration basins, landscaping of the area surrounding the basin should adhere to the following criteria so as not to hinder maintenance operations:

    a. No trees or shrubs may be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, should not be used within 50 feet of pipes.

    b. Prohibited non-native plant species will not be permitted. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

Maintenance Access

1) Maintenance access road(s) shall be provided to the drainage structures associated with the basin (e.g., inlet, emergency overflow, or bypass structures). Manhole and catch basin lids should be in or at the edge of the access road.

2) An access ramp to the basin bottom is required to facilitate the entry of sediment removal and vegetation maintenance equipment without compaction of the basin bottom and side slopes.

Construction Considerations

To preserve and avoid the loss of infiltration capacity, the following construction guidelines are specified:

1) The entire area draining to the facility should be stabilized before construction begins. If this is impossible, a diversion berm should be placed around the perimeter of the infiltration site to prevent sediment entrance during construction.

2) Infiltration basins should not be hydraulically connected to the stormwater conveyance system until all contributing tributary areas are stabilized as shown on the Contract Plans and to the satisfaction of the Engineer. Infiltration basins should not be used as sediment control facilities.

3) Compaction of the subgrade with heavy equipment should be minimized to the maximum extent possible. If the use of heavy equipment on the base of the facility cannot be avoided, the infiltrative capacity should be restored by tilling or aerating prior to placing the infiltrative bed.

4) The exposed soils should be inspected by a civil engineer after excavation to confirm that soil conditions are suitable.

Operations and Maintenance

Infiltration facility maintenance should include frequent inspections to ensure that surface ponding infiltrates into the subsurface completely within the design infiltration time after a storm (see Appendix I for an infiltration BMP inspection and maintenance checklist).

Maintenance and regular inspections are of primary importance if infiltration BMPs are to continue to function as originally designed. A specific maintenance plan shall be formulated specifically for each facility outlining the schedule and scope of maintenance operations, as well as the data handling and reporting requirements. The following are general maintenance requirements:

1) Regular inspection should determine if the pretreatment sediment removal BMPs require routine maintenance.

2) If water is noticed in the basin more than 72 hours after a major storm the infiltration facility may be clogged. Maintenance activities triggered by a potentially clogged facility include:

    a. Check for debris/sediment accumulation, rake surface, and remove sediment (if any) and evaluate potential sources of sediment and debris (e.g., embankment erosion, channel scour, overhanging trees, etc). If suspected upland sources are outside of the immediate jurisdiction, additional pretreatment operations (e.g., trash racks, vegetated swales, etc.) may be necessary.

    b. For basins, removal of the top layer of native soil may be required to restore infiltrative capacity.

    c. Any debris or algae growth located on top of the infiltration facility should be removed and disposed of properly.

    d. Facilities shall be inspected annually. Trash and debris should be removed as needed, but at least annually prior to the beginning of the wet season.

3) Site vegetation should be maintained as frequently as necessary to maintain the aesthetic appearance of the site, and as follows:

   a. Vegetation, large shrubs, or trees that limit access or interfere with basin operation should be pruned or removed.

   b. Slope areas that have become bare should be revegetated and eroded areas should be regraded prior to being revegetated.

   c. Grass should be mowed to 4" - 9" high and grass clippings should be removed.

   d. Fallen leaves and debris from deciduous plant foliage should be raked and removed.

   e. Invasive vegetation, such as Alligatorweed (Alternanthera philoxeroides), Halogeton (Halogeton glomeratus), Spotted Knapweed (Centaurea maculosa), Giant Reed (Arundo donax), Castor Bean (Ricinus communis), Perennial Pepperweed (Lepidium latifolium), and Yellow Starthistle (Centaurea solstitalis) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 25% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

   f. Dead vegetation should be removed if it exceeds 10% of area coverage. Vegetation should be replaced immediately to maintain cover density and control erosion where soils are exposed.

4) For infiltration basins, sediment build-up exceeding 50% of the forebay capacity should be removed. Sediment from the remainder of the basin should be removed when 6 inches of sediment accumulates. Sediments should be tested for toxic substance accumulation in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed. If toxic substances are encountered at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, the sediment should be disposed of in a hazardous waste landfill and the source of the contaminated sediments should be investigated and mitigated to the extent possible.

5) Following sediment removal activities, replanting and/or reseeding of vegetation may be required for reestablishment.

INF-2: Infiltration Trench

Infiltration trenches are long, narrow, gravel-filled trenches, often vegetated, that infiltrate stormwater runoff from small drainage areas. Infiltration trenches may include a shallow depression at the surface, but the majority of runoff is stored in the void space within the gravel and infiltrates through the sides and the bottom of the trench.

Rural Highway Infiltration Trench

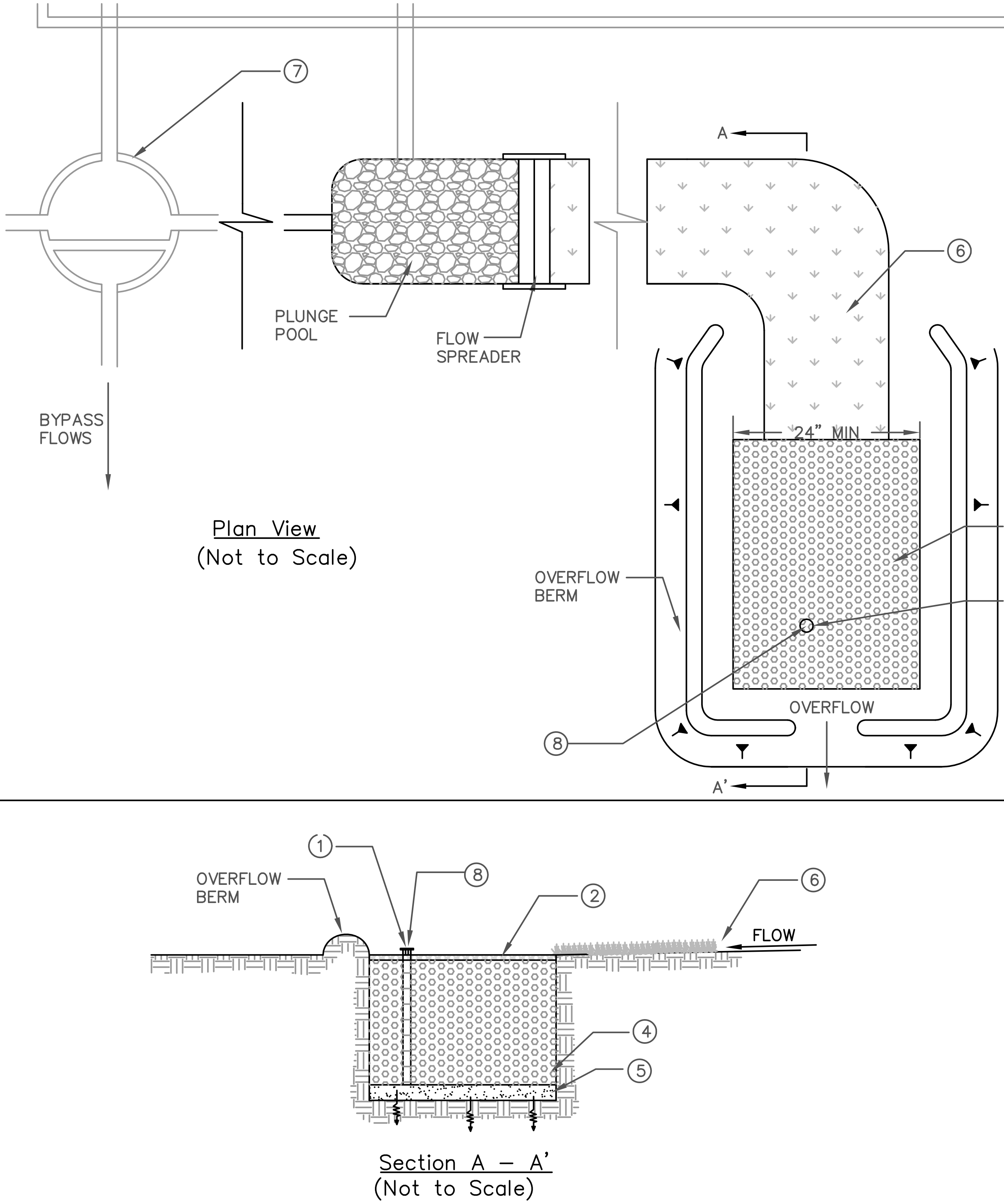
http://stormwater.wordpress.com/2007/05/23/infiltration--trenches/

Application

- Open areas adjacent to parking lots, driveways, and buildings
- Roadway medians and shoulders

Routine Maintenance

- Removal trash, debris, and sediment at inlet and outlets
- Wet weather inspection to ensure drain time
- Remove weeds
- Inspect for mosquito breeding



NOTES:

1. OBSERVATION WELL WITH LOCKABLE ABOVE–GROUND CAP.
2. 2" PEA GRAVEL FILTER LAYER.
3. MINIMUM 10' ABOVE SEASONAL HIGH GROUNDWATER TABLE AND 3' ABOVE BEDROCK.
4. 3' – 5' DEEP TRENCH FILLED WITH 2" – 6" DIAMETER CLEAN STONE WITH 30% – 40% VOIDS.
5. 6" DEEP SAND FILTER LAYER (OR FABRIC EQUIVALENT).
6. RUNOFF FILTERS THROUGH GRASS FILTER STRIP OR VEGETATED SWALE.
7. OPTIONAL FLOW CONTROL DEVICE FOR OFF–LINE CONFIGURATIONS.

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Figure 6-3: Infiltration Trench

Limitations

The following limitations should be considered before choosing to use an infiltration trench:

- Native soil infiltration rate – soil permeability at the infiltration trench location must be at least 0.5 inches per hour.

- Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration trench and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.

- Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

- Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields and springs. Infiltration BMPs must be setback from building foundations at least eight feet or an alternative setback established by the geotechnical expert for the project.

- Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer to ensure groundwater is protected for pollutants of concern.

- Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines that infiltration would be beneficial.

- High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.

- High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.

Design Criteria

The main challenge associated with infiltration trenches is preventing system clogging and subsequent infiltration inhibition. Infiltration trenches should be designed according to the requirements listed in Table 6-5 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-5: Infiltration Trench Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Design drawdown time	hr	12 – 72, see Appendix D, Section D.2
Trench bottom elevation	feet	5 feet from seasonally high groundwater table
Setbacks	feet	100 feet from wells, fields, springs Geotechnical expert should establish the setback requirement from building foundations that must be ≥ 8 ft Do not locate under tree drip-lines
Pretreatment	-	BIO-3: Vegetated Swale, BIO-4: Filter Strip, proprietary device, or sedimentation forebay, for all surfaces other than roofs
Design percolation rate, (P_{design})	in/hr	Measured percolation rate must be corrected based onsite suitability assessment and design related considerations described in this fact sheet
Maximum depth of facility (d_{max})	feet	8.0; Defined by the design infiltration rate and the design drawdown time (includes ponding depth and depth of media)
Surface area of facility (A)	square feet	Based on depth of ponding (if applicable) and depth of trench media
Facility geometry	-	Minimum 24 inches wide and maximum 5 feet deep; max 3% bottom slope
Filter media diameter	inches	1 – 3 (gravel); prefabricated media may also be used
Trench lining material	-	Geotextile fabric
Overflow device	-	Required if system is on-line

Geotechnical Considerations

An extensive geotechnical site investigation must be undertaken early in the site planning process to verify site suitability for the installation of infiltration facilities due to the potential to contaminate groundwater, cause slope instability, impact surrounding structures, and have insufficient infiltration capacity. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration facility. See Appendix C for guidance on infiltration testing.

The project designer must demonstrate through infiltration testing, soil logs, and the written opinion of a licensed civil engineer that sufficiently permeable soils exist onsite to allow the construction of a properly functioning infiltration facility.

1) Infiltration facilities require a minimum soil infiltration rate of 0.5 inches/hour. If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect groundwater quality. Pretreatment for coarse sediment removal is required in all instances.

2) Groundwater separation must be at least 5 feet from the trench bottom to the measured season high groundwater elevation or estimated high groundwater mounding elevation. Groundwater level measurements must be made during the time when water level is expected to be at a maximum (i.e., toward the end of the wet season).

3) Sites with a slope greater than 25% (4:1) should be excluded. A geotechnical analysis and report addressing slope stability are required if located on slopes greater than 15%.

Soil Assessment and Site Geotechnical Investigation Reports

The soil assessment report should:

- State whether the site is suitable for the proposed infiltration trench;
- Recommend a design infiltration rate (see the Step 2 of sizing methodology section, "Determine the design percolation rate," in the Infiltration Basin fact sheet above);
- Identify the seasonally high depth to groundwater table surface elevation.
- Provide a good understanding of how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water; and
- If a geotechnical investigation and report are required, the report should:
  - Provide a written opinion by a professional civil engineer describing whether the infiltration trench will compromise slope stability; and

- Identify potential impacts to nearby structural foundations.

Setbacks

1) Infiltration facilities shall be setback a minimum of 100 feet from proposed or existing potable wells, non-potable wells, septic drain fields, and springs.

2) Infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

3) Infiltration BMPs must be setback from building foundations at least eight feet or an alternative setback established by the geotechnical expert for the project.

Pretreatment

Pretreatment is required for infiltration trenches in order to reduce the sediment load entering the facility and maintain the infiltration rate of the facility. Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice; easing the long-term maintenance burden. Pretreatment is important for most all structural stormwater BMPs, but it is particularly important for infiltration BMPs. To ensure that pretreatment mechanisms are effective, designers should incorporate sediment reduction practices. Sediment reduction BMPs may include vegetated swales, vegetated filter strips, sedimentation basins or forebays, sedimentation manholes and hydrodynamic separation devices.

For design specification of selected pre-treatment devices, refer to:

- VEG-3: Vegetated swales
- VEG-4: Vegetated filter strips
- TCM-4: Sand filters
- TCM-5: Cartridge media filters
- PT-1: Hydrodynamic separation device

Sizing Criteria

See Sizing Criteria section in the INF-1: Infiltration Basin fact sheet.

Geometry and Sizing

1) Infiltration trenches should be at least 2 feet wide and 3 to 5 feet deep.

2) The longitudinal slope of the trench should not exceed 3%.

3) The filter bed media layers should have the following composition and thickness:

a. Top layer – If stormwater runoff enters the top of the trench via sheet flow at the ground surface, then the top 2 inches should be pea gravel with a thin 2 to 4 inch layer of pure sand and 2 inch layer of chocking stone (e.g., #8) to capture sediment before entering the trench. If stormwater runoff enters the trench from an underground pipe, pretreatment prior to entry into the trench is required.

b. Middle layer (3 to 5 feet of washed, 1.5 to 3 inch gravel). Void space should be in the range of 30 percent to 40 percent.

c. Bottom layer (6 inches of clean, washed sand to encourage drainage and prevent compaction of the native soil while the stone aggregate is added).

4) One or more observation wells should be installed, depending on trench length, to check for water level, drawdown time, and evidence of clogging. A typical observation well consists of a slotted PVC well screen, 4 to 6 inches in diameter, capped with a lockable, above-ground lid.

Drainage

1) The bottom of the infiltration bed must be native soil, over-excavated to at least one foot in depth and replaced uniformly without compaction. Amending the excavated soil with 2 to 4 inches (~15% to 30%) of coarse sand is recommended.

2) The hydraulic conductivity of the subsurface layers should be sufficient to ensure the design drawdown time. An observation well should be incorporated to allow observation of drain time.

Emergency Overflow

1) There must be an overflow route for stormwater flows that overtop the facility or in case the infiltration facility becomes clogged.

2) The overflow channel must be able to safely convey flows from the peak design storm to the downstream stormwater conveyance system or other acceptable discharge point.

Vegetation

1) Trees and other large vegetation should be planted away from trenches such that drip lines do not overhang infiltration beds.

Maintenance Access

1) The facility and outlet structures must all be safely accessible during wet and dry weather conditions.

2) An access road along the length of the trench is required, unless the trench is located along an existing road or parking lot that can be safely used for maintenance access.

3) If the infiltration trench becomes plugged and fails, then access is needed to excavate the facility to remove and replace the top layer or the filter bed media, as well as to increase all dimensions of the facility by 2 inches to provide a fresh surface for infiltration. To prevent damage and compaction, access must be able to accommodate a backhoe working at “arms length”.

Construction Considerations

To preserve and avoid the loss of infiltration capacity, the following construction guidelines are specified:

1) The entire area draining to the facility must be stabilized before construction begins. If this is impossible, a diversion berm should be placed around the perimeter of the infiltration site to prevent sediment entering during construction.

2) Infiltration trenches should not be hydraulically connected to the stormwater conveyance system until all contributing tributary areas are stabilized as shown on the Contract Plans and to the satisfaction of the Engineer. Infiltration trenches should not be used as sediment control facilities.

3) Compaction of the subgrade with heavy equipment should be minimized to the maximum extent possible. If the use of heavy equipment on the base of the facility cannot be avoided, the infiltrative capacity should be restored by tilling or aerating prior to placing the infiltrative bed.

4) The exposed soils should be inspected by a civil engineer after excavation to confirm that soil conditions are suitable.

Operations and Maintenance

Infiltration facility maintenance should include frequent inspections to ensure that water infiltrates into the subsurface completely within the design drawdown time after a storm.

Maintenance and regular inspections are of primary importance if infiltration trenches are to continue to function as originally designed. A specific maintenance plan shall be developed specific to each facility outlining the schedule and scope of maintenance operations, as well as the documentation and reporting requirements. The following are general maintenance requirements:

1) Regular inspection should determine if the sediment pretreatment structures require preventative maintenance. Inspect a minimum of twice a year, before and after the rainy season, after large storms, or more frequently if needed.

2) If water is noticed in the observation well of the infiltration trench more than 72 hours after a major storm, the infiltration trench may be clogged. Maintenance activities triggered by a potentially clogged facility include:

   a. For trenches, assess the condition of the top aggregate layer for sediment buildup and crusting. Remove top layer of pea gravel and replace. If slow draining conditions persist, entire trench may need to be excavated and replaced.

3) Any debris or algae growth located on top of the infiltration facility should be removed and disposed of properly.

4) Inspect a minimum of twice a y ear, before and after the rainy season, after large storms, or more frequently if needed.

5) Clean when loss of infiltrative capacity is observed. If drawdown time is observed to have increased significantly over the design drawdown time, removal of sediment may be necessary. This is an expensive maintenance activity and the need for it can be minimized through prevention of upstream erosion.

6) Mow as appropriate for vegetative cover species.

7) Monitor health of vegetation and replace as necessary.

8) Control mosquitoes as necessary.

9) Remove litter and debris from trench area as required.

INF-3: Bioretention

Bioretention stormwater treatment facilities are landscaped shallow depressions that capture and filter stormwater runoff. These facilities function as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. The facilities normally consist of a ponding area, mulch layer, planting soils, and plantings. An optional gravel layer can be added below the planting soil to provide additional storage volume for infiltration. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants. For areas with low permeability native soils or steep slopes, see section INF-7: Bioinfiltration or BIO-1: Bioretention with Underdrain for relevant design specifications.

Bioretention in Parkway and parking lots

Photo Credits: Geosyntec Consultants

Application

- Commercial, residential, mixed use, institutional, and recreational uses
- Parking lot islands, traffic circles
- Road parkways & medians

Preventative Maintenance

- Repair small eroded areas
- Remove trash and debris and rake surface soils
- Remove accumulated fine sediments, dead leaves and trash
- Remove weeds and prune back excess plant growth
- Remove sediment and debris accumulation near inlet and outlet structures
- Periodically observe function under wet weather conditions

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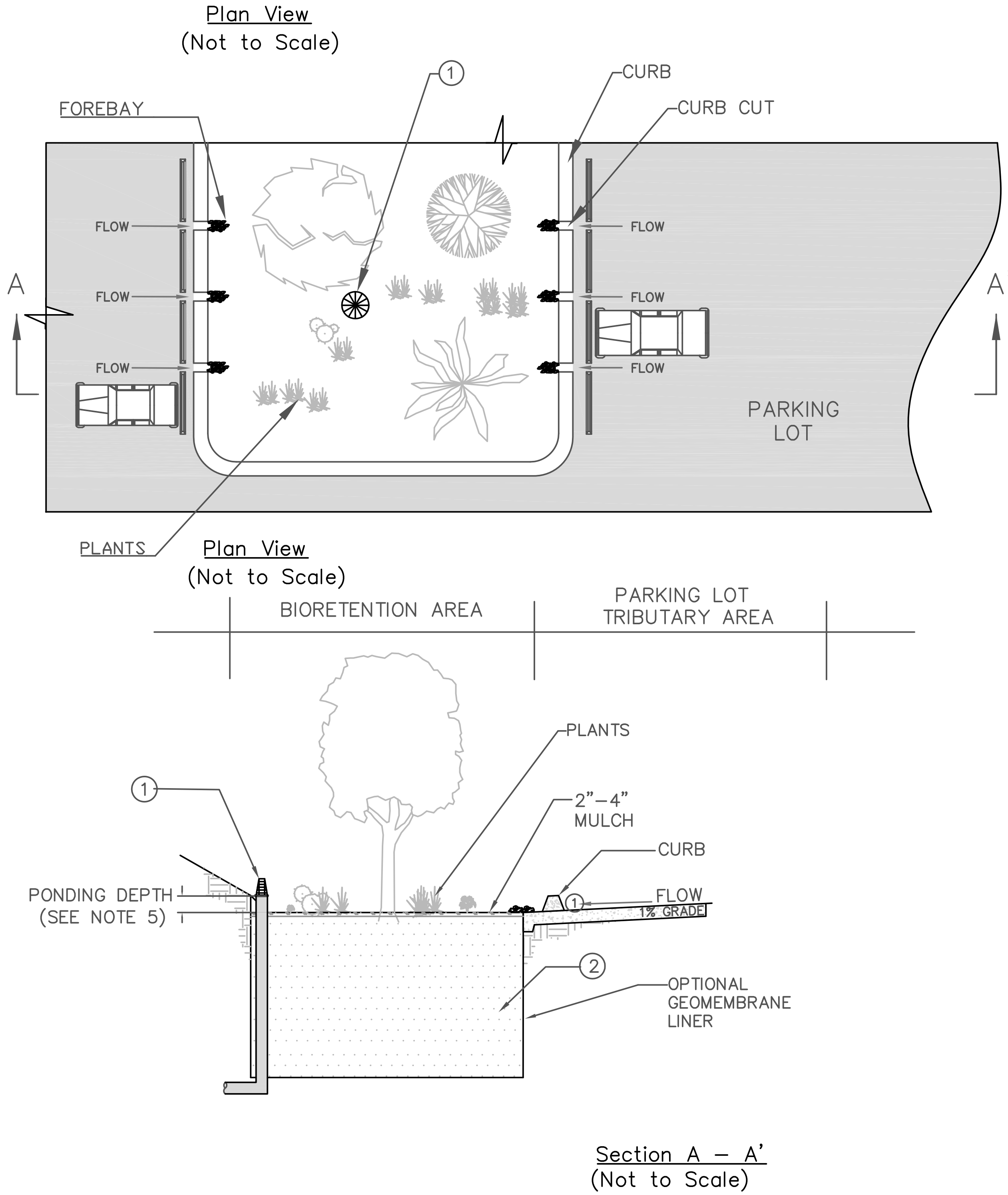

NOTES:

① OVERFLOW DEVICE: VERTICAL RISER OR EQUIVALENT.
② 2' MIN PLANTING MIX; 3' PREFERRED.
③ PONDING DEPTH 18" WITH FENCE; 6" WITHOUT FENCE.

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Figure 6-4: Bioretention

Limitations

The following limitations should be considered before choosing to use bioretention:

1) Native soil infiltration rate - soil permeability at the bioretention location must be at least 0.5 inches per hour.

2) Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration trench and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.

3) Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

4) Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

5) Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer to ensure groundwater is protected for pollutants of concern.

6) Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines that infiltration would be beneficial.

7) High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.

8) High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.

9) Vertical relief and proximity to storm drain - site must have adequate relief between the land surface and storm drain to permit vertical percolation through the soil media and collection.

Design Criteria

Bioretention should be designed according to the requirements listed in Table 6-6 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-6: Bioretention Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Forebay	-	Forebay should be provided for all tributary surfaces that contain landscaped areas. Forebays should be designed to prevent standing water during dry weather and should be planted with a plant palette that is tolerant of wet conditions.
Maximum drawdown time of water ponded on surface	hours	48
Maximum drawdown time of surface ponding plus subsurface pores	hours	96 (72 preferred)
Maximum ponding depth	inches	18
Minimum thickness of amended soil	feet	2 (3 preferred)
Minimum thickness of stabilized mulch	inches	2 to 3
Planting mix composition	-	60 to 80% fine sand, 20 to 40% compost
Overflow device	-	Required

Sizing Criteria

Bioretention facilities can be sized using one of two methods: a simple sizing method or a routing modeling method. With either method the SQDV volume must be completely infiltrated within 96 hours (including subsurface pore space), and surface ponding must be infiltrated within 48 hours. The simple sizing procedure is provided below. For the routing modeling method, refer to TCM-4 Sand Filters.

Step 1: Calculate the Design Volume

Bioretention facilities shall be sized to capture and infiltrate the SQDV volume (see Section 2.3 and Appendix E).

Step 2: Determine the Design Percolation Rate

The percolation rate through the BMP and to the subsurface will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the infiltration layer. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For bioretention facilities, the design percolation rate discussed here is the adjusted percolation rate of the underlying soils and not the percolation rate of the filter media bed.

<u>Considerations for Design Percolation Rate Corrections</u>

Suitability assessment-related considerations include (Table 6-7):

- Soil assessment methods – the site assessment extent (e.g., number of borings, test pits, etc.) and the measurement method used to estimate the short-term infiltration rate.
- Predominant soil texture/percent fines – soil texture and the percent of fines can greatly influence the potential for clogging.
- Site soil variability – site with spatially heterogeneous soils (vertically or horizontally) as determined from site investigations are more difficult to estimate average properties, resulting in a higher level of uncertainty associated with initial estimates.
- Depth to seasonal high groundwater/impervious layer – groundwater mounding may become an issue during excessively wet conditions where shallow aquifers or shallow clay lenses are present.

Localized infiltration testing refers to methods such as the double ring infiltrometer test (ASTM D3385-88), which measure infiltration rates over an area less than 10 sq-ft and do not attempt to account for soil heterogeneity. Extensive infiltration testing refers to methods that include excavating a significant portion of the proposed infiltration area, filling the excavation with water, and monitoring drawdown. In all cases, testing should be conducted in the area of the proposed BMP where, based on geotechnical data, soils appear least likely to support infiltration.

Table 6-7: Suitability Assessment Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Assessment methods	Use of soil survey maps or simple texture analysis to estimate short-term infiltration rates	Direct measurement of ≥ 20 percent of infiltration area with localized infiltration measurement methods (e.g., infiltrometer)	Direct measurement of ≥ 50 percent of infiltration area with localized infiltration measurement methods or Use of extensive test pit infiltration measurement methods
Ventura Hydrology Manual soil number (measured infiltration rate)	3 (f = 0.5 – 0.64)	4 or 5 (f = 0.65 – 0.91)	6 or 7 (f = 0.92 or higher)
Site soil variability	Highly variable soils indicated from site assessment or limited soil borings collected during site assessment	Soil borings/test pits indicate moderately homogeneous soils	Multiple soil borings/test pits indicate relatively homogeneous soils
Depth to groundwater/ impervious layer	<10 ft below facility bottom	10-30 ft below facility bottom	>30 below facility bottom

Design related considerations include:

- Size of area tributary to facility – all things being equal, both physical and economic risk factors related to infiltration facilities increase with an increase in the tributary area served. Therefore facilities serving larger tributary areas should use more restrictive adjustment factors.

- Level of pretreatment/expected influent sediment loads – credit should be given for good pretreatment by allowing less restrictive factors to account for the reduced probability of clogging from high sediment loading. Also, facilities designed to capture runoff from relatively clean surfaces such as rooftops are likely to see low sediment loads and therefore should be allowed to apply less restrictive safety factors.

- Redundancy – facilities that consist of multiple subsystems operating in parallel such that parts of the system remain functional when other parts fail and/or bypass should be rewarded for the built-in redundancy with less restrictive correction and safety factors. For example, if bypass flows would be at least partially treated in another BMP, the risk of discharging untreated runoff in the event of clogging the primary facility is reduced. A bioretention facility that overflows to a landscaped area is another example.

- Compaction during construction – proper construction oversight is needed during construction to ensure that the bottoms of bioretention facility are not overly compacted. Facilities that do not commit to proper construction practices and oversight should have to use more restrictive correction and safety factors.

Table 6-8: Design Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Tributary area size	Greater than 10 acres.	Greater than 2 acres but less than 10 acres.	2 acres or less.
Level of pre-treatment/ expected influent sediment loads	Pre-treatment from gross solids removal devices only, such as hydrodynamic separators, racks and screens, AND tributary area includes landscaped areas, steep slopes, high traffic areas, or any other areas expected to produce high sediment, trash, or debris loads.	Good pre-treatment with BMPs that mitigate coarse sediments such as vegetated swales AND influent sediment loads from the tributary area are expected to be relatively low (e.g., low traffic, mild slopes, disconnected impervious areas, etc.).	Excellent pre-treatment with BMPs that mitigate fine sediments such as bioretention or media filtration OR sedimentation or facility only treats runoff from relatively clean surfaces, such as rooftops.
Redundancy of treatment	No redundancy in BMP treatment train.	Medium redundancy, other BMPs available in treatment train to maintain at least 50% of function of facility in event of failure.	High redundancy, multiple components capable of operating independently and in parallel, maintaining at least 90% of facility functionality in event of failure.
Compaction during construction	Construction of facility on a compacted site or elevated probability of unintended/ indirect compaction.	Medium probability of unintended/ indirect compaction.	Heavy equipment actively prohibited from infiltration areas during construction and low probability of unintended/ indirect compaction.

Adjust the measured short-term infiltration rate using a weighted average of several safety factors using the worksheet shown in Table 6-9 below. The design percolation rate would be determined as follows:

- For each consideration shown in Tables 6-7 and 6-8 above, determine whether the consideration is a high, medium, or low concern.
- For all high concerns assign a factor value of 3, for medium concerns assign a factor value of 2, and for low concerns assign a factor value of 1.
- Multiply each of the factors by the corresponding weight to get a product.
- Sum the products within each factor category to obtain a safety factor for each.
- Multiply the two safety factors together to get the final combined safety factor. If the combined safety factor is less than 2, then use 2 as the safety factor.
- Divide the measured short-term infiltration rate by the combined safety factor to obtain the adjusted design percolation rate for use in sizing the infiltration facility.

Table 6-9: Infiltration Facility Safety Factor Determination Worksheet

Factor Category		Factor Description	Assigned Weight (w)	Factor Value (v)	Product (p) p = w x v
A	Suitability Assessment	Soil assessment methods	0.25		
		Predominant soil texture	0.25		
		Site soil variability	0.25		
		Depth to groundwater / impervious layer	0.25		
		Suitability Assessment Safety Factor, $S_A = \Sigma p$			
B	Design	Tributary area size	0.25		
		Level of pre-treatment/ expected sediment loads	0.25		
		Redundancy	0.25		
		Compaction during construction	0.25		
		Design Safety Factor, $S_B = \Sigma p$			
Combined Safety Factor = $S_A \times S_B$					

Note: The minimum combined adjustment factor shall not be less than 2.0 and the maximum combined adjustment factor shall not exceed 9.

Step 3: Calculate the surface area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus the void spaces in the media, based on the computed porosity of the filter media and optional aggregate layer.

1) Determine the maximum depth of surface ponding that can be infiltrated within the required surface drain time (48 hr), (d_{max}), as follows:

$$d_{\max} = \frac{P_{design} \times t_{ponding}}{12\frac{in}{ft}} \quad \text{(Equation 6-6)}$$

Where:

$t_{ponding}$	=	required drain time of surface ponding (48 hrs)
P_{design}	=	design percolation rate of underlying soils (in/hr) (see Step 2, above)
d_{max}	=	the maximum depth of surface ponding water that can be infiltrated within the required drain time (ft), calculated using Equation 6-6

2) Choose surface ponding depth (d_p) such that:

$$d_p \le d_{\max} \quad \text{(Equation 6-7)}$$

Where:

d_p	=	selected surface ponding depth (ft)
d_{max}	=	the maximum depth of water that can be infiltrated within the required drain time (ft)

Choose thickness(es) of amended media and optional gravel storage layer and calculate total effective storage depth of the bioretention area ($d_{effective}$), as follows:

$$d_{effective} \le (d_p + n^*_{media} l_{media} + n_{gravel} l_{gravel}) \quad \text{(Equation 6-8)}$$

Where:

$d_{effective}$	=	total equivalent depth of water stored in bioretention area (ft), including surface ponding and volume available in pore spaces of media and gravel layers
d_p	=	surface ponding depth (ft), chosen using Equation 6-7
n^*_{media}	=	available porosity of amended soil media (ft/ft), approximately 0.25 ft/ft accounting for antecedent moisture conditions. This represents the volume of

available pore space as a fraction of the total soil volume; sometimes has units of (ft^3/ft^3) or described as a percentage.

l_{media} = thickness of amended soil media layer (ft), minimum 2 ft

n_{gravel} = porosity of optional gravel layer (ft/ft), approximately 0.40 ft/ft

l_{gravel} = thickness of optional gravel layer (ft)

3) Check that entire effective depth (surface plus subsurface storage), $d_{effective}$, infiltrates in no greater than 96 hours as follows:

$$t_{total} = \frac{d_{effective}}{P_{design}} \times 12 \frac{in}{ft} \leq 96\ hr \qquad \text{(Equation 6-9)}$$

Where:

$d_{effective}$ = total equivalent depth of water stored in bioretention area (ft), calculated using Equation 6-8

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

If $t_{total} > 96$ hrs, then reduce surface ponding depth and/or amended media thickness and/or gravel thickness and return to 1).

If $t_{total} \leq 96$ hrs, then proceed to 5).

4) Calculate required infiltrating surface area, (A_{req}):

$$A_{req} = \frac{SQDV}{d_{effective}} \qquad \text{(Equation 6-10)}$$

Where:

A_{req} = required infiltrating area (ft^2). Should be calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility).

$SQDV$ = stormwater quality design volume (ft^3)

$d_{effective}$ = total equivalent depth of water stored in bioretention area (ft), calculated using Equation 6-8

5) Calculate total footprint required by including a buffer for side slopes and freeboard; A_{req} is calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility).

Geometry

1) Bioretention areas shall be sized to capture and treat the stormwater quality design volume (See Section 2 and Appendix E for calculating SQDV) with an 18-inch maximum ponding depth. *The intention is that ponding depth be limited to a depth that will allow for a health vegetation layer.*

2) Minimum planting soil depth should be 2 feet, although 3 feet is preferred. *The intention is that the minimum planting soil depth should provide a beneficial root zone for the chosen plant palette and adequate water storage for the SQDV.*

3) A gravel storage layer below the bioretention soil media to promote infiltration into the native soil is optional.

4) Bioretention should be designed to drain below the planting soil in less than 48 hours and completely drain in less than 96 hours. *The intention is that soils must be allowed to dry out periodically in order to restore hydraulic capacity needed to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.*

Flow Entrance and Energy Dissipation

The following types of flow entrance can be used for bioretention cells:

1) Dispersed, low velocity flow across a landscape area. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.

2) Dispersed flow across pavement or gravel and past wheel stops for parking areas.

3) Curb cuts for roadside or parking lot areas: curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 2 to 3 inches from curb line and it should provide a settling area and periodic sediment removal of coarse material before flow dissipates to the remainder of the cell.

4) Pipe flow entrance: Piped entrances, such as roof downspouts, should include rock, splash blocks, or other appropriate measures at the entrance to dissipate energy and disperse flows.

Woody plants (trees, shrubs, etc.) can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path.

Overflow

An overflow device is required at the 18-inch ponding depth. The following, or equivalent should be provided:

1) A vertical PVC pipe (SDR 35) to act as an overflow riser.

2) The overflow riser(s) should be 6 inches or greater in diameter, so it can be cleaned without damage to the pipe.

The inlet to the riser should be at the ponding depth (18 inches for fenced bioretention areas and 6 inches for areas that are not fenced), and be capped with a spider cap to exclude floating mulch and debris. Spider caps should be screwed in or glued, i.e., not removable.

Hydraulic Restriction Layers

Infiltration pathways may need to be restricted due to the close proximity of roads, foundations, or other infrastructure. A geomembrane liner, or other equivalent water proofing, may be placed along the vertical walls to reduce lateral flows. This liner should have a minimum thickness of 30 mils.

Planting/Storage Media

1) The planting media placed in the cell should achieve a long-term, in-place infiltration rate of at least 1 inch per hour. Higher infiltration rates are permissible. If the design long-term, in-place infiltration rate of the soil exceeds 12 inches per hour, documentation should be provided to demonstrate that the media will adequately address pollutants of concern at a higher flowrate. Bioretention soil shall also support vigorous plant growth.

2) Planting media should consist of 60 to 80% fine sand and 20 to 40% compost.

3) Sand should be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for bioretention should be analyzed by an accredited lab using #200, #100, #40, #30, #16, #8, #4, and 3/8 sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation (Note: all sands complying with ASTM C33 for fine aggregate comply with the gradation requirements below):

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
3/8 inch	100	100
#4	90	100
#8	70	100
#16	40	95
#30	15	70
#40	5	55
#100	0	15
#200	0	5

Note: the gradation of the sand component of the media is believed to be a major factor in the hydraulic conductivity of the media mix. If the desired hydraulic conductivity of the media cannot be achieved within the specified proportions of sand and compost (#2), then it may be necessary to utilize sand at the coarser end of the range specified in above ("minimum" column).

4) Compost should be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes, or other organic materials not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program). Compost quality should be verified via a lab analysis to be:

- Feedstock materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.

- Organic matter: 35-75% dry weight basis.

- Carbon and Nitrogen Ratio: 15:1 < C:N < 25:1

- Maturity/Stability: shall have dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120 F) upon delivery or rewetting is not acceptable.

- Toxicity: any one of the following measures is sufficient to indicate non-toxicity:

  - $NH_4:NH_3 < 3$

  - Ammonium < 500 ppm, dry weight basis

  - Seed Germination > 80% of control

  - Plant trials > 80% of control

    - Solvita® > 5 index value

- Nutrient content:

    - Total Nitrogen content 0.9% or above preferred

    - Total Boron should be <80 ppm, soluble boron < 2.5 ppm

- Salinity: < 6.0 mmhos/cm

- pH between 6.5 and 8 (may vary with plant palette)

Compost for bioretention should be analyzed by an accredited lab using #200, ¼ inch, ½ inch, and 1 inch sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation:

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
1 inch	99	100
½ inch	90	100
¼ inch	40	90
#200	2	10

Tests should be sufficiently recent to represent the actual material that is anticipated to be delivered to the site. If processes or sources used by the supplier have changed significantly since the most recent testing, new tests should be requested.

Note: the gradation of compost used in bioretention media is believed to play an important role in the saturated hydraulic conductivity of the media. To achieve a higher saturated hydraulic conductivity, it may be necessary to utilize compost at the coarser end of this range ("minimum" column). The percent passing the #200 sieve (fines) is believed to be the most important factor in hydraulic conductivity.

In addition, a coarser compost mix provides more heterogeneity of the bioretention media, which is believed to be advantageous for more rapid development of soil structure needed to support health biological processes. This may be an advantage for plant establishment with lower nutrient and water input.

5) The bioretention area should be covered with 2 to 4 inches (average 3 inches) of mulch at the start and an additional placement of 1 to 2 inches of mulch should be added annually. *The intention is that to help sustain the nutrient levels, suppress weeds, retain moisture, and maintain infiltration capacity.*

Plants

1) Plant materials should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 96 hours.

2) It is recommended that a minimum of three types of tree, shrubs, and/or herbaceous groundcover species be incorporated to protect against facility failure due to disease and insect infestations of a single species.

3) Native plant species and/or hardy cultivars that are not invasive and do not require chemical inputs should be used to the maximum extent practicable.

Operations and Maintenance

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, bioretention maintenance requirements are typical landscape care procedures and include:

1) Watering: Plants should be drought-tolerant. Watering may be required during prolonged dry periods after plants are established.

2) Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred (see Appendix I for a b ioretention inspection and maintenance checklist). Properly designed facilities with appropriate flow velocities should not have erosion problems, except perhaps in extreme events. If erosion problems occur, the following should be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.

3) Plant material: Depending on aesthetic requirements, occasional pruning and removing of dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants excluded.

4) Nutrients and pesticides: The soil mix and plants should be selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioretention area, as well as contribute pollutant loads to receiving waters. By design, bioretention facilities are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

5) Mulch: Replace mulch annually in bioretention facilities where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In residential lots or other areas where metal

deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.

6) Soil: Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. Replacing mulch in bioretention facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

INF-4: Drywell

A dry well is defined as a bored, drilled, or driven shaft or hole whose depth is greater than its width. A dry well is designed specifically for flood alleviation and stormwater disposal. Drywells are similar to infiltration trenches in their design and function, as they are designed to temporarily store and infiltrate runoff, primarily from rooftops or other impervious areas with low pollutant loading. A dry well may be either a small excavated pit filled with aggregate or a prefabricated storage chamber or pipe segment.

Dry wells can be used to reduce the increased volume of stormwater runoff caused by roofs of buildings. While generally not a significant source of runoff pollution, roofs are one of the most important sources of new or increased runoff volume from land development sites. Dry wells can also be used to indirectly enhance water quality by reducing the amount of SQDV to be treated by the other, downstream stormwater management facilities.

Drywell installation

Photo Credits: 1. K&A Enterprises; 2. Canale Landscaping

Application

- Infiltration of roof runoff

Preventative Maintenance

- Remove trash, debris, and sediment at inlet and outlets
- Wet weather inspection to ensure drain time
- Inspect for mosquito breeding

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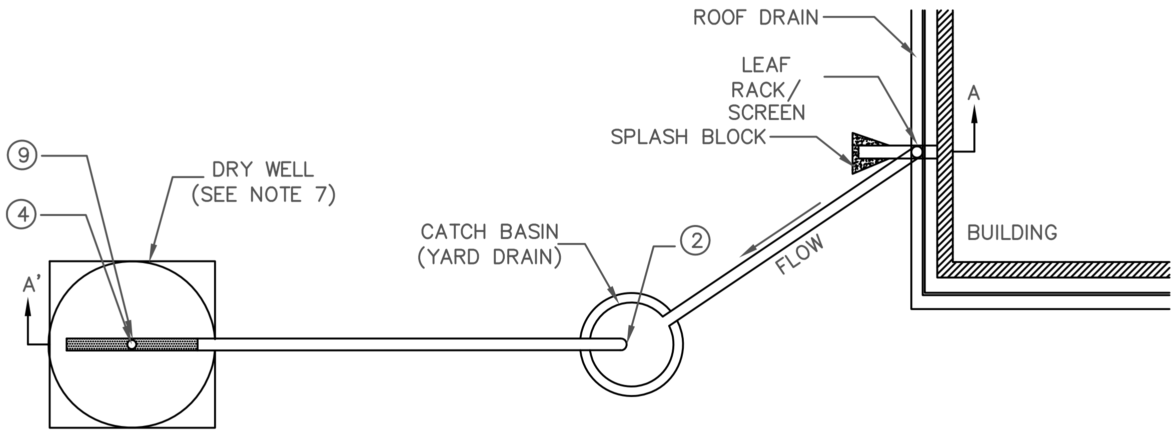
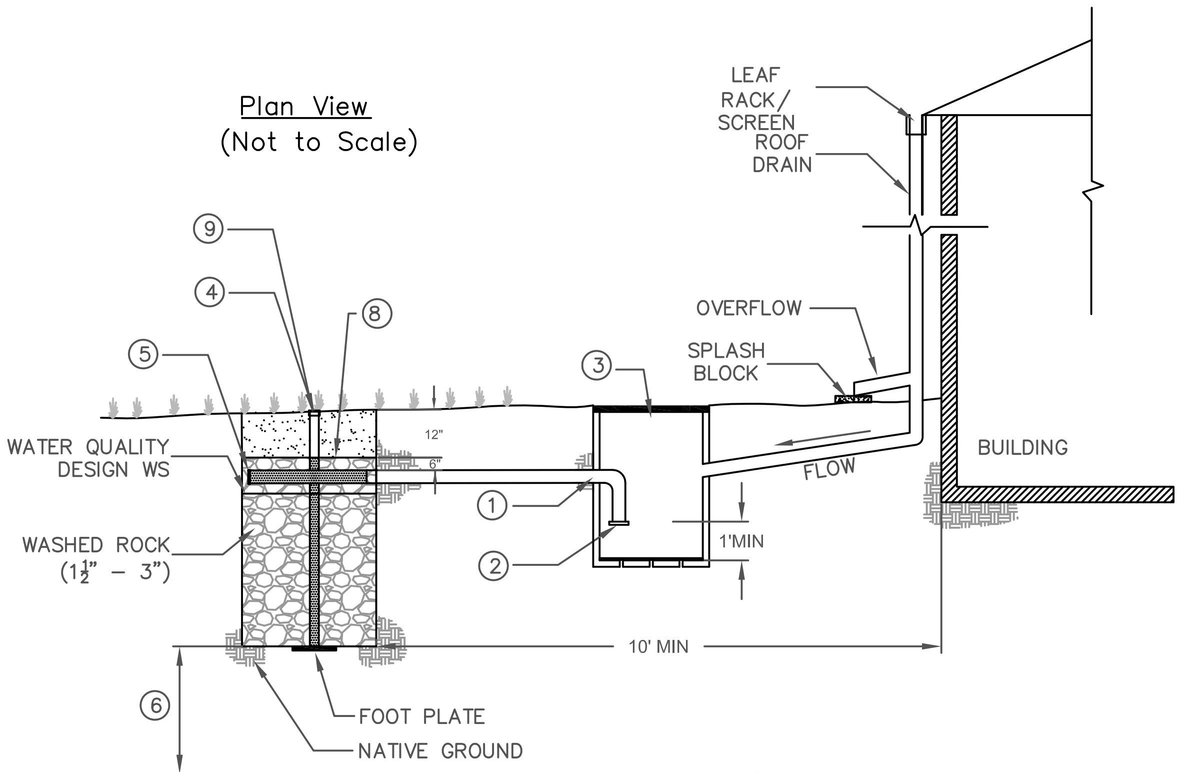


Plan View
(Not to Scale)



Section A – A'
(Not to Scale)

NOTES:

1. MINIMUM 4" – 6" DIAMETER PVC PIPE. INSTALL AT FLAT SLOPE.
2. INSTALL FINE MESH SCREEN AT INLET TO DRY WELL. SET INLET ELEVATION AT 1' MINIMUM ABOVE CATCH BASIN BOTTOM.
3. CATCH BASIN (YARD DRAIN) INSTALLED WITH A SOLID LID FLUSH WITH GROUND SURFACE.
4. 4–6" VERTICAL PERFORATED PVC INSPECTION WELL WITH SCREW LID (NUT DOWN) FLUSH WITH GROUND SURFACE.
5. CAP END OF 4–6" HORZONTAL PERFORATED PVC DISPERSION PIPE.
6. MINIMUM 10' ABOVE SEASONAL HIGH GROUNDWATER TABLE AND 3' ABOVE BEDROCK.
7. DRY WELL CONFIGURATION MAY VARY (E.G. PRE–FAB MAY BE CIRCULAR).
8. CHOKING STONE LAYER SHALL BE PLACED ON TOP OF THE DRY WELL TO SEPARATE IT FROM THE TOPSOIL AND PREVENT CLOGGING.

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Figure 6-5: Drywell

Limitations

The following limitations shall be considered before choosing to use a dry well:

- Native soil infiltration rate – soil permeability at the infiltration basin location must be at least 0.5 inches per hour.
- Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration basin and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.
- Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.
- Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.
- Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer, to ensure groundwater is protected from pollutants of concern.
- Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines the infiltration would be beneficial.
- High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.
- High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.
- Dry wells cannot receive untreated stormwater runoff, except rooftop runoff. Pretreatment of runoff from other surfaces is necessary to prevent premature failure that results from clogging with fine sediment, and to prevent potential groundwater contamination due to nutrients, salts, and hydrocarbons.

- Infiltration structures cannot be used to treat runoff from portions of the site that are not stabilized.
- Rehabilitation of failed dry wells requires complete reconstruction.

Design Criteria

The main challenge associated with drywells, as with infiltration trenches, is the prevention of system clogging and subsequent infiltration inhibition. Drywells should be designed according to the requirements listed in Table 6-10 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-10: Infiltration BMP Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Design drawdown time	hour	12
Pretreatment	-	BIO-3: Vegetated Swale, BIO-4: Filter Strip, proprietary device, or equivalent.
Design percolation rate (k_{design})	in/hr	Shall be corrected for testing method, potential for clogging and compaction over time, and facility geometry.
Maximum depth of facility (d_{max})	feet	Defined by the design infiltration rate and the design drawdown time (includes depth of media).
Surface area of facility (A)	ft^2	Based on depth of dry well media.
Facility geometry	-	Geometry varies; max 10 feet deep; flat bottom slope.
Filter media diameter	inches	1.5 – 3 (gravel); prefabricated media may also be used
Overflow device	-	Required if system is on-line

Geotechnical Considerations

An extensive geotechnical site investigation must be undertaken early in the site planning process to verify site suitability for the installation of infiltration facilities, due to the potential to contaminate groundwater, cause slope instability, impact surrounding structures, and have insufficient infiltration capacity. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration facility. See Appendix C for guidance on infiltration testing.

The project designer must demonstrate through infiltration testing, soil logs, and the written opinion of a licensed civil engineer that sufficiently permeable soils exist on site to allow the construction of a properly functioning infiltration facility.

1) Infiltration facilities require a minimum soil infiltration rate of 0.5 inches/hour. If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully-treated in an upstream BMP prior to infiltration to protect groundwater quality. Pretreatment for coarse sediment removal is required in all instances.

2) Groundwater separation must be at least 5 feet from the basin bottom to the measured season high groundwater elevation or estimated high groundwater mounding elevation. Measurements of groundwater levels must be made during the time when water level is expected to be at a maximum (i.e., toward the end of the wet season).

3) Sites with a slope greater than 25% (4:1) should be excluded. A geotechnical analysis and report addressing slope stability are required if located on slopes greater than 15%.

Soil Assessment and Site Geotechnical Investigation Reports

The soil assessment report should:

- State whether the site is suitable for the proposed drywell;
- Recommend a design infiltration rate (see the Step 2 of sizing methodology section, "Determine the design percolation rate," in the INF-1: Infiltration Basin fact sheet above);
- Identify the seasonal high depth to groundwater table surface elevation;
- Provide a good understanding of how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water; and
- If a geotechnical investigation and report are required, the report should:
  - Provide a written opinion by a professional civil engineer describing whether the drywell will compromise slope stability; and
  - Identify potential impacts to nearby structural foundations.

Setbacks

1) Infiltration facilities shall be setback a minimum of 100 feet from proposed or existing potable wells, non-potable wells, septic drain fields, and springs.

2) Infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

3) Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

Pretreatment

- A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.

- Though roofs are generally not a significant source of runoff pollution, they can still be source of particulates and organic matter. Measures such as roof gutter guards, roof leader clean-out with sump, or an intermediate sump box can provide pretreatment for dry wells by minimizing the amount of sediment and other particulates that may enter it.

Sizing Criteria

See Sizing Criteria section in the INF-1: Infiltration Basin fact sheet.

Geometry and Sizing

1) Dry well configurations vary, but generally they have length and width dimensions closer to square than infiltration trenches. Pre-fabricated dry-wells are often circular. The surface area of the dry well must be large enough to infiltrate the storage volume in 12 hours based on the maximum depth allowable (d_{max}).

2) The filter bed media layers are the same as for infiltration trenches unless prefabricated dry wells and/or media are used. The porosity of gravel media systems is generally 30 to 40% and is 80 to 95% for prefabricated media systems.

3) If a dry well receives runoff from an underground pipe (i.e., runoff does not enter the top of the dry well from the ground surface), a fine mesh screen should be installed at the inlet. The inlet elevation should be 18 inches below the ground surface (i.e., below 12 inches of surface soil and 6 inches of dry well media).

4) An observation well should be installed to check for water levels, drawdown time, and evidence of clogging. A typical observation well consists of a slotted PVC well screen, 4 to 6 inches in diameter, capped with a lockable, above-ground lid.

Drainage

1) The bottom of infiltration bed must be native soil, over-excavated to at least one foot in depth and replaced uniformly without compaction. Amending the excavated soil with 2 to 4 inches (~15% to 30%) of coarse sand is recommended.

2) The hydraulic conductivity of the subsurface layers should be sufficient to ensure a maximum 12 hr drawdown time. An observation well should be incorporated to allow observation of drain time.

Emergency Overflow

1) There must be an overflow route for stormwater flows that overtop the facility or in case the infiltration facility becomes clogged.

2) The overflow channel must be able to safely convey flows from the peak design storm to the downstream stormwater conveyance system or other acceptable discharge point.

Vegetation

1) Drywells should be kept free of vegetation.

2) Trees and other large vegetation should be planted away from drywells such that drip lines do not overhang infiltration beds.

Maintenance Access

1) The facility and outlet structures must all be safely accessible during wet and dry weather conditions.

2) Maintenance access is required.

3) If the drywell becomes plugged and fails, then access is needed to excavate the facility to remove and replace the top layer and the filter bed media of the structure. To prevent damage and compaction, access must be able to accommodate a backhoe working at "arms length".

Construction Considerations

To preserve and avoid the loss of infiltration capacity, the following construction guidelines should be specified:

1) The entire area draining to the facility must be stabilized before construction begins. If this is impossible, a diversion berm should be placed around the perimeter of the infiltration site to prevent sediment entering during construction.

2) Drywells should not be hydraulically connected to the stormwater conveyance system until all contributing tributary areas are stabilized as shown on the Contract Plans and to the satisfaction of the Engineer. Drywells should not be used as sediment control facilities.

3) Compaction of the subgrade with heavy equipment should be minimized to the maximum extent possible. If the use of heavy equipment on the base of the facility

cannot be avoided, the infiltration capacity should be restored by tilling or aerating prior to placing the infiltrative bed.

4) The exposed soils should be inspected by a civil engineer after excavation to confirm that soil conditions are suitable.

Operations and Maintenance

Drywell maintenance should be performed frequently to ensure that water infiltrates into the subsurface completely within the recommended infiltration time (or drain time if a drywell receives runoff from an underground pipe) of 72 hours or less after a storm.

Maintenance and regular inspections are important for the proper function of drywells. A specific maintenance plan shall be developed specifically for each facility outlining the schedule and scope of maintenance operations, documentation, and reporting requirements.

RB-AR34672

INF-5: Permeable Pavement

Permeable pavements contain small voids that allow water to pass through to a stone base. They come in a variety of forms; they may be a modular paving system (concrete pavers, grass-pave, or gravel-pave) or a poured-in-place solution (porous concrete or permeable asphalt). All permeable pavements with a stone reservoir base treat stormwater and remove sediments and metals to some degree. While conventional pavement result in increased rates and volumes of surface runoff, porous pavements when properly constructed and maintained, allow some of the stormwater to percolate through the pavement and enter the soil below. This facilitates groundwater recharge while providing the structural and functional features needed for the roadway, parking lot, or sidewalk. The paving surface, subgrade, and installation requirements of permeable pavements are more complex than those for conventional asphalt or concrete surfaces. For porous pavements to function properly over an expected life span of 15 to 20 years, they must be properly sited and carefully designed and installed, as well as periodically maintained. Failure to protect paved areas from construction-related sediment loads can result in their premature clogging and failure. Note that the 2011 TGM does not provide specific instructions on how to design and construct pavement.

Permeable pavement applications

Photo Credits: 1. Geosyntec Consultants; 2. EPA Stormwater Management

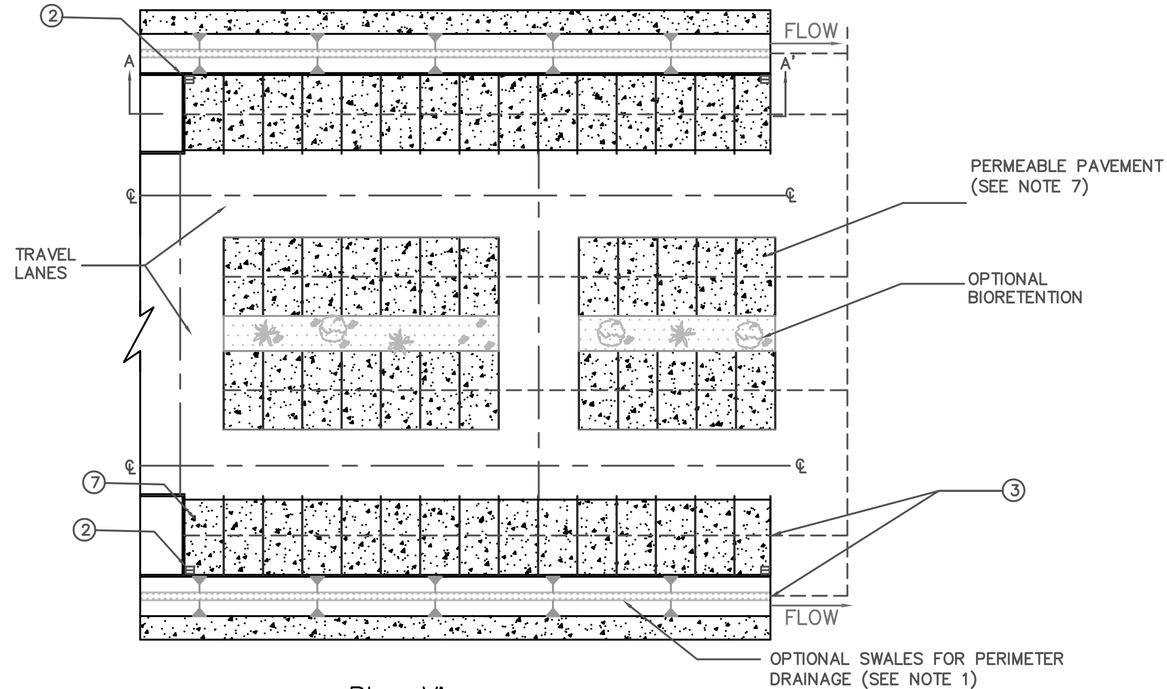
Application

- Parking lots
- Driveways
- Sidewalks and walkways
- Outdoor athletic courts

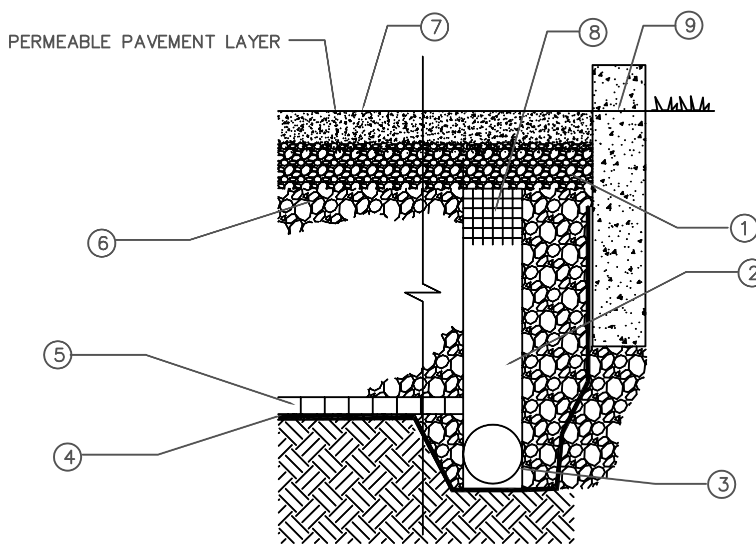
Preventative Maintenance

- Trash removal
- Post-rain inspections
- Vacuum sweeping
- Vegetation inspection and removal

RB-AR34673



Plan View
(Not to Scale)



Section A – A'
(Not to Scale)

NOTES:

1. BEDDING COURSE SHALL BE 1½" TO 3" MIN THICKNESS (TYP NO. 8 AGGREGATE).
2. OPTIONAL OVERFLOW PIPE(S) SHALL BE PROVIDED IF OVERFLOWS ARE NOT MANAGED VIA PERIMETER DRAINAGE TO SWALES, BIORETENTION OR STORM WATER CONVEYANCE SYSTEM INLETS.
3. CONNECT OUTFALL PIPES TO DOWNSTREAM STORMWATER CONVEYANCE SYSTEM. OUTFALL PIPES SHALL BE SLOPED TOWARDS COLLECTION SYSTEM.
4. SOIL SUBGRADE SHALL HAVE ZERO SLOPE.
5. INSTALL GEOTEXTILE OR CHOKING LAYER ON BOTTOM & SIDES OF OPEN-GRADED BASE FOR FULL AND PARTIAL INFILTRATION, OR AN IMPERMEABLE LINER FOR NO INFILTRATION.
6. OPEN-GRADED BASE. THICKNESS AND GRADATION VARIES WITH DESIGN. TYP. NO. 57 AGGREGATE OR 4" THICK NO. 57 OVER NO. 2 STONE SUBASE. THICKNESS OF SUB-BASE VARIES WITH DESIGN.
7. PERMEABLE PAVEMENT INFILTRATIVE LAYER
8. OPTIONAL RIGID PLASTIC SCREEN FASTENED OVER OVERFLOW INLETS.
9. CURB/EDGE RESTRAINT WITH CUT-OUTS FOR OVERFLOW DRAINAGE TO PERIMETER BMPS, STORMWATER CONVEYANCE SYSTEM INLETS OR OPTIONAL OVERFLOW PIPES.
10. PARTIAL EXFILTRATION THROUGH THE SOIL. PERFORATED PIPES DRAIN EXCESS RUNOFF THAT CAN NOT BE ABSORBED BY SLOW-DRAINING SOIL.

Geosyntec consultants

Figure 6-6: Permeable Pavement

Limitations

The following describes limitations for the use of permeable pavement.

- Native soil infiltration rate - permeability of soils at the BMP location must be at least 0.5 inches per hour.
- Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration trench and the seasonal high groundwater level or mounded groundwater level, bedrock, or other infiltration barrier to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.
- Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.
- Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback from building foundations at least eight feet or an alternative setback established by the geotechnical expert for the project.
- Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer, to ensure groundwater is protected for pollutants of concern.
- Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines the infiltration would be beneficial.
- High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near a service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas that have little chance of spill migration.
- High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.
- Permeable pavement cannot receive untreated stormwater runoff from other surfaces. Pretreatment of run-on from other surfaces is necessary to prevent premature failure that results from clogging with fine sediment.

- Permeable pavement cannot be used to treat runoff from portions of the site that are not stabilized.

Design Criteria

Permeable pavement should be designed according to the requirements listed in Table 6-11 and outlined in the section below.

Table 6-11: Permeable Pavements Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater Quality Design Volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Pretreatment	-	Runoff from pervious areas should be minimized but, if provided, BIO-3: Vegetated Swale or BIO-4: Filter Strip should be provided for all runoff from offsite sources that are not directly adjacent to the permeable pavement.
Drawdown time of gravel drainage layer	hrs	12 - 72
Porous Pavement Infill		ASTM C-33 sand or equivalent
Minimum depth to bedrock	ft	2 (without underdrains)
Minimum depth to seasonal high water table	ft	2 (with underdrains); 10 (without underdrains)
Infiltration rate of subsoil	in/hr	1.0 (minimum without an underdrain)
Overflow device	-	Required

Geotechnical Considerations

An extensive geotechnical site investigation must be undertaken early in the site planning process to verify site suitability for the installation of infiltration facilities, due to the potential to contaminate groundwater, cause slope instability, impact surrounding structures, and have insufficient infiltration capacity. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration facility. See Appendix C for guidance on infiltration testing.

The project designer must demonstrate through infiltration testing, soil logs, and the written opinion of a licensed civil engineer that sufficiently permeable soils exist onsite to allow the construction of a properly functioning infiltration facility.

1) Infiltration facilities require a minimum native soil infiltration rate of 0.5 inches/hour. If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect groundwater quality.

Pretreatment for removing coarse sediment present in runoff from the tributary area is required in all instances.

2) Groundwater separation must be at least 5 feet from the basin bottom to the measured season high groundwater elevation or estimated high groundwater mounding elevation. Groundwater levels measurements must be made during the time when the water level is expected to be at a maximum (i.e., toward the end of the wet season).

3) Sites with a slope greater than 25% (4:1) should be excluded. A geotechnical analysis and report addressing slope stability are required if located on slopes greater than 15%.

Soil Assessment and Site Geotechnical Investigation Reports

The soil assessment report should:

- State whether the site is suitable for the proposed permeable pavement;
- Recommend a design infiltration rate (see the Step 2 of sizing methodology section, "Determine the design percolation rate," in the Infiltration Basin fact sheet above);
- Identify the seasonal high depth to groundwater table surface elevation;
- Provide a good understanding of how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water; and
- If a geotechnical investigation and report are required, the report should:
  - Provide a written opinion by a professional civil engineer describing whether the infiltration trench will compromise slope stability; and
  - Identify potential impacts to nearby structural foundations.

Setbacks

1) Infiltration facilities shall be setback a minimum of 100 feet from proposed or existing potable wells, non-potable wells, septic drain fields, and springs.

2) Infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

3) Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

Pretreatment

1) Depending on how and where permeable pavements will be used, pretreatment of the runoff entering the permeable pavement may be necessary. This is particularly important when the permeable pavement will be accepting run-on from pervious areas or areas that are not completely stabilized. If this is the case, then the run-on should be treated prior to contacting the permeable pavement. Without adequate pretreatment, the life of the permeable pavement may be significantly decreased.

2) If sheet flow is conveyed to the permeable pavement over stabilized grassed areas, the site must be graded in such a way that minimizes erosive conditions.

Sizing Criteria

Permeable pavement must be designed to meet Ventura County codes and/or applicable local permitting authority codes. These sizing criteria are meant to provide guidance for runoff volume storage only.

Step 1: Calculate the Design Volume

Infiltration facilities shall be sized to capture and infiltrate the SQDV volume (see Section 2 and Appendix E) with a 12 to 72 hour drawdown time (see Appendix D, Section D.2).

Step 2: Determine the Design Percolation Rate

The percolation rate will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the infiltration layer. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For infiltration trenches, the design percolation rate discussed here is the percolation rate of the underlying soils and not the percolation rate of the filter media bed (refer to the "Geometry and Sizing" section of INF-2 for the recommended composition of the filter media bed for infiltration trenches).

Considerations for Design Percolation Rate Corrections

Suitability assessment related considerations include (Table 6-12):

- Soil assessment methods – the site assessment extent (e.g., number of borings, test pits, etc.) and the measurement method used to estimate the short-term infiltration rate.
- Predominant soil texture/percent fines – soil texture and the percent of fines can greatly influence the potential for clogging.
- Site soil variability – site with spatially heterogeneous soils (vertically or horizontally) as determined from site investigations are more difficult to estimate

average properties resulting in a higher level of uncertainty associated with initial estimates.

- Depth to seasonal high groundwater/impervious layer – groundwater mounding may become an issue during excessively wet conditions where shallow aquifers or shallow clay lenses are present.

Table 6-12: Suitability Assessment Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Assessment methods	Use of soil survey maps or simple texture analysis to estimate short-term infiltration rates	Direct measurement of ≥ 20 percent of infiltration area with localized infiltration measurement methods (e.g., infiltrometer)	Direct measurement of ≥ 50 percent of infiltration area with localized infiltration measurement methods or Use of extensive test pit infiltration measurement methods
Ventura Hydrology Manual soil number (measured infiltration rate)	3 (f = 0.5 – 0.64)	4 or 5 (f = 0.65 – 0.91)	6 or 7 (f = 0.92 or higher)
Site soil variability	Highly variable soils indicated from site assessment or limited soil borings collected during site assessment	Soil borings/test pits indicate moderately homogeneous soils	Multiple soil borings/test pits indicate relatively homogeneous soils
Depth to groundwater/ impervious layer	<10 ft below facility bottom	10-30 ft below facility bottom	>30 below facility bottom

Localized infiltration testing refers to methods such as the double ring infiltrometer test (ASTM D3385-88) which measure infiltration rates over an area less than 10 sq-ft and do not attempt to account for soil heterogeneity. Extensive infiltration testing refers to methods that include excavating a significant portion of the proposed infiltration area, filling the excavation with water, and monitoring drawdown. In all cases, testing should be conducted in the area of the proposed BMP where, based on geotechnical data, soils appear least likely to support infiltration.

Design related considerations include (Table 6-13):

- Size of area tributary to facility – all things being equal, both physical and economic risk factors related to infiltration facilities increase with an increase in the tributary area served. Therefore facilities serving larger tributary areas should use more restrictive adjustment factors.

- Level of pretreatment/expected influent sediment loads – credit should be given for good pretreatment by allowing less restrictive factors to account for the reduced probability of clogging from high sediment loading. Also facilities designed to capture runoff from relatively clean surfaces such as rooftops are likely to see low sediment loads and therefore should be allowed to apply less restrictive safety factors.

- Redundancy – facilities that consist of multiple subsystems operating in parallel such that parts of the system remains functional when other parts fail and/or bypass should be rewarded for the built-in redundancy with less restrictive correction and safety factors. For example, if bypass flows would be at least partially treated in another BMP, the risk of discharging untreated runoff in the event of clogging the primary facility is reduced. A bioretention facility that overflows to a landscaped area is another example.

Compaction during construction – proper construction oversight is needed during construction to ensure that the bottom of the infiltration facility are not overly compacted. Facilities that do not commit to proper construction practices and oversight should have to use more restrictive correction and safety factors.

Table 6-13: Design Related Considerations for Infiltration Facility Safety Factors

Consideration	High Concern	Medium Concern	Low Concern
Tributary area size	Greater than 10 acres.	Greater than 2 acres but less than 10 acres.	2 acres or less.
Level of pre-treatment/ expected influent sediment loads	Pre-treatment from gross solids removal devices only, such as hydrodynamic separators, racks and screens AND tributary area includes landscaped areas, steep slopes, high traffic areas, or any other areas expected to produce high sediment, trash, or debris loads.	Good pre-treatment with BMPs that mitigate coarse sediments such as vegetated swales AND influent sediment loads from the tributary area are expected to be relatively low (e.g., low traffic, mild slopes, disconnected impervious areas, etc.).	Excellent pre-treatment with BMPs that mitigate fine sediments such as bioretention or media filtration OR sedimentation or facility only treats runoff from relatively clean surfaces, such as rooftops.
Redundancy of treatment	No redundancy in BMP treatment train.	Medium redundancy, other BMPs available in treatment train to maintain at least 50% of function of facility in event of failure.	High redundancy, multiple components capable of operating independently and in parallel, maintaining at least 90% of facility functionality in event of failure.
Compaction during construction	Construction of facility on a compacted site or elevated probability of unintended/ indirect compaction.	Medium probability of unintended/ indirect compaction.	Heavy equipment actively prohibited from infiltration areas during construction and low probability of unintended/ indirect compaction.

Adjust the measured short-term infiltration rate using a weighted average of several safety factors, using the worksheet shown in Table 6-14 below. The design percolation rate would be determined as follows:

- For each consideration shown in Table 6-12 and Table 6-13 above, determine whether the consideration is a high, medium, or low concern.
- For all high concerns assign a factor value of 3, for medium concerns assign a factor value of 2, and for low concerns assign a factor value of 1.
- Multiply each of the factors by the corresponding weight to get a product.

- Sum the products within each factor category to obtain a safety factor for each.
- Multiply the two safety factors together to get the final combined safety factor. If the combined safety factor is less than 2, then use 2 as the safety factor.
- Divide the measured short term infiltration rate by the combined safety factor to obtain the adjusted design percolation rate for use in sizing the infiltration facility.

Table 6-14: Infiltration Facility Safety Factor Determination Worksheet

Factor Category		Factor Description	Assigned Weight (w)	Factor Value (v)	Product (p) p = w x v
A	Suitability Assessment	Soil assessment methods	0.25		
		Predominant soil texture	0.25		
		Site soil variability	0.25		
		Depth to groundwater / impervious layer	0.25		
		Suitability Assessment Safety Factor, $S_A = \Sigma p$			
B	Design	Tributary area size	0.25		
		Level of pre-treatment/ expected sediment loads	0.25		
		Redundancy	0.25		
		Compaction during construction	0.25		
		Design Safety Factor, $S_B = \Sigma p$			
Combined Safety Factor = S_A x S_B					

Note: The minimum combined adjustment factor shall not be less than 2.0 and the maximum combined adjustment factor shall not exceed 9.

Step 3: Determine the Gravel Drainage Layer Depth

Permeable pavement (including the base layers) should be designed to drain in less than 72 hours. The basis for this is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate sub soil oxygen levels for healthy soil biota, and to provide proper soil conditions for biodegradation and retention of pollutants.

1) Calculate the maximum depth of runoff (d_{max}) that can be infiltrated within the drawdown time:

$$d_{\max} = \frac{P_{design} \bullet t}{12} \quad \text{(Equation 6-11)}$$

Where:

d_{max} = maximum depth that can be infiltrated (ft)

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

t = drawdown time (12-72 hours) (hr)

2) Select the gravel drainage layer depth, (l), such that:

$$d_{\max} \geq n \times l$$ (Equation 6-12)

Where:

d_{max} = maximum depth that can be infiltrated (ft) (see 1) above)

n = gravel drainage layer porosity(unitless)(generally about 40% or 0.40 for gravel)

l = gravel drainage layer depth (ft)

Step 4: Determine infiltrating surface area

3) Calculate infiltrating surface area for permeable pavement (A):

$$A = \frac{SQDV}{\frac{TP_{design}}{12} + nl}$$ (Equation 6-13)

Where:

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

n = gravel drainage layer porosity(unitless)[about 40% or 0.40 for gravel]

l = depth of gravel drainage layer (ft)

T = time to fill the gravel drainage layer with water (use 2 hours for most designs) (hr)

Geometry and Size

1) Permeable pavement shall be sized to capture and treat the stormwater quality design volume (SQDV).

2) Pavement design options include:

a. Full or partial infiltration – A design for full infiltration uses an open graded base for maximum infiltration and storage of stormwater. The water infiltrates directly into the base and through the soil. Pipes may provide drainage in overflow conditions. Partial infiltration does not rely completely on infiltration through the soil to dispose all of the captured runoff. Some of the water may infiltrate into the soil and the remainder drained by pipes.

b. No infiltration – No infiltration is desirable when the soil has low permeability and low strength, or there are other site limitations. An underdrain should be provided if the depth to bedrock is less than 2 feet or the depth to the water table is less than 10 feet. By storing water for a time in the base and then slowly releasing it through pipes, the design behaves like an underground detention pond. In other cases, the soil of the sub-base may be compacted and stabilized to render improved support for vehicular loads. This practice reduces infiltration into the soil to nearly zero. The "no infiltration" option requires the use of geotextile and bedding between the pavement and the open graded base.

3) If permeable pavement is located on a site with a slope greater than 2%, the permeable pavement area should be terraced to prevent lateral flow through the subsurface. Permeable pavement cannot be located on a site with a slope greater than 5%.

4) Porous pavement systems generally consist of at least four different layers of material:

a. The top or wearing layer consists of either asphalt or concrete with a greater than normal percentage of voids (typically 12 to 20 percent in the case of asphalt). The wearing layer may also be comprised of lattice-type pavers (either hollow concrete blocks or paving stones made from solid conventional concrete or stone), which are set in a bedding material (sand, pea-sized gravel or turf grass).

b. Below the wearing layer, a stone reservoir layer or a thick layer of aggregate (e.g., 2 inch stone) provides the bulk of the water storage capacity for a porous pavement system. In the pavement design, it is important to ensure that this reservoir layer retains its load bearing capacity under saturated conditions, because it may take several days for complete drainage to occur.

c. Typically, porous pavement designs include two (or more) transition layers that can be constructed from 1 to 2 inch diameter stone. One transition layer separates the top wearing layer from the underlying stone reservoir layer. Another transition layer is used to separate the stone reservoir from the undisturbed subgrade soil. Some designs also add a geotextile layer to this bottom layer or some combination of stones and geotextiles.

d. Porous asphalt pavement, for example, consists of open grade asphalt mixture ranging in depth from 2 to 4 inches with 16 percent voids. The thickness selected depends on bearing strength and pavement design requirements. This layer sits on a 2 to 4 inch transition layer located over a stone reservoir. The bottom layer completes the transition to the underlying undisturbed soil using a combination transition/filter fabric layer.

e. The depth of each layer should be determined by a licensed civil engineer based on analyses of the hydrology, hydraulics, and structural requirements of the site.

5) Modular paving stones are also used to create porous pavements. These pavements can be constructed in situ by pouring concrete into special frames or by using preformed blocks. The top layer of these porous pavements consists of conventional concrete, with the intervening void areas filled with either turf or sand. A transition or bedding layer is used to make the transition to the reservoir layer. These lattice-type pavers or hollow concrete blocks are often used in conjunction with turf grasses and are used in low-traffic parking lots, lanes, or driveways. Porous pavements using paving stones have similar construction, but can be designed to have a much higher load bearing capacity, and therefore have more widespread applicability. Construction guidelines and design specifications are available from the manufacturers of these products.

6) Permeable pavement (including the base layers) should be designed to drain in less than 72 hours. The basis for this is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate subsoil oxygen levels for healthy soil biota, and to provide proper soil conditions for biodegradation and retention of pollutants.

7) The percolation rate will decline as the surface becomes occluded and particulates accumulate in the infiltration layer. It is important that adequate conservatism is incorporated in the selection of design percolation rates.

Overflow

An overflow mechanism is required. Two options are provided:

Option 1: Perimeter control

Flows in excess of the design capacity of the permeable pavement system will require an overflow system connected to a downstream conveyance or other stormwater runoff BMP. In addition, if the pavement becomes clogged and infiltration decreases to the point that there is ponding, runoff will migrate off of the pavement via overland flow instead of infiltrating into the subsurface gravel layer. There are several options for handling overflow using perimeter controls such as:

1) Perimeter vegetated swale.
2) Perimeter bioretention.
3) Storm drain inlets.
4) Rock filled trench that funnels flow around pavement and into the subsurface gravel layer.

Option 2: Overflow pipe(s)

1) A vertical pipe should be connected to the underdrain.
2) The diameter, location, and quantity may vary with design and should be determined by a licensed civil engineer.
3) The pipe should be located away from vehicular traffic.
4) The piping system may incorporate an observational and/or cleanout well.
5) The top of the overflow pipe should be covered with a screen fastened over the overflow inlet.

Construction Considerations

1) Permeable pavement should be laid close to level and the bottom of the base layers must be level to ensure uniform infiltration.
2) Permeable pavement surfaces should not be used to store site materials, unless the surface is well protected from accidental spillage or other contamination.
3) To prevent/minimize soil compaction in the area of the permeable pavement installation, use light equipment with tracks or oversized tires.
4) Divert stormwater from the area as needed (before and during installation).
5) The pavement should be the last installation done at a development site. Landscaping should be completed and adjacent areas stabilized, before pavement installation to minimize the risk of clogging.
6) Vehicular traffic should be prohibited for at least 2 days after installation.

Operations and Maintenance

Permeable pavement mainly requires vacuuming and management of adjacent areas to limit sediment contamination and prevent clogging by fine sediment particles. Therefore, little special training is needed for maintenance crews. The following maintenance concerns and maintenance activities shall be considered and provided:

1) Trash tends to accumulate in paved areas, particularly in parking lots and along roadways. The need for litter removal should be determined through periodic inspection.

2) Regularly (e.g., monthly for a few months after initial installation, then quarterly) inspect pavement for pools of standing water after rain events, this could indicate surface clogging.

3) Actively (3 to 4 times per year, or more frequently depending onsite conditions) vacuum sweep the pavement to reduce the risk of clogging by frequently removing fine sediments before they can clog the pavement and subsurface layers. This also helps to prolong the functional period of the pavement.

4) Inspect for vegetation growth on pavement and remove when present.

5) Inspect for missing sand/gravel in spaces between pavers and replace as needed.

6) Activities that lead to ruts or depressions on the surface should be prevented or the integrity of the pavement should be restored by patching or repaving. Examples are vehicle tracks and utility maintenance.

7) Spot clogging of porous concrete may be remedied by drilling 0.5 inch holes every few feet in the concrete.

8) Interlocking pavers that are damaged should be replaced.

9) Maintain landscaped areas and reseed bare areas.

INF-6: Proprietary Infiltration

A number of vendors offer proprietary infiltration products that allow for similar or enhanced rates of infiltration and subsurface storage while offering durable prefrabricated structures. There are many varieties of proprietary infiltration BMPs.

Proprietary Infiltration BMPs

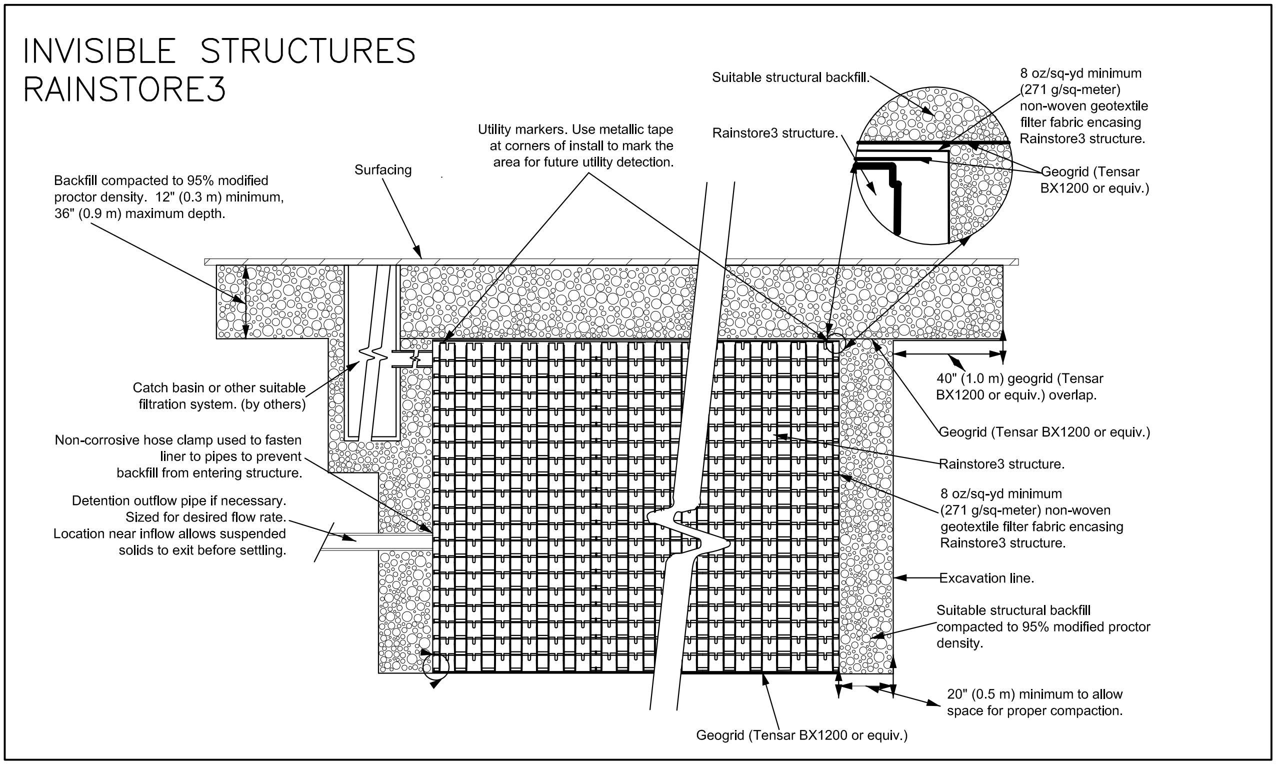
Photo Credits: 1. & 2. Contech Stormwater Solutions, Inc.

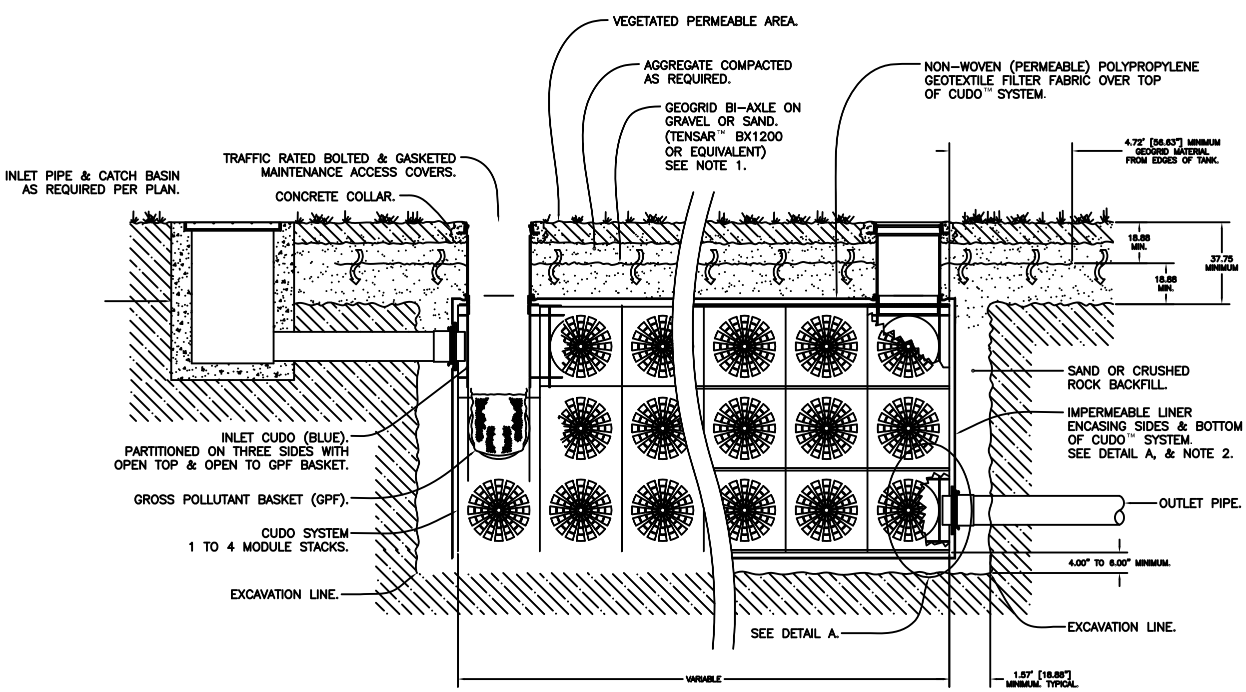
Application

- Mixed-use and commercial
- Roads and parking lots
- Parks and open spaces
- Single and multi-family residential

Routine Maintenance

- Removal trash, debris, and sediment at inlet and outlets
- Wet weather inspection to ensure drain time
- Inspect for mosquito breeding





SECTION / CUTAWAY VIEW
SCALE: NONE

CUDO Stormwater Products, Inc.
P.O. Box 497 Occidental, CA 95465
Ph. (877) 876-3345 Fax (707) 876-3346

Geosyntec consultants

Figure 6-7: Proprietary Infiltration BMPs

Limitations

The following limitations shall be considered before choosing to use an infiltration BMP:

- Native soil infiltration rate - soil permeability of the infiltration basin location must be at least 0.5 inches per hour.
- Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration basin and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.
- Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.
- Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields and springs. Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.
- Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer, to ensure groundwater is protected for pollutants of concern.
- Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines the infiltration would be beneficial.
- High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration
- High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.

Table 6-15: Proprietary Infiltration Manufacturer Websites

Device	Manufacturer	Website
A-2000™	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
ChamberMaxx™	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
CON/SPAN Vaults™	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
CON/Storm™	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
Perforated Corrugated Metal Pipe (CMP)	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
Drywell StormFilter	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13
CUDO® Water Storage System	KriStar Enterprises Inc.	www.kristar.com
D-Raintank® Matrix Tank Modules	Atlantis®	www.atlantis-america.com
EcoRain™ Modular Rain Tank	EcoRain Systems Inc.	www.ecorain.com
Landmax®	Hancor®	www.hancor.com
Landsaver™	Hancor®	www.hancor.com
Precast Concrete Dry Well	Jensen Precast®	www.jensenprecast.com
Rainstore[3]	Invisible Structures Inc.	www.invisiblestructures.com
StormChambers™	Hydrologic Solutions, Inc.	www.hydrologicsolutions.com
Stormtech® SC-740 and SC-310 Chambers	StormTech LLC	www.stormtech.com
StormTrap®	StormTrap	www.stormtrap.com
Triton Chambers™	Triton Stormwater Solutions	www.tritonsws.com

Geotechnical Considerations

An extensive geotechnical site investigation must be undertaken early in the site planning process to verify site suitability for the installation of infiltration facilities, due to the potential to contaminate groundwater, cause slope instability, impact surrounding structures, and have insufficient infiltration capacity. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration facility. See Appendix C for guidance on infiltration testing.

The project designer must demonstrate through infiltration testing, soil logs, and the written opinion of a licensed civil engineer that sufficiently permeable soils exist onsite to allow the construction of a properly functioning infiltration facility.

1) Infiltration facilities require a minimum soil infiltration rate of 0.5 inches/hour. If infiltration rates exceed 2.4 inches/hour such that pollutant removal may not be adequate to protect groundwater quality, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect groundwater quality. Pretreatment for coarse sediment removal is required in all instances.

2) Groundwater separation must be at least 5 feet from the basin bottom to the measured season high groundwater elevation or estimated high groundwater mounding elevation. Measurements of groundwater levels must be made during the time when water level is expected to be at a maximum (i.e., toward the end of the wet season).

3) Sites with a slope greater than 25% (4:1) should be excluded. A geotechnical analysis and report addressing slope stability are required if located on slopes greater than 15%.

Soil Assessment and Site Geotechnical Investigation Reports

The soil assessment report should:

- State whether the site is suitable for the proposed proprietary infiltration BMP.;
- Recommend a design infiltration rate (see the Step 2 of sizing methodology section, "Determine the design percolation rate," in the Infiltration Basin fact sheet above);
- Identify the seasonal high depth to groundwater table surface elevation;
- Provide a good understanding of how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water; and
- If a geotechnical investigation and report are required, the report should:
    - Provide a written opinion by a professional civil engineer describing whether the infiltration trench will compromise slope stability; and
    - Identify potential impacts to nearby structural foundations.

Setbacks

1) Infiltration facilities shall be setback a minimum of 100 feet from proposed or existing potable wells, non-potable wells, septic drain fields, and springs.

2) Infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an al ternative setback established by the geotechnical expert for the project.

3) Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

Pretreatment

Pretreatment is required for proprietary infiltration BMPs in order to reduce the sediment load entering the facility and maintain the infiltration rate of the facility. Pretreatment refers to design features that provide settling of sediment particles before runoff reaches a management practice. This eases the long-term maintenance burden and likelihood of failure. Pretreatment is important for most stormwater treatment BMPs, but it is particularly important for infiltration BMPs. To ensure that pretreatment mechanisms are effective, designers should incorporate sediment reduction practices. Sediment reduction BMPs may include vegetated swales, vegetated filter strips, sedimentation basins, sedimentation manholes and hydrodynamic separation devices. The use of at least two pretreatment devices is highly recommended for infiltration BMPs.

Sizing

1) Proprietary infiltration BMPs shall be sized to capture and treat the stormwater quality design volume (SQDV). See Section 2 and Appendix E for calculating for further detail.

2) The percolation rate will decline as the surface becomes occluded and particulates accumulate in the infiltrative layer. It is important that adequate conservatism is incorporated in the selection of design percolation rates.

3) For the sizing guidelines, refer to the manufacturer's website.

Operations and Maintenance

See vendor's website for maintenance requirements.

INF-7: Bioinfiltration

Bioinfiltration facilities are designed for partial infiltration of runoff and partial biotreatment. These facilities are similar to bioretention devices with underdrains, but the underdrain is raised above the gravel sump to facilitate infiltration. These facilities can be used in areas where there are no hazards associated with infiltration, but infiltration of the full DCV may not be feasible due to low infiltration rates (Soil Type 3) or high depths of fill. These facilities may not result in retention of the DCV but they can be used to meet the MEP standards.

Bioretention in Parkway and parking lots

Photo Credits: Geosyntec Consultants

<u>Application</u>

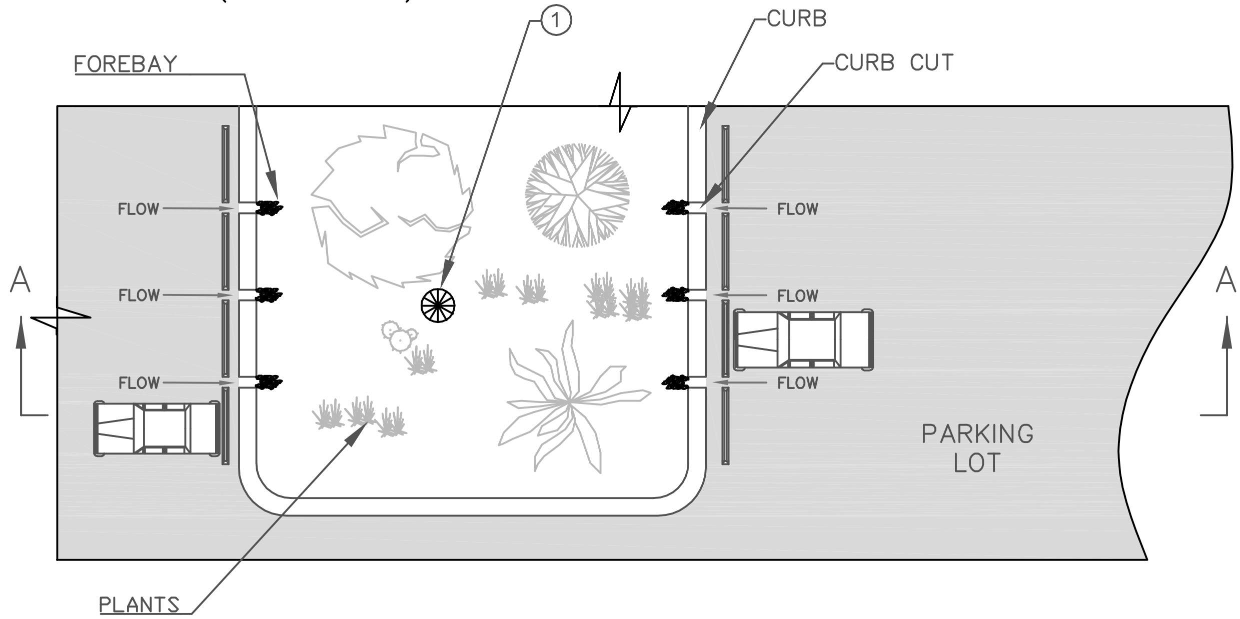
- Commercial, residential, mixed use, institutional, and recreational uses
- Parking lot islands, traffic circles
- Road parkways & medians

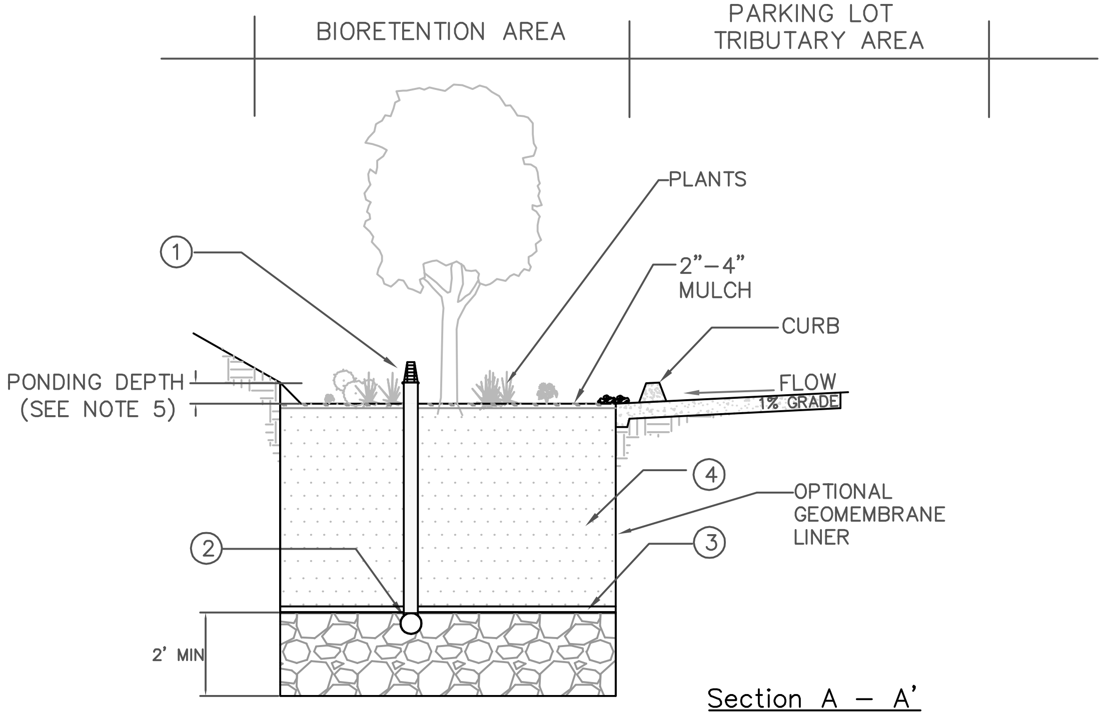
<u>Preventative Maintenance</u>

- Repair small eroded areas
- Remove trash and debris and rake surface soils
- Remove accumulated fine sediments, dead leaves and trash
- Remove weeds and prune back excess plant growth
- Remove sediment and debris accumulation near inlet and outlet structures
- Periodically observe function under wet weather conditions

RB-AR34694

Plan View
(Not to Scale)





Section A – A'
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NOTES:

① OVERFLOW DEVICE: VERTICAL RISER OR EQUIVALENT.
② PERFORATED 6" MIN PVC PIPE UNDERDRAIN.
③ OPTIONAL CHOKING GRAVEL LAYER.
④ 2' MIN PLANTING MIX; 3' PREFERRED.
⑤ PONDING DEPTH 18" WITH FENCE; 6" WITHOUT FENCE.
⑥ 2' MIN GRAVEL LAYER DEPTH.

Geosyntec consultants

Figure 6-8: Bioinfiltration

Limitations

The following limitations should be considered before choosing to use bioinfiltration:

1) Native soil infiltration rate - soil permeability at the bioinfiltration location must be no less than 0.3 inches per hour.

2) Depth to groundwater, bedrock, or low permeability soil layer – 5 feet vertical separation is required between the bottom of the infiltration trench and the seasonal high groundwater level or mounded groundwater level, bedrock, or other barrier to infiltration to ensure that the facility will completely drain between storms and that infiltrating water will receive adequate treatment though the soils before it reaches the groundwater.

3) Slope stability - infiltration BMPs must be sited at least 50 feet away from slopes steeper than 15 percent or an alternative setback established by the geotechnical expert for the project.

4) Setbacks - a minimum setback (100 feet or more) must be provided between infiltration BMPs and potable wells, non-potable wells, drain fields, and springs. Infiltration BMPs must be setback from building foundations at least eight feet or have an alternative setback established by the geotechnical expert for the project.

5) Groundwater contamination - the application of infiltration BMPs should include significant pretreatment in an area identified as an unconfined aquifer to ensure groundwater is protected for pollutants of concern.

6) Contaminated soils or groundwater plumes - infiltration BMPs are not allowed at locations with contaminated soils or groundwater where the pollutants could be mobilized or exacerbated by infiltration, unless a site-specific analysis determines that infiltration would be beneficial.

7) High pollutant land uses - infiltration BMPs should not be placed in high-risk areas such as at or near service/gas stations, truck stops, and heavy industrial sites due to the groundwater contamination risk unless a site-specific evaluation demonstrates that sufficient pretreatment is provided to address pollutants of concern, high risks areas are isolated from stormwater runoff, or infiltration areas have little chance of spill migration.

8) High sediment loading rates – infiltration BMPs may clog quickly if sediment loads are high (e.g., unstabilized site) or if flows are not adequately pretreated.

9) Vertical relief and proximity to storm drain - site must have adequate relief between the land surface and storm drain to permit vertical percolation through the soil media and collection.

Design Criteria

Bioinfiltration should be designed according to the requirements listed in Table 6-16 and outlined in the section below.

Table 6-16: Bioretention Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Forebay	-	Forebay should be provided for all tributary surfaces that contain landscaped areas. Forebays should be designed to prevent standing water during dry weather and should be planted with a plant palette that is tolerant of wet conditions.
Maximum drawdown time of water ponded on surface	hours	48
Maximum drawdown time of surface ponding plus subsurface pores	hours	96 (72 preferred)
Maximum ponding depth	inches	18
Minimum thickness of amended soil	feet	2 (3 preferred)
Minimum thickness of stabilized mulch	inches	2 to 4
Planting mix composition	-	60 to 80% fine sand, 20 to 40% compost
Underdrain sizing	-	Underdrain should be installed below the choking stone; 6 inch minimum diameter; 0.5% minimum slope; slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent); spacing shall be determined to provide capacity for maximum rate filtered through amended media
Minimum thickness of gravel layer	feet	2
Overflow device	-	Required

Sizing Criteria

Bioinfiltration facilities can be sized using one of two methods: a simple sizing method or a routing modeling method. With either method the SQDV volume must be completely infiltrated within 96 hours (including subsurface pore space), and surface ponding must be infiltrated within 48 hours. The simple sizing procedure is provided below. For the routing modeling method, refer to TCM-4 Sand Filters.

Step 1: Calculate the Design Volume

Bioinfiltration facilities shall be sized to capture and partially infiltrate and partially biotreat the SQDV volume (see Section 2.3 and Appendix E).

Step 2: Determine the Design Percolation Rate

The percolation rate through the BMP and to the subsurface will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the infiltration layer. Monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For bioinfiltration facilities, the design percolation rate discussed here is the adjusted percolation rate of the underlying soils and not the percolation rate of the filter media bed. The measured short-term infiltration rate should be adjusted using a factor of safety of 2.0.

Step 3: Calculate the surface area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus the void spaces in the media, based on the computed porosity of the filter media and optional aggregate layer.

1) Determine the maximum depth of surface ponding that can be infiltrated within the required surface drain time (48 hr), (d_{max}), as follows:

$$d_{\max} = \frac{P_{design} \times t_{ponding}}{12\frac{in}{ft}} \quad \text{(Equation 6-14)}$$

Where:

$t_{ponding}$ = required drain time of surface ponding (48 hrs)

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

d_{max} = the maximum depth of surface ponding water that can be infiltrated within the required drain time (ft), calculated using Equation 6-14

2) Choose surface ponding depth (d_p) such that:

$$d_p \leq d_{\max} \qquad \text{(Equation 6-15)}$$

Where:

d_p = selected surface ponding depth (ft)

d_{max} = the maximum depth of water that can be infiltrated within the required drain time (ft)

Choose thickness(es) of amended media and aggregate layer(s) and calculate total effective storage depth of the bioinfiltration area ($d_{effective}$), as follows:

$$d_{effective} \leq (d_p + n^*_{media} l_{media} + n_{gravel} l_{gravel}) \qquad \text{(Equation 6-16)}$$

Where:

$d_{effective}$ = total equivalent depth of water stored in bioinfiltration area (ft), including surface ponding and volume available in pore spaces of media and gravel layers

d_p = surface ponding depth (ft), chosen using Equation 6=15

n^*_{media} = available porosity of amended soil media (ft/ft), approximately 0.25 ft/ft accounting for antecedent moisture conditions. This represents the volume of available pore space as a fraction of the total soil volume; sometimes has units of (ft^3/ft^3) or described as a percentage.

l_{media} = thickness of amended soil media layer (ft), minimum 2 ft

n_{gravel} = porosity of gravel layer (ft/ft), approximately 0.40 ft/ft

l_{gravel} = thickness of gravel layer (ft), minimum 2 ft

3) Check that entire effective depth (surface plus subsurface storage), $d_{effective}$, infiltrates in no greater than 96 hours as follows:

$$t_{total} = \frac{d_{effective}}{P_{design}} \times 12\frac{in}{ft} \leq 96\ hr$$ (Equation 6-17)

Where:

$d_{effective}$ = total equivalent depth of water stored in bioinfiltration area (ft), calculated using Equation 6-16

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

If $t_{total} > 96$ hrs, then reduce surface ponding depth and/or amended media thickness and/or gravel thickness and return to 1).

If $t_{total} \leq 96$ hrs, then proceed to 5).

4) Calculate required infiltrating surface area, (A_{req}):

$$A_{req} = \frac{SQDV}{d_{effective}}$$ (Equation 6-18)

Where:

A_{req} = required infiltrating area (ft^2). Should be calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility).

$SQDV$ = stormwater quality design volume (ft^3)

$d_{effective}$ = total equivalent depth of water stored in bioinfiltration area (ft), calculated using Equation 6-16

5) Calculate total footprint required by including a buffer for side slopes and freeboard; A_{req} is calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility).

Geometry

1) Minimum planting soil depth should be 2 feet, although 3 feet is preferred.

The intention is that the minimum planting soil depth should provide a beneficial root zone for the chosen plant palette and adequate water storage for the stormwater quality design volume. A deeper soil depth will provide a smaller surface area footprint.

2) Minimum gravel layer depth is 2 feet.

The intention is that the gravel sump provides partial retention of captured water.

3) Bioinfiltration should be designed to drain below the planting soil in less than 48 hours and completely drain from the gravel layer in 96 hours (both starting from the end of inflow).

   The intention is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

Flow Entrance and Energy Dissipation

The following types of flow entrance can be used for bioinfiltration cells:

1) Dispersed, low velocity flow across a landscape area. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.

2) Dispersed flow across pavement or gravel and past wheel stops for parking areas.

3) Curb cuts for roadside or parking lot areas: curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 2 to 3 inches from curb line and it should provide a settling area and periodic sediment removal of coarse material before flow dissipates to the remainder of the cell.

4) Pipe flow entrance: Piped entrances, such as roof downspouts, should include rock, splash blocks, or other appropriate measures at the entrance to dissipate energy and disperse flows.

Woody plants (trees, shrubs, etc.) can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path.

Underdrains

Underdrains should meet the following criteria:

1) 6-inch minimum diameter.

2) Underdrains should be made of slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent). *The intention is that compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

3) Slotted pipe should have 2 to 4 rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inches and should have a length of 1 to 1.25 inches. Slots should be longitudinally spaced such that the pipe has a minimum of one square inch of slot per lineal foot of pipe and should be placed with slots facing the bottom of the pipe.

4) Underdrains should be sloped at a minimum of 0.5%.

5) Rigid non-perforated observation pipes with a diameter equal to the underdrain diameter should be connected to the underdrain every 100 feet to provide a clean-out port as well as an observation well to monitor dewatering rates. The wells/cleanouts should be connected to the perforated underdrain with the appropriate manufactured connections. The wells/cleanouts should extend 6 inches above the top elevation of the bioinfiltration facility mulch, and should be capped with a lockable screw cap. The ends of the underdrain pipes not terminating in an observation well/cleanout should also be capped.

Gravel Layer

1) The following aggregate should be used for the gravel layer below the underdrain pipe. Place the underdrain below the choking stone, within the top 6 inches of the gravel layer.

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

2) At the option of the designer/geotechnical engineer, a geotextile fabric may be placed between the planting media and the gravel layer. If a geotextile fabric is used, it should meet a minimum permittivity rate of 75 gal/min/ft^2, should not impede the infiltration rate of the soil medium, and should meet the following minimum materials requirements.

Geotextile Property	Value	Test Method
Trapezoidal Tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

Preferably, aggregate (choking stone) should be used in place of filter fabric to reduce the potential for clogging. This aggregate layer should consist of 2 to 4 inches of washed sand underlain with 2 inches of choking stone (Typically #8 or #89 washed).

3) Bioinfiltration facilities have the added benefit of enhanced nitrogen removal due to the elevated underdrain. This allows for a fluctuating anaerobic/aerobic zone below the drain pipe. *The intention is that denitrification within the anaerobic/anoxic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration.*

4) The underdrain should drain freely to an acceptable discharge point. The underdrain can be connected to a d ownstream open conveyance (vegetated swale), to another bioinfiltration cell as part of a connected treatment system, to a storm drain, daylight to a vegetated dispersion area using an effective flow dispersion device, or to a storage facility for harvesting.

Overflow

An overflow device is required at the 18-inch ponding depth. The following, or equivalent should be provided:

1) A vertical PVC pipe (SDR 35) to act as an overflow riser.

2) The overflow riser(s) should be 6 inches or greater in diameter, so it can be cleaned without damage to the pipe.

The inlet to the riser should be at the ponding depth (18 inches for fenced bioinfiltration areas and 6 inches for areas that are not fenced), and be capped with a spider cap to exclude floating mulch and debris. Spider caps should be screwed in or glued, i.e., not removable.

Hydraulic Restriction Layers

Infiltration pathways may need to be restricted due to the close proximity of roads, foundations, or other infrastructure. A geomembrane liner, or other equivalent water proofing, may be placed along the vertical walls to reduce lateral flows. This liner should have a minimum thickness of 30 mils.

Planting/Storage Media

1) The planting media placed in the cell should achieve a long-term, in-place infiltration rate of at least 1 inch per hour. Higher infiltration rates are permissible. If the design long-term, in-place infiltration rate of the soil exceeds 12 inches per hour, documentation should be provided to demonstrate that the media will adequately address pollutants of concern at a higher flowrate. Bioinfiltration soil shall also support vigorous plant growth.

2) Planting media should consist of 60 to 80% fine sand and 20 to 40% compost.

3) Sand should be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for bioinfiltration should be analyzed by an accredited lab using #200, #100, #40, #30, #16, #8, #4, and 3/8 sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation (Note: all sands complying with ASTM C33 for fine aggregate comply with the gradation requirements below):

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
3/8 inch	100	100
#4	90	100
#8	70	100
#16	40	95
#30	15	70
#40	5	55
#100	0	15
#200	0	5

Note: the gradation of the sand component of the media is believed to be a major factor in the hydraulic conductivity of the media mix. If the desired hydraulic conductivity of the media cannot be achieved within the specified proportions of sand and compost (#2), then it may be necessary to utilize sand at the coarser end of the range specified in above (“minimum” column).

4) Compost should be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes, or other organic materials not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program). Compost quality should be verified via a lab analysis to be:

- Feedstock materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.
- Organic matter: 35-75% dry weight basis.
- Carbon and Nitrogen Ratio: 15:1 < C:N < 25:1
- Maturity/Stability: shall have dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120 F) upon delivery or rewetting is not acceptable.

- Toxicity: any one of the following measures is sufficient to indicate non-toxicity:
  - NH4:NH3 < 3
  - Ammonium < 500 ppm, dry weight basis
  - Seed Germination > 80% of control
  - Plant trials > 80% of control
  - e. Solvita® > 5 index value
- Nutrient content:
  - Total Nitrogen content 0.9% or above preferred
  - Total Boron should be <80 ppm, soluble boron < 2.5 ppm
- Salinity: < 6.0 mmhos/cm
- pH between 6.5 and 8 (may vary with plant palette)

Compost for bioinfiltration should be analyzed by an accredited lab using #200, ¼ inch, ½ inch, and 1 inch sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation:

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
1 inch	99	100
½ inch	90	100
¼ inch	40	90
#200	2	10

Tests should be sufficiently recent to represent the actual material that is anticipated to be delivered to the site. If processes or sources used by the supplier have changed significantly since the most recent testing, new tests should be requested.

Note: the gradation of compost used in bioinfiltration media is believed to play an important role in the saturated hydraulic conductivity of the media. To achieve a higher saturated hydraulic conductivity, it may be necessary to utilize compost at the coarser end of this range ("minimum" column). The percent passing the #200 sieve (fines) is believed to be the most important factor in hydraulic conductivity.

In addition, a coarser compost mix provides more heterogeneity of the bioinfiltration media, which is believed to be advantageous for more rapid development of soil structure needed to support health biological processes. This may be an advantage for plant establishment with lower nutrient and water input.

5) The bioinfiltration area should be covered with 2 to 4 inches (average 3 inches) of mulch at the start and an additional placement of 1 to 2 inches of mulch should be added annually. *The intention is that to help sustain the nutrient levels, suppress weeds, retain moisture, and maintain infiltration capacity*.

Planting/Storage Media Design for Nutrient Sensitive Receiving Waters

1) Where the BMP discharges to receiving waters with nutrient impairments or nutrient TMDLs, the planting media placed in the cell should be designed with the specific goal of minimizing the potential for initial and long term leaching of nutrients from the media.

2) In general, the potential for leaching of nutrients can be minimized by:

    a. Utilizing stable, aged compost (as required of media mixes under all conditions).

    b. Utilizing other sources of organic matter, as appropriate, that are safe, non-toxic, and have lower potential for nutrient leaching than compost.

    c. Reducing the content of compost or other organic material in the media mix to the minimum amount necessary to support vigorous plant growth and healthy biological processes.

3) A landscape architect should be consulted to assist in the design of planting/storage media to balance the interests of plant establishment, water retention capacity (irrigation demand), and the potential for nutrient leaching. The following practices should be considered in developing the media mix design:

    a. The actual nutrient content and organic content of the selected compost source should be considered when specifying the proportions of compost and sand. The compost specification allows a range of organic content over approximately a factor of 2 and nutrient content may vary more widely. Therefore determining the actual organic content and nutrient content of the compost expected to be supplied is important in determining the proportion to be used for amendment.

    b. A commitment to periodic soil testing for nutrient content and a commitment to adaptive management of nutrient levels can help reduce the amount of organic amendment that must be provided initially. Generally, nutrients can be added planting areas through the addition of organic mulch, but cannot be removed.

    c. Plant palettes and the associated planting mix should be designed with native plants where possible. Native plants generally have a broader tolerance for nutrient content, and can be longer lived in leaner/lower nutrient soils. An additional benefit of lower nutrient levels is that native plants will generally have less competition from weeds.

d. Nutrients are better retained in soils with higher cation exchange capacity (CEC). C EC can be increased through selection of organic material with naturally high CEC, such as peat, and/or selection of inorganic material with high CEC such as some sands or engineered minerals (e.g., low P-index sands, zeolites, rhyolites, etc). Including higher CEC materials would tend to reduce the net leaching of nutrients.

e. Soil structure can be more important than nutrient content in plant survival and biologic health of the system. If a good soil structure can be created with very low amounts of compost, plants survivability should still be provided. Soil structure is loosely defined as the ability of the soil to conduct and store water and nutrients as well as the degree of aeration of the soil. While soil structure generally develops with time, planting/storage media can be designed to promote earlier development of soil structure. Soil structure is enhanced by the use of amendments with high hummus content (as found in well-aged organic material). In addition, soil structure can be enhanced through the use of compost/organic material with a distribution of particle sizes (i.e., a more heterogeneous mix). Finally, inorganic amendments such as polymer beads may be useful for promoting aeration and moisture retention associated with a good soil structure. An example of engineered soil to promote soil structure can be found here:

   http://www.hort.cornell.edu/uhi/outreach/pdfs/custructuralsoilwebpdf.pdf

f. Younger plants are generally more tolerant of lower nutrient levels and tend to help develop soil structure as they grow. Starting plants from smaller transplants can help reduce the need for organic amendments and improve soil structure. The project should be able to accept a plant mortality rate that is somewhat higher than starting from larger plants and providing high organic content.

g. With these considerations, it is anticipated that less than 10 percent compost amendment could be used, while still balancing plant survivability and water retention.

Plants

1) Plant materials should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 96 hours.

2) It is recommended that a minimum of three types of tree, shrubs, and/or herbaceous groundcover species be incorporated to protect against facility failure due to disease and insect infestations of a single species.

3) Native plant species and/or hardy cultivars that are not invasive and do not require chemical inputs should be used to the maximum extent practicable.

Operations and Maintenance

Bioinfiltration areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, bioinfiltration maintenance requirements are typical landscape care procedures and include:

1) Watering: Plants should be drought-tolerant. Watering may be required during prolonged dry periods after plants are established.

2) Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred (see Appendix I for a bioinfiltration inspection and maintenance checklist). Properly designed facilities with appropriate flow velocities should not have erosion problems, except perhaps in extreme events. If erosion problems occur, the following should be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioinfiltration area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.

3) Plant material: Depending on aesthetic requirements, occasional pruning and removing of dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants excluded.

4) Nutrients and pesticides: The soil mix and plants should be selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioinfiltration area, as well as contribute pollutant loads to receiving waters. By design, bioinfiltration facilities are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

5) Mulch: Replace mulch annually in bioinfiltration facilities where heavy metal deposition is likely (e.g., contributing areas that include industrial and auto dealer/repair parking lots and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.

6) Soil: Soil mixes for bioinfiltration facilities are designed to maintain long-term fertility and pollutant processing capability. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental

concern for at least 20 years in bioinfiltration systems. Replacing mulch in bioinfiltration facilities where heavy metal deposition is likely provides an additional level of protection for prolonged performance. If in question, have soil analyzed for fertility and pollutant levels.

RWH-1: Rainwater Harvesting

Rainwater harvesting BMPs capture and store stormwater runoff for later use. These BMPs are engineered to store a specified volume of water with no surface discharge until this volume is exceeded. Storage facilities that can be used to harvest rainwater include cisterns (above ground tanks), open storage reservoirs (e.g., ponds and lakes), and underground storage devices (tanks, vaults, pipes, arch spans, and proprietary storage systems). Uses of captured water may potentially include irrigation demand, indoor non-potable demand, industrial process water demand, or other demands. Rainwater harvesting systems typically include several components: (1) methods to divert runoff to the storage device, (2) an overflow for when the storage device is full, and (3) a distribution system to get the water to where it is intended to be used. Harvesting systems typically include pretreatment to remove large sediment and vegetative debris. Systems used for internal uses may require an additional level of treatment prior to use.

Cistern

Photo Credit: MetaEfficient

Application

- Any type of land use, provided adequate water demand

Preventative Maintenance

- Debris and sediment removal
- After-rain inspections

Limitations

Rainwater harvesting may be used to meet all of the 5% EIA requirement if reliable demand is available. Rainwater harvesting is not required to be used if the available demands do not meet the volume required for 80% capture using a 72 hour drawdown time.

Design Criteria

Specific considerations for cistern rainwater harvesting systems include:

- Cisterns should include screens on gutters and downspouts to remove vegetative debris and sediment from the runoff prior to entering the cistern.
- Above-ground cisterns should be secured in place.
- Above-ground cisterns should not be located on uneven or sloped surfaces; if installed on a sloped surface, the base where the cistern will be installed should be leveled and designed for the weight of the filled cistern prior to installation.
- Child-resistant covers and mosquito screens should be placed on all water entry holes.
- A first flush diverter may be installed so that initial runoff bypasses the cistern. Where a first flush diverter is used, the diverted flows must be directed to a pervious area so that no runoff is produced or another form of treatment must be provided for this flow.
- Above-ground cisterns should be installed in a location with easy access for maintenance or replacement.

Specific considerations for underground detention include:

- Access entry covers (36" diameter minimum) should be locking and within 50 feet of all areas of the detention tank.
- In cases where the detention facility provides sediment containment, the facility should be laid flat and there should be at least ½ foot of dead storage within the tank or vault.
- Outlet structures should be designed using the 100-year storm as overflow and should be easily accessible for maintenance activities.
- For detention facilities beneath roads and parking areas, structural requirements should meet H20 load requirements.
- In cases where groundwater may cause flotation, these forces should be counteracted with backfill, anchors, or other measures.

- Underground detention facilities should be installed on consolidated and stable native soil; if the facility is constructed in fill slopes, a geotechnical analysis should be performed to ensure stability.

General considerations include:

- In cases where there is non-potable indoor demand, proper pretreatment measures should be installed such as pre-filtration, cartridge filtration, and/or disinfection (which can also be provided between the cistern and point of use).
- Plumbing systems should be installed in accordance with the current California Building and Plumbing Codes (CBC – part of California Code of Regulations, Title 24).
- Underground detention facilities can be incorporated into a treatment train to provide initial or supplemental storage to other detention storage facilities and/or infiltration BMPs.
- Treatment of the captured rainwater (i.e. disinfection) may be required depending on the end use of the water.

Rainwater harvesting uses include:

- Harvested rainwater can be used for irrigation and other non-potable uses (if local, State, and Federal ordinances allow). The use of captured stormwater allows a reduced demand on the potable water supply. Cross-contamination should be prevented when make-up water is required for rainwater use demand by providing a backflow prevention system on the potable water supply line and/or an air gap.
- Irrigation Use
  - Subsurface (or drip) irrigation should not require disinfection pretreatment prior to use; other irrigation types, such as spray irrigation, may require additional pre-treatment prior to use
  - Selecting native and/or drought tolerant plants for landscaped area will reduce irrigation demand; however, they are still recommended for use.
- Domestic Use
  - Domestic uses may include toilet flushing and clothes washing (if local, State, and Federal ordinances allow).
  - Pretreatment requirements per local, State, or Federal codes and ordinances may apply.
- Other Non-Potable Uses

- Other potential non-potable uses may include vehicle/equipment washing, evaporative cooling, industrial processes, and dilution water for recycled water systems.

Sizing Criteria

The effectiveness of rainwater harvesting (RWH) systems is a function of tributary area, storage volume, demand patterns and magnitudes, and operational regime. If either of the latter two factors are too complex, simple design criteria metrics are not possible. The rainwater harvesting design criteria provided in this Fact Sheet are intended for the evaluation of systems that have relatively simple demand regimes and passive operation. If the answer to any of the following complexity screening questions is yes, a site-specific evaluation of rainwater harvesting effectiveness should be completed using a continuous simulation model with a long-term precipitation record.

Complexity Screening Questions:

- Does the proposed system have seasonally-varying demand other than irrigation?
- Will the system be operated by advanced control systems or otherwise actively controlled?
- Does the operational regime call for the system be shut down at any time during the rainy season?

Effectiveness of a harvesting system for retaining the SQDV depends on the cistern's effective storage capacity (i.e., the volume available for storage at the beginning of each event). Therefore, the required storage volume varies based on precipitation and demand. Using the following sizing charts, cisterns should be sized to achieve 80 percent capture efficiency. These nomographs are based on continuous simulation performed in EPA SWMM using precipitation and ET records representative of lowland regions (Oxnard Airport Precipitation Gauge, El Rio Spreading Grounds ET station) and mountainous regions (Ojai-Stewart Canyon Precipitation Gauge, Matilja ET Station) of the County.

Instructions for determining required cistern volume and demand are provided below:

Step 1: Determine Required Rainwater Harvesting Design Volume (RWHDV)

Note that a rainwater harvesting system sized for 80% capture runoff (as determined by continuous modeling), which can draw down in 72 hours is required to meet the 5% EIA standard. If the demand required to draw a tank sized for these parameters is not available, rainwater harvesting is not mandated for use. Partial capture of runoff is allowable if rainwater harvesting is desired for use. Sizing instructions for partial capture are included in Step 3.

1) Determine the design storm required for 80% capture with a 72 hour drawdown time by selecting the project region (lowland or mountainous), then determining where the 72 hour drawdown curve intersects the 80% capture line. Pivot down from this intersection to the x axis to read the design storm, d_{design}.

2) Determine the required rainwater harvesting system volume using the following equation:

$$RWHDV = C^*(d_{design}/12)^*A_{retain} \qquad \text{(Equation 6-19)}$$

Where:

RWHDV	=	rainwater harvesting design volume (acre-ft)
C	=	runoff coefficient, calculated using Appendix E and the site imperviousness
d_{design}	=	design storm required for 80% capture with a 72 hour drawdown time, estimated as described in 1) (inches)
A_{retain}	=	the drainage area from which runoff must be retained (acres)

Step 2: Determine the Required Daily Demand to Achieve 80% Capture

1) The required daily demand to achieve 80% capture of runoff can be calculated as follows:

$$Demand = [RWHDV/(72/24)] * (325{,}851) \qquad \text{(Equation 6-20)}$$

Where:

Demand	=	required project daily demand to draw down rainwater harvesting system sized for 80% capture in 72 hours (gallons)
RWHDV	=	rainwater harvesting design volume (acre-ft), from Step 1 above

If the project daily demand is less than the Demand calculated, the project is not required to utilize rainwater harvesting. If rainwater harvesting is desired for use for partial retention, if a longer drawdown time is desired, or if a predetermined daily demand is to be used, refer to Steps 3 and 4 below.

Step 3: Determine RWHDV for Partial Retention or a Longer Drawdown Time

1) Calculate RWHDV for selected combination of % capture and drawdown time using nomographs and the following equation:

$$RWHDV = C*(d_{design}/12)*A_{retain} \quad \text{(Equation 6-21)}$$

Where:

RWHDV	=	rainwater harvesting design volume (acre-ft)
C	=	runoff coefficient, calculated using Appendix E and the site imperviousness
d_{design}	=	design storm required for selected % capture and drawdown time (inches)
A_{retain}	=	the drainage area from which runoff must be retained (acres)

2) Determine the required daily demand for the selected capture efficiency and/or drawdown time:

$$Demand = [RWHDV/(t_{drawdown}/24)] * (325{,}851) \quad \text{(Equation 6-22)}$$

Where:

Demand	=	required project daily demand to draw down rainwater harvesting system sized for 80% capture in 72 hours (gallons)
RWHDV	=	rainwater harvesting design volume (acre-ft), from 1) above
$t_{drawdown}$	=	selected drawdown time (hours)

Step 4: Determine RWHDV for a Predetermined Daily Demand

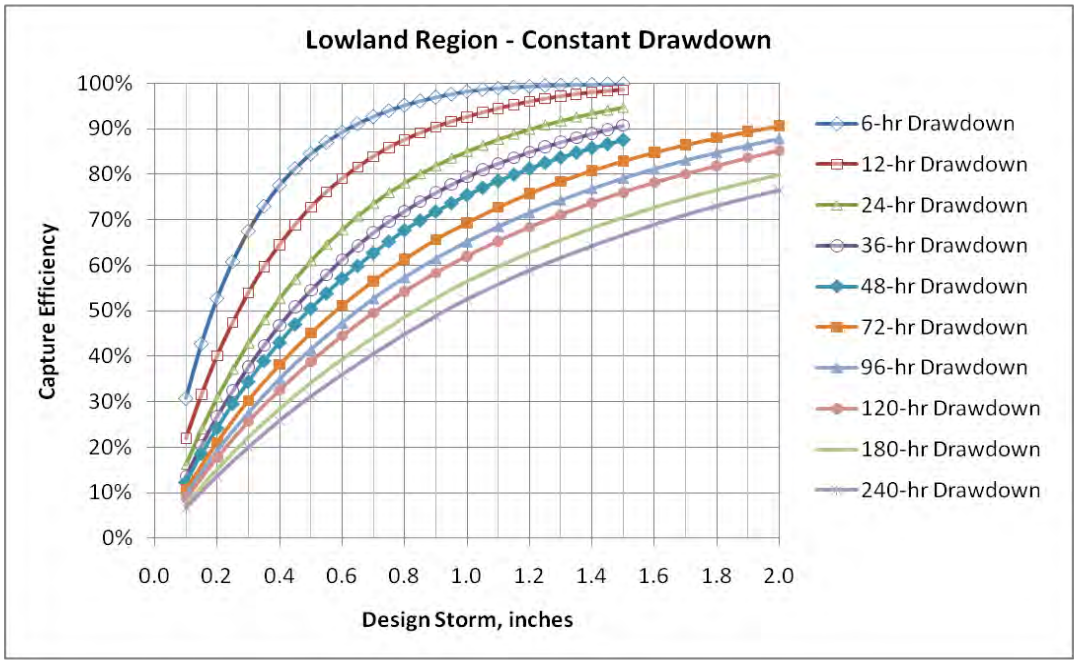
1) Determine the daily demand requirement in acre-feet (1 acre-foot = 325,851 gallons).

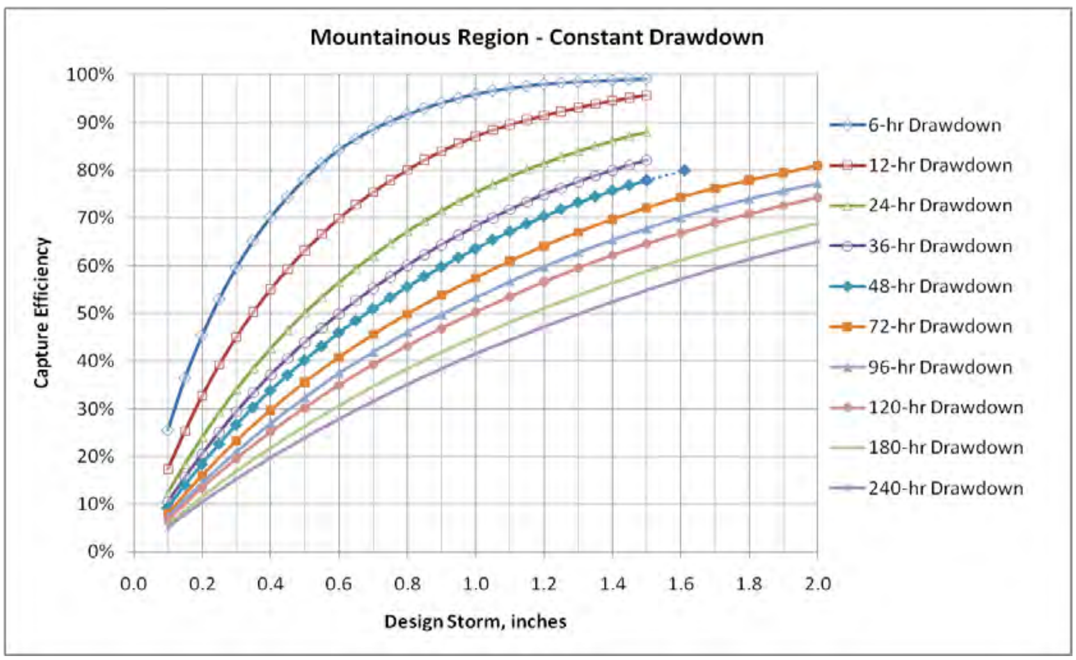
2) Calculate the required RWHDV for the desired drawdown time using the following equation:

$$RWHDV = Demand *(t_{drawdown}/24) \quad \text{(Equation 6-23)}$$

Where:

Demand	=	required project daily demand (acre-feet)
RWHDV	=	rainwater harvesting design volume (acre-ft)
$t_{drawdown}$	=	selected drawdown time (hours)


Lowland Region - Constant Drawdown
Capture Efficiency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Design Storm, inches
6-hr Drawdown
12-hr Drawdown
24-hr Drawdown
36-hr Drawdown
48-hr Drawdown
72-hr Drawdown
96-hr Drawdown
120-hr Drawdown
180-hr Drawdown
240-hr Drawdown


Mountainous Region - Constant Drawdown
Capture Efficiency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
Design Storm, inches
6-hr Drawdown
12-hr Drawdown
24-hr Drawdown
36-hr Drawdown
48-hr Drawdown
72-hr Drawdown
96-hr Drawdown
120-hr Drawdown
180-hr Drawdown
240-hr Drawdown

Operations and Maintenance

1) Inspect storage facilities, associated pipes, and valve connections for leaks.
2) Clean gutters and filters of debris that has accumulated and is obstructing flow into the storage facility.
3) Clean and remove accumulated sediment annually.
4) Check cisterns for stability and anchor if necessary.
5) If the storage device is underground, ensure that a manhole is accessible, operational, and secure.

ET-1: Green Roof

Green roofs (also known as eco-roofs and vegetated roof covers) are roofing systems that layer a soil/vegetative cover over a waterproofing membrane. Green roofs rely on highly porous media and moisture retention layers to store intercepted precipitation and to support vegetation that can reduce the volume of stormwater runoff via evapotranspiration. There are two types of green roofing systems: extensive, which is a light-weight system; and intensive, which is a heavier system that allows for larger plants but requires additional structural support.

Green Roof Examples

Photo Credits:

1. Milwaukee Department of Environmental Sustainability;

2. Geosyntec Consultants

Application

- Building roofs
- Outdoor eating area roofs
- Parking structure or turnaround roofs

Preventative Maintenance

- Weeding and pruning
- Leaf and debris removal
- Regular membrane inspection
- Drain cleanout

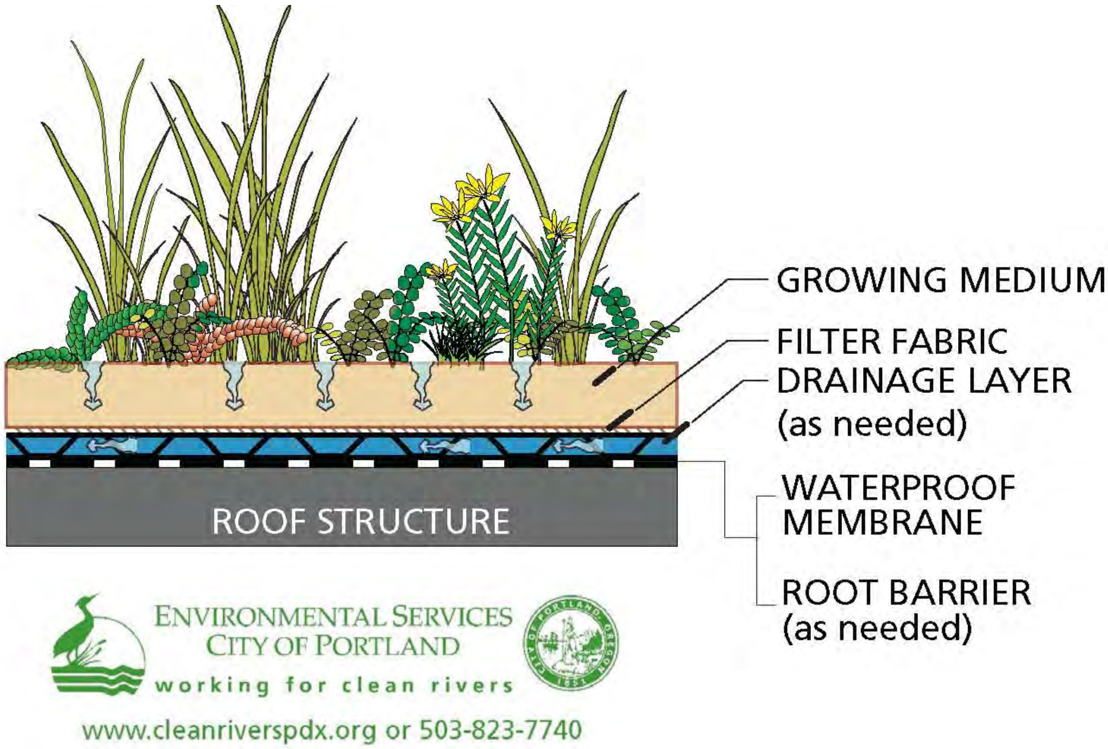


Exhibit A: Green Roof Schematic Courtesy of Portland, OR Environmental Services Department

Exhibit B: Green Roof Schematic Courtesy of American Wick

Geosyntec consultants

Figure 6-9: Green Roofs

Limitations

The following describes additional site suitability recommendations and limitations for green roofs.

- Typically not used for steep roofs (>25%); and
- Structural roof support must be sufficient to support additional roof weight.

Design Criteria

Green roofs should be designed according to the requirements listed in Table 6-17 and outlined in the section below.

Table 6-17: Green Roof Design Criteria

Design Parameter	Unit	Design Criteria
Soil depth range	inch	2 – 6
Saturated soil weight	lbs. / sq. ft.	10 – 25
Maximum roof slope	%	25
Minimum roof slope	--	Flat
Vegetation type	--	Varies (see vegetation section below)
Vegetation height	--	Varies (see vegetation section below)

Sizing

Green roofs may provide quantifiable reduction in volume. However, they are not explicitly sized to meet the water quality treatment requirements. Rather, the volume reduction is accounted for implicitly in sizing calculations for the treatment BMPs for the remainder of the site by assuming that the roof area is pervious rather than impervious when calculating a runoff coefficient for the site.

Green Roof Components

Structural Support

The first requirement that must be met before installing a green roof is the structural support of the roof. The roof must be able to support the additional weight of the soil, water, and vegetation. A licensed structural engineer should be consulted to determine the proposed structural support during the design phase.

Waterproof Roofing Membrane

Waterproof roofing membrane is an i ntegral part of a g reen roofing system. The waterproof membrane prevents the roof runoff from penetrating and damaging the roofing material. There are many materials available for this purpose and come in various forms (i.e., rolls, sheets, liquid) and exhibit different characteristics (e.g., flexibility, strength, etc.). Depending on the type of membrane chosen a root barrier may be required to prevent roots from compromising the integrity of the membrane.

Drainage Layer

Depending on the design of the roof, a drainage layer may be required to convey the excess runoff from of the roof. If a drainage layer is needed, there are numerous options including a g ravel layer (which may require additional structural support), and many styles and types of plastic drainage layers.

Soil Considerations

The soil layer is an important factor in the construction and operation of green roofs. The soil layer must have excellent drainage, not be too heavy when saturated, and be adequately fertile as a growing medium for plants. Many companies sell their own proprietary soil mixes. However, a simple mix of ¼ topsoil, ¼ compost, and the remainder pumice perlite may be used for many applications. Other soil amendments may be substituted for the compost and the pumice perlite. The soil mix used should not contain any clay.

Vegetation

Green roofs must be vegetated in order to provide adequate treatment of runoff via filtration and evapotranspiration. Vegetation, when chosen and maintained appropriately, also improves the aesthetics of a site. Green roofs should be vegetated with a mix of erosion-resistant plant species that effectively bind the soil and can withstand the extreme environment of rooftops. A diverse selection of low growing plants that thrive under the specific site, climatic, and watering conditions should be identified. A mixture of drought-tolerant, self-sustaining (perennial or self-sowing without need for fertilizers, herbicides, and or pesticides) is most effective in the Ventura County region. Plants selected should also be low maintenance and able to withstand heat, cold, and high winds. Native or adapted sedum/succulent plants are preferred because they generally require less fertilizer, limited maintenance, and are more drought resistant than exotic plants. When appropriate, green roofs may be planted with larger plants. However, this depends on structural support and soil depth.

The following provides additional vegetation guidance for green roofs.

1) For extensive roofs, trees or shrubs may be used as long as the increased soil depth required may be supported.

2) Irrigation is required if the seed is planted in spring or summer. The use of a permanent smart (self-regulating) irrigation system or other watering system, may help provide maximal water quality performance. Drought-tolerant plants should be specified to minimize irrigation requirements. For projects seeking “High Performance Building” recognition, ASHRAE Standard 189.1 states that potable water cannot be used for irrigating green roofs after they are established.

3) Locate the green roof vegetation in an area without excessive shade to avoid poor vegetative growth. For moderately shaded areas, shade tolerant plants should be used.

4) A relevant plant list should be provided by a landscape professional and used as a guide to support project-specific planting recommendations, including recommendations on appropriate plants, fertilizer, mulching applications, and irrigation requirements (if any) to ensure healthy vegetation growth.

Drain

1) There must be a drain pipe (gutter) to convey runoff (both overflow and underdrain flow, if appropriate) safely from the roof to another basic or stormwater runoff BMP, a pervious area, or the stormwater conveyance system.

Construction Considerations

1) Building structure must be adequate to hold the additional weight of the soil, retained water, and plants.

2) Plants should be selected carefully to minimize maintenance and function properly.

Operations and Maintenance

1) During the establishment period, green roofs may need irrigation and occasional light fertilization until the plants have fully established themselves. Once healthy and fully established, properly selected climate-appropriate plants will no longer need irrigation except during extreme drought.

2) Weeding during the establishment period may be required to ensure proper establishment of the desired vegetation. Once established and assuming proper selection of vegetation, the vegetation should not require any preventative maintenance.

3) The roofing membrane should be inspected routinely, as it is a crucial element of the green roof. In addition, preventative inspection of the drainage paths is required to ensure that there are no clogs in the system. If a green roof is not properly draining, the moisture in the system may cause the roof to leak and/or the plants to drown or rot. Leaks in the roof may occur not only due to improper drainage, but also if the incorrect combination of waterproofing barrier, root barrier, and drainage systems

are selected. Leak inspections in the roofing system are advised, especially in locations prone to leaks, such as at all joints.

4) Inspect green roofs for erosion or damage to vegetation after every storm greater than 0.75 inches and at the end of the wet season to schedule summer maintenance and in the fall to ensure readiness for winter. Additional inspection after periods of heavy runoff is recommended. Green roofs should be checked for debris, litter, and signs of clogging.

5) Replanting and/or reseeding of vegetation may be required for reestablishment.

6) Vegetation should be healthy and dense enough to provide filtering while protecting underlying soils from erosion.

7) Fallen leaves and debris from deciduous plant foliage should be removed.

8) Invasive vegetation, such as Alligatorweed (*Alternanthera philoxeroides*), Halogeton (*Halogeton glomeratus*), Spotted Knapweed (*Centaurea maculosa*), Giant Reed (*Arundo donax*), Castor Bean (*Ricinus communis*), Perennial Pepperweed (*Lepidium latifolium*), and Yellow Starthistle (*Centaurea solstitalis*) should be removed and replaced with non-invasive species. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

9) Dead vegetation should be removed if greater than 10% of the area coverage. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.

ET-2: Hydrologic Source Control BMPs

Hydrologic source control (HSC) BMPs are simple BMPs that are highly integrated with the site design to reduce runoff volume. The practices described in this fact sheet include impervious area dispersion, street trees, and rain barrels.

Application

- Building roofs
- Sidewalks and patios
- Landscaping hardscapes

Preventative Maintenance

- Weeding and pruning
- Leaf and debris removal

Hydrologic Source Control Examples

Photo Credits:

1. http://www.auburn.edu/projects/sustainability/website/newsletter/0910.php;

2. Geosyntec Consultants;

3. toronto.ca/environment/water.htm

Accounting for Hydrologic Source Controls in Hydrologic Calculations

The effects of HSC BMPs are accounted for in hydrologic calculations as an adjustment to the storm depth used in the SQDV calculations described in Section 2. Runoff volume calculations are performed exactly as described in Section 2, with the exception that the storm depth used in the calculation is adjusted prior to the calculation. Adjustments are based on the type and magnitude of HSC BMPs employed for the drainage area per guidance outlined in this Fact Sheet.

EXAMPLE 6.1: ACCOUNTING FOR HSCS IN HYDROLOGIC CALCULATIONS

Given:

- A drainage area consists of a 1 acre building roof surrounded by 0.25 acres of landscaping (80 percent composite imperviousness);
- The drainage from the roof is spread uniformly over the entire pervious area via splash pads and level spreaders;
- Soils are moderately well drained and have a shallow slope;
- For the purpose of this example, assume the hydrologic source control adjustment for this configuration of disconnected downspouts is 0.3 inches. For an actual project, hydrologic source control adjustment would be calculated based on instructions in this section; and
- The unadjusted design storm depth at the project site is 0.75 inches.

Result:

1) The designer uses 0.75 inches – 0.3 inches = 0.45 inches in the calculation of SQDV.

Impervious Area Dispersion

Impervious area dispersion refers to the practice of routing runoff from impervious areas, such as rooftops, walkways, and patios, onto the surface of adjacent pervious areas. Runoff is dispersed uniformly via splash block or dispersion trench and soaks into the ground as it moves slowly across the surface of the pervious area. Minor ponding may occur, but it is not the intent of this practice to actively promote localized on-lot infiltration, which should be designed as an infiltration BMP (see INF-1 through INF-6 above).

Design Considerations

1) Not likely to result in net increased infiltration over existing condition for previously pervious sites, but has potential to result in some geotechnical hazards associated with infiltration.

2) Significant pervious area should be available, at a ratio of at least 1 part pervious area capable of receiving flow to 5 parts impervious.

3) Pervious area receiving flow should have a slope ≤ 2 percent and path lengths of ≥ 10 feet per 1000 sf of impervious area.

4) Overflow from the pervious area up to the SQDV should be directed to a Retention BMP, Biofiltration BMP, or Treatment Control Measure. Larger flows should be directed to the storm drain system.

5) Soils in the pervious area should be preserved in their natural condition or improved with soil amendments (see Soil Amendments below).

6) Impervious area disconnection is an HSC that may be used as the first element in any treatment train.

7) The use of impervious area disconnection reduces the sizing requirement for downstream Retention BMPs, Biofiltration BMPs, and/or Treatment Control Measures.

Calculating HSC Retention Volume

1) The retention volume provided by downspout dispersion is a function of the ratio of impervious to pervious area.

2) Determine flow patterns in pervious area and estimate footprint of pervious area receiving dispersed flow. Calculate the ratio of pervious to impervious area.

3) Check soil conditions using the checklist below; amend if necessary.

4) Look up the storm retention depth (d_{HSC}), from the chart to the right.

[1] Pervious area used in calculation should only include the pervious area receiving flow, not pervious area receiving only direct rainfall or upslope pervious drainage.

5) The max d_{HSC} is equal to the design storm depth for the project site.

Soil Condition Checklist

1) Soil should have a maximum slope of 2 percent.

2) Landscaping should be well-established.

3) Amended soils should consist of: 60 to 70% sand, 15 to 25% compost, 10 to 20% clean topsoil. The organic content of the soil mixture should be 8 to 12%; the pH range should be 5.5 to 7.5.

Additional References

- SMC LID Manual (pp 131): http://www.lowimpactdevelopment.org/guest75/pub/All_Projects/SoCal_LID_Manual/SoCalLID_Manual_FINAL_040910.pdf
- City of Portland Bureau of Environmental Services. 2010. How to manage stormwater – Disconnect Downspouts: http://www.portlandonline.com/bes/index.cfm?c=43081&a=177702
- Seattle Public Utility: http://www.cityofseattle.org/util/stellent/groups/public/@spu/@usm/documents/webcontent/spu01_006395.pdf
- Thurston County, Washington State (pp 10): http://www.co.thurston.wa.us/wwm/Engineering_Standards/Drainage_Manual/PDFs/DG-5%20Roof%20Runoff%20Control.pdf

Amended Soils

A soil amendment is any material added to the upper layer of soil especially in the vicinity of the root zone soil to improve its physical properties, such as the water retention, permeability, water infiltration, drainage, aeration and structure. The goal is to provide a better environment for roots. To do its work, an amendment should be thoroughly mixed into the soil. If it is merely buried, its effectiveness is reduced and it will interfere with water and air movement and root growth.

Amending a soil is different from mulching, although many mulches also are used as amendments. A mulch is left on the soil surface. Its purpose is to reduce evaporation and runoff, inhibit weed growth, and create an attractive appearance. Mulches also moderate soil temperature, helping to warm soils in the spring and cool them in the summer. Mulches may be incorporated into the soil as amendments after they have decomposed to the point that they no longer serve their purpose.

Organic amendments, such as compost, increase soil organic matter content and offer many benefits. Organic matter improves soil aeration, water infiltration, and both water- and nutrient-holding capacity. Many organic amendments contain plant nutrients and act as organic fertilizers. Organic matter also is an important energy source for bacteria, fungi and earthworms that live in the soil.

Design Considerations

1) Landscaped and other developed pervious areas can be amended to improve evapotranspiration and soil moisture storage capacity.
2) Landscape and other developed pervious areas can be amended to increase infiltration rates in cases where the limiting infiltration horizon exists near the surface of the soil column.

3) Soil amendments are common components of several Retention BMPs, Biofiltration BMPs, and Treatment Control Measures, including infiltration basins, bioretention, vegetated swales, filter strips, planter boxes, green roofs, dry extended detention basins, wet retention basins, and constructed treatment wetlands.

4) Compost, soil conditioners, and fertilizers should be rototilled into the native soil to a minimum depth of 6 inches; 12 inches preferred.

5) All soil amendments shall be free of sticks, glass, plastic, metal, debris larger than 1 inch, and other deleterious material.

6) Compost shall meet criteria listed in the guidelines for planting and storage media.

Calculating HSC Retention Volume

No retention credit is given for amended soils alone. Amended soils should be used to increase the retention volume of Retention BMPs, Biofiltration BMPs, and Treatment Control Measures.

Additional References

- San Diego County LID Handbook Appendix 4 (Factsheet 30): http://www.sdcounty.ca.gov/dplu/docs/LID-Appendices.pdf
- Colorado State University Extension website: http://www.ext.colostate.edu/pubs/garden/07235.html

Street Trees

By intercepting rainfall, trees can provide several aesthetic and stormwater benefits including peak flow control, increased infiltration and evapotranspiration, and runoff temperature reduction. The volume of precipitation intercepted by the canopy reduces the treatment volume required for downstream treatment BMPs. Shading reduces the heat island effect as well as the temperature of adjacent impervious surfaces over which stormwater flows, and thus reduces the heat transferred to the downstream waterbody. Tree roots also strengthen the soil structure and provide infiltrative pathways, simultaneously reducing erosion potential and enhancing infiltration.

Design Considerations

1) Street trees can be incorporated along sidewalks, streets, parking lots, or driveways.

2) Street trees can be used in combination with bioretention systems along medians or in traffic calming bays.

3) There should be sufficient space available to accommodate both the tree canopy and the root system.

4) The mature tree canopy, height, and root system should not interfere with subsurface utilities, overhead powerlines, buildings and foundations, or other existing or planned structures.

5) Depending on space constraints, a 20 to 30 foot canopy (at maturity) is recommended for stormwater mitigation.

6) Native, drought-tolerant species should be selected in order to minimize irrigation requirements and improve the long-term viability of the tree.

7) Trees should not impede pedestrian or vehicle sight lines.

8) Planting locations should receive adequate sunlight and wind protection. Other environmental factors should be considered prior to planting.

9) Soils should be preserved in their natural condition (if appropriate for planting) or restored via soil amendments. If necessary, a landscape architect should be consulted.

Calculating HSC Retention Volume

1) The retention volume provided by streets trees via canopy interception is dependent on the tree species, time of the year, and maturity.

2) To compute the retention credit, the expected impervious area covered by the full tree canopy after 4 years of growth should be computed (IA_{HSC}). The maximum retention depth credit for canopy interception (d_{HSC}) is 0.05 inches.

Additional References

- California Stormwater BMP Handbook: http://www.cabmphandbooks.com/Documents/Development/Section_3.pdf
- City of Los Angeles, Street Tree Division - Street Tree Selection Guide: http://bss.lacity.org/UrbanForestryDivision/StreetTreeSelectionGuide.htm
- Portland Stormwater Management Manual: http://www.portlandonline.com/bes/index.cfm?c=35122&a=55791
- San Diego County LID Handbook Fact Sheets: http://www.sdcounty.ca.gov/dplu/docs/LID-Appendices.pdf

Residential Rain Barrels

Rain barrels are above ground storage vessels that capture runoff from roof downspouts during rain events and detain that runoff for later use for irrigating landscaped areas.

Design Considerations

1) If detained water will be used for irrigation, sufficient vegetated areas and other impervious surfaces should be present in the drainage area.

2) Storage capacity and sufficient area for overflow dispersion should be accounted for.

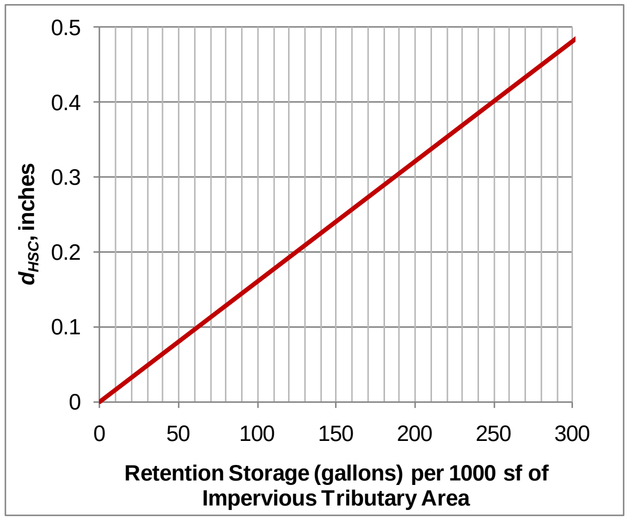
3) Screens on gutters and downspouts to remove sediment and particles as the water enters the barrel or cistern should be provided.

4) Removable child-resistant covers and mosquito screening should be provided to prevent unwanted access.

5) Above-ground barrels should be secured in place.

6) Above-ground barrels should not be located on uneven or sloped surfaces. If installed on a sloped surface, the base where the rain barrel will be installed should be leveled prior to installation.

7) Overflow dispersion should occur greater than 5 feet from building foundations.



8) Dispersion should not cause geotechnical hazards related to slope stability.

9) Effective energy dissipation and uniform flow spreading methods should be employed to prevent erosion and facilitate dispersion.

10) Placement should allow easy access for regular maintenance.

Calculating HSC Retention Volume

1) The retention volume provided by rain barrels that are not actively managed can be computed as 50% of the total storage volume (e.g., 22.5 gallons for each 55 gallon barrel).

2) If the rain barrel is actively managed, then it should be treated as a cistern (see RWH-1).

3) Estimate the average retention volume per 1000 square feet impervious tributary area provided by rain barrels.

4) Look up the storm retention depth (d_{HSC}), from the chart to the right.

5) The max d_{HSC} is equal to the design storm depth for the project site.

Additional References

- Santa Barbara BMP Guidance Manual, Chapter 6: http://www.santabarbaraca.gov/NR/rdonlyres/91D1FA75-C185-491E-A882-49EE17789DF8/0/Manual_071008_Final.pdf
- County of Los Angeles LID Standards Manual: http://dpw.lacounty.gov/wmd/LA_County_LID_Manual.pdf
- SMC LID Manual (pp 114): http://www.lowimpactdevelopment.org/guest75/pub/All_Projects/SoCal_LID_Manual/SoCalLID_Manual_FINAL_040910.pdf
- San Diego County LID Handbook Appendix 4 (Factsheet 26): http://www.sdcounty.ca.gov/dplu/docs/LID-Appendices.pdf

BIO-1: Bioretention with Underdrain

Bioretention stormwater treatment facilities are landscaped shallow depressions that capture and filter stormwater runoff. These facilities function as a soil and plant based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. The facilities normally consist of a ponding area, mulch layer, planting soils, and plantings. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants. Bioretention with an underdrain is a treatment control measures that can be used for areas with low permeability native soils or steep slopes. Bioretention may be designed without an underdrain to serve as a retention BMP in areas of high soil permeability (see INF-3 Bioretention) or partial retention/ partial biofiltration BMP (see INF-7: Bioinfiltration).

Bioretention in Parking Lots

Photo Credits: Geosyntec Consultants

Application

- Parking lots
- Roadway parkways and medians
- School entrances, courtyards, and walkways
- Playgrounds and sports fields

Preventative Maintenance

- Repair small eroded areas
- Remove trash and debris and rake surface soils
- Remove accumulated fine sediments, dead leaves, and trash
- Remove weeds and prune back excess plant growth
- Remove sediment and debris accumulation near inlet and outlet structures
- Periodically observe function under wet weather conditions

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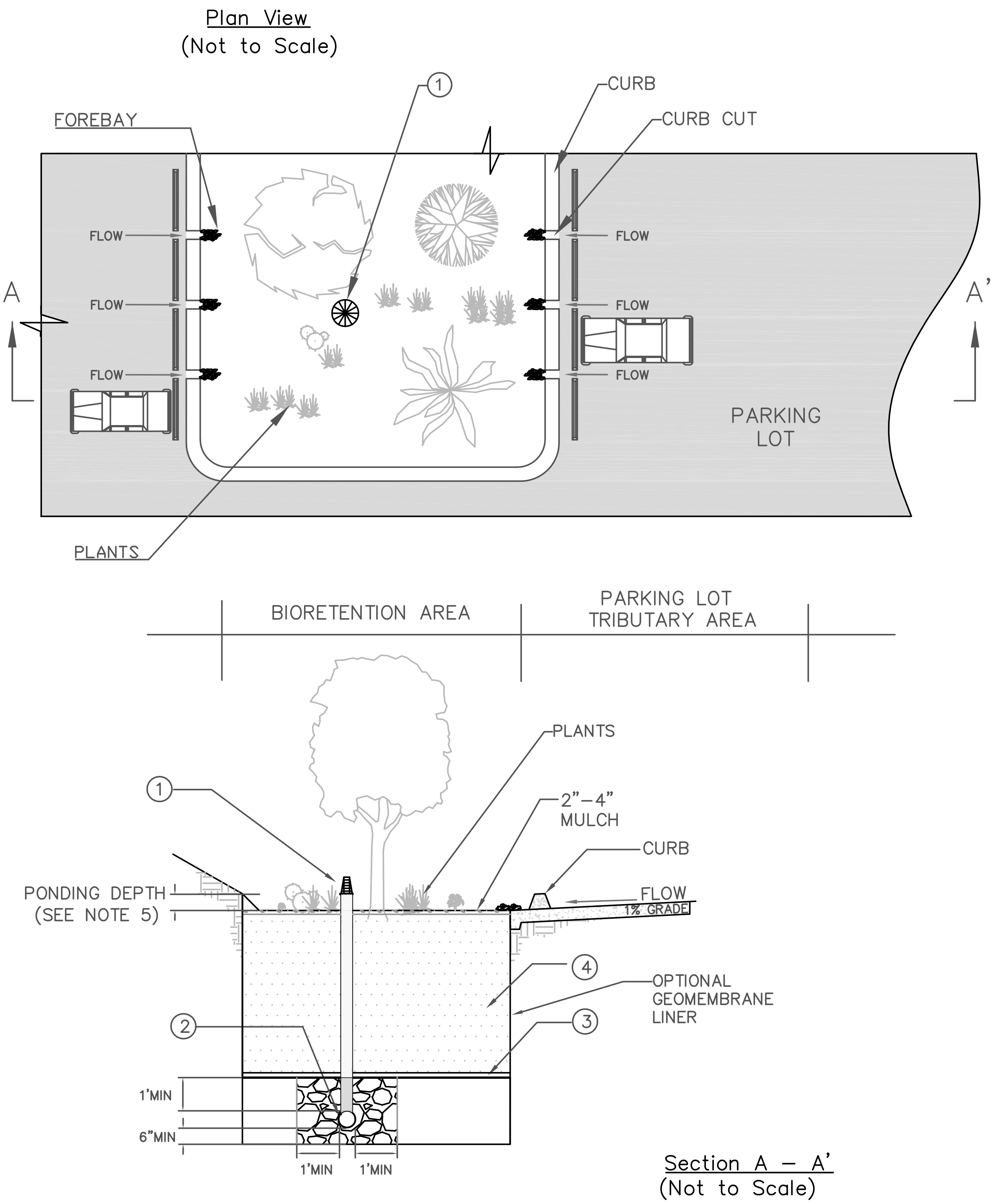


NOTES:

1. OVERFLOW DEVICE: VERTICAL RISER OR EQUIVALENT.
2. PERFORATED 6" MIN PVC PIPE UNDERDRAIN.
3. OPTIONAL CHOKING GRAVEL LAYER.
4. 2' MIN PLANTING MIX; 3' PREFERRED.
5. PONDING DEPTH 18" WITH FENCE; 6" WITHOUT FENCE.

Geosyntec consultants

Figure 6-10: Bioretention with Underdrain

Limitations

1) Vertical relief and proximity to storm drain - site must have adequate relief between land surface and storm drain to permit vertical percolation through the soil media and collection and conveyance in underdrain to storm drain system.

2) Depth to groundwater - shallow groundwater table may not permit complete drawdown between storms.

Design Criteria

Bioretention with an underdrain should be designed according to the requirements listed in Table 6-18 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-18: Bioretention with an Underdrain Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Forebay	-	Forebay should be provided for all tributary surfaces that contain landscaped areas. Forebays should be designed to prevent standing water during dry weather and should be planted with a plant palette that is tolerant of wet conditions.
Maximum drawdown time of water ponded on surface	hours	72
Maximum drawdown time of surface ponding plus subsurface pores	hours	96 (72 preferred)
Maximum ponding depth	inches	18 inches
Minimum thickness of amended soils layer	feet	2 (3 preferred)
Minimum thickness of stabilized mulch	inches	2 to 4
Planting mix composition	-	60 to 80% fine sand, 20 to 40% compost
Underdrain sizing	-	6 inch minimum diameter; 0.5% minimum slope; slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent); spacing shall be determined to provide

Design Parameter	Unit	Design Criteria
		capacity for maximum rate filtered through amended media
Gravel layer	-	A gravel bed should be provided around underdrain. Underdrain should have at least 1 foot of gravel installed to the sides and on top of the underdrain, and at least 0.5 feet of gravel installed below underdrain.
Overflow device	-	Required

Sizing Criteria

Bioretention facilities with underdrains shall be designed to capture and treat the SQDV. However because these systems commonly have a relatively high amended soil infiltration rate and shallow depth, these systems are typically capable of filtering a significant portion of the SQDV during a storm event. Therefore, a simplified routing approach is described in the following steps that accounts for the portion of the SQDV that is filtered during the storm event.

Step 1: Calculate the Design Volume

Bioretention facilities shall be sized to capture and biofilter the SQDV (see Section 2.3 and Appendix E).

Step 2: Determine the Design Percolation Rate

Sizing is based on the design saturated hydraulic conductivity (K_{sat}) of the amended soil layer. A target K_{sat} of 5 inches per hour is recommended for non-proprietary amended soil media. The media K_{sat} will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the amended soil layer. A factor of safety of 2.0 should be applied such that the resulting recommended design K_{sat} is 2.5 inches per hour. This value should be used for sizing unless sufficient rationale is provided to justify a higher design K_{sat}.

Step 3: Calculate the surface area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus the void spaces in the media, based on the computed porosity of the filter media and aggregate layer.

1) Select a surface ponding depth (d_p) that satisfies geometric criteria and is congruent with the constraints of the site. Selecting a deeper ponding depth (18 inches maximum) generally yields a smaller footprint, however, it requires greater consideration for public safety, energy dissipation, and plant selection.

2) Compute time for selected ponding depth to filter through media:

$$t_{ponding} = \frac{d_p}{K_{design}} 12 \frac{in}{ft}$$ (Equation 6-24)

Where:

$t_{ponding}$ = required drain time of surface ponding (≤ 72 hrs)

d_p = selected surface ponding water depth (ft)

K_{design} = media design saturated hydraulic conductivity (in/hr) (see Step 2, above)

If $t_{ponding}$ exceeds 72 hours, return to (1) and reduce surface ponding or increase media K_{design}. Otherwise, proceed to next step.

Note: In nearly all cases, $t_{ponding}$ will not approach 72 hours unless a low K_{design} is specified.

3) Compute depth of water that may be filtered during the design storm event as follows:

$$d_{filtered} = Minimum\left[\frac{K_{design} \times T_{routing}}{12 \, in/ft}, d_p\right]$$ (Equation 6-25)

Where:

$d_{filtered}$ = depth of water that may be considered to be filtered during the design storm event (ft) for routing calculations; this value should not exceed the surface ponding depth (d_p)

K_{design} = design saturated hydraulic conductivity (in/hr) (see Step 2, above)

$T_{routing}$ = storm duration that may be assumed for routing calculations; this should be assumed to be 3 hours unless rationale for an alternative assumption is provided

d_p = selected surface ponding water depth (ft)

The intention is that routing is important in the appropriate sizing of bioretention with underdrains. However, the depth of water considered to be filtered during the storm should be limited to the maximum ponding depth. This *results in designs that are robust to account for a variety of storm depths and durations. This limitation is for sizing calculations only. In reality, the depth that is filtered during a storm will vary based on storm depth, duration, and intensity. This TGM does not intend to limit the amount that may actually be filtered.*

4) Calculate required infiltrating surface area (filter bottom area):

$$A_{req} = \frac{SQDV}{d_p + d_{filtered}}$$ (Equation 6-26)

Where:

A_{req}	=	required infiltrating area (ft^2). Should be calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility)
$SQDV$	=	stormwater quality design volume (ft^3)
d_p	=	selected surface ponding water depth (ft)
$d_{filtered}$	=	depth of water that can be considered to be filtered during the design storm event (ft) for routing calculations (See Equation 6-15)

5) Calculate total footprint required by including a buffer for side slopes and freeboard; A_{req} is calculated at the contour corresponding to the mid ponding depth (i.e., $0.5 \times d_p$ from the bottom of the facility).

Geometry

1) Minimum planting soil depth should be 2 feet, although 3 feet is preferred.

The intention is that the minimum planting soil depth should provide a beneficial root zone for the chosen plant palette and adequate water storage for the stormwater quality design volume. A deeper soil depth will provide a smaller surface area footprint.

2) Bioretention should be designed to drain below the planting soil in less than 72 hours and completely drain from the underdrain in 96 hours (both starting from the end of inflow).

The intention is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate soil oxygen levels for healthy soil biota and vegetation, and to provide proper soil conditions for biodegradation and retention of pollutants.

Flow Entrance and Energy Dissipation

The following types of flow entrance can be used for bioretention cells:

1) Dispersed, low velocity flow across a landscape area. Dispersed flow may not be possible given space limitations or if the facility is controlling roadway or parking lot flows where curbs are mandatory.

2) Dispersed flow across pavement or gravel and past wheel stops for parking areas.

3) Curb cuts for roadside or parking lot areas: Curb cuts should include rock or other erosion protection material in the channel entrance to dissipate energy. Flow entrance should drop 2 to 3 inches from curb line and provide an area for settling and periodic removal of sediment and coarse material before flow dissipates to the remainder of the cell.

4) Pipe flow entrance: Piped entrances, such as roof downspouts, should include rock, splash blocks, or other appropriate measures at the entrance to dissipate energy and disperse flows.

5) Woody plants (trees, shrubs, etc.) can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path.

Underdrains

Underdrains should meet the following criteria:

1) 6-inch minimum diameter.

2) Underdrains should be made of slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent). *The intention is that compared to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

3) Slotted pipe should have 2 to 4 rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inches and should have a length of 1 to 1.25 inches. Slots should be longitudinally spaced such that the pipe has a minimum of one square inch of slot per lineal foot of pipe and should be placed with slots facing the bottom of the pipe.

4) Underdrains should be sloped at a minimum of 0.5%.

5) Rigid non-perforated observation pipes with a diameter equal to the underdrain diameter should be connected to the underdrain every 100 feet to provide a clean-out port as well as an observation well to monitor dewatering rates. The wells/cleanouts should be connected to the perforated underdrain with the appropriate manufactured connections. The wells/cleanouts should extend 6 inches above the top

elevation of the bioretention facility mulch, and should be capped with a lockable screw cap. The ends of the underdrain pipes not terminating in an observation well/cleanout should also be capped.

6) The following aggregate should be used to provide a gravel blanket and bedding for the underdrain pipe. Place the underdrain on a bed of washed aggregate at a minimum thickness of 6 inches and cover it with the same aggregate to provide a 1 foot minimum depth around the top and sides of the slotted pipe.

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

7) At the option of the designer/geotechnical engineer, a geotextile fabric may be placed between the planting media and the drain rock. If a geotextile fabric is used, it should meet a minimum permittivity rate of 75 gal/min/ft^2, should not impede the infiltration rate of the soil medium, and should meet the following minimum materials requirements.

Geotextile Property	Value	Test Method
Trapezoidal Tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

Preferably, aggregate should be used in place of filter fabric to reduce the potential for clogging. This aggregate layer should consist of 2 to 4 inches of washed sand underlain with 2 inches of choking stone (Typically #8 or #89 washed).

8) For bioretention facilities enhanced to remove address nitrogen as the primary pollutant class, the underdrain should be elevated from the bottom of the bioretention facility by at least 6 inches within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. *The intention is that denitrification within the anaerobic/anoxic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration.*

An alternative enhanced nitrogen removal design is to include an internal water storage layer by adding a 90-degree elbow to the underdrain to raise the outlet. This design feature provides additional storage in the media. The bioretention facility must have at least 30 inches of planting media. The top of the elbow should be at least 12 inches below the top of the planting media, and in poorly draining soils, should preferably be 18 to 24 inches below the top of the planting media. The top of the water storage layer should not be less than 12 inches from the bottom of the planting media layer. (For more information, see Urban Waterways publication).

9) The underdrain should drain freely to an acceptable discharge point. The underdrain can be connected to a d ownstream open conveyance (vegetated swale), to another bioretention cell as part of a connected treatment system, to a storm drain, daylight to a vegetated dispersion area using an effective flow dispersion device, or to a storage facility for rainwater harvesting.

Overflow

An overflow device is required at the maximum ponding depth. The following, or equivalent, should be provided:

1) A vertical PVC pipe (SDR 35) should be connected to the underdrain.

2) The overflow riser(s) should be 6 inches or greater in diameter, so it can be cleaned without damage to the pipe. The vertical pipe will provide access to cleaning the underdrains.

3) The inlet to the riser should be at the ponding depth (maximum 18 inches for fenced bioretention areas and 6 inches for areas that are not fenced), and be capped with a spider cap to exclude floating mulch and debris. Spider caps should be screwed in or glued (i.e., not removable).

Hydraulic Restriction Layers

Infiltration pathways may need to be restricted due to the close proximity of roads, foundations, or other infrastructure. A geomembrane liner, or other equivalent water proofing, may be placed along the vertical walls to reduce lateral flows. This liner should have a minimum thickness of 30 mils.

Planting/Storage Media

1) The planting media placed in the cell should achieve a long-term, in-place infiltration rate of at least 1 inch per hour. Higher infiltration rates are permissible. If the design long-term, in-place infiltration rate of the soil exceeds 12 inches per hour, documentation should be provided to demonstrate that the media will adequately address pollutants of concern at a higher flowrate. Bioretention soil shall also support vigorous plant growth.

2) Planting media should consist of 60 to 80% fine sand and 20 to 40% compost.

3) Sand should be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for bioretention should be analyzed by an accredited lab using

#200, #100, #40, #30, #16, #8, #4, and 3/8 sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation (Note: all sands complying with ASTM C33 for fine aggregate comply with the gradation requirements below):

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
3/8 inch	100	100
#4	90	100
#8	70	100
#16	40	95
#30	15	70
#40	5	55
#100	0	15
#200	0	5

Note: the gradation of the sand component of the media is believed to be a major factor in the hydraulic conductivity of the media mix. If the desired hydraulic conductivity of the media cannot be achieved within the specified proportions of sand and compost (#2), then it may be necessary to utilize sand at the coarser end of the range specified in above ("minimum" column).

4) Compost should be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes, or other organic materials not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program). Compost quality should be verified via a lab analysis to be:

- Feedstock materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.
- Organic matter: 35-75% dry weight basis.
- Carbon and Nitrogen Ratio: 15:1 < C:N < 25:1
- Maturity/Stability: shall have dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120 F) upon delivery or rewetting is not acceptable.
- Toxicity: any one of the following measures is sufficient to indicate non-toxicity:
    - $NH_4:NH_3 < 3$
    - Ammonium < 500 ppm, dry weight basis

- Seed Germination > 80% of control
- Plant trials > 80% of control
- Solvita® > 5 index value
- Nutrient content:
  - Total Nitrogen content 0.9% or above preferred
  - Total Boron should be <80 ppm, soluble boron < 2.5 ppm
- Salinity: < 6.0 mmhos/cm
- pH between 6.5 and 8 (may vary with plant palette)

Compost for bioretention should be analyzed by an accredited lab using #200, ¼ inch, ½ inch, and 1 inch sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation:

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
1 inch	99	100
½ inch	90	100
¼ inch	40	90
#200	2	10

Tests should be sufficiently recent to represent the actual material that is anticipated to be delivered to the site. If processes or sources used by the supplier have changed significantly since the most recent testing, new tests should be requested.

Note: the gradation of compost used in bioretention media is believed to play an important role in the saturated hydraulic conductivity of the media. To achieve a higher saturated hydraulic conductivity, it may be necessary to utilize compost at the coarser end of this range ("minimum" column). The percent passing the #200 sieve (fines) is believed to be the most important factor in hydraulic conductivity.

In addition, a coarser compost mix provides more heterogeneity of the bioretention media, which is believed to be advantageous for more rapid development of soil structure needed to support health biological processes. This may be an advantage for plant establishment with lower nutrient and water input.

5) The bioretention area should be covered with 2 to 4 inches (average 3 inches) of mulch at the start and an additional placement of 1 to 2 inches of mulch should be added annually. *The intention is that to help sustain the nutrient levels, suppress weeds, retain moisture, and maintain infiltration capacity.*

Plants

Plant materials should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 96 hours.

It is recommended that a minimum of three types of tree, shrubs, and/or herbaceous groundcover species be incorporated to protect against facility failure due to disease and insect infestations of a single species.

Native plant species and/or hardy cultivars that are not invasive and do not require chemical inputs should be used to the maximum extent practicable.

Operations and Maintenance

Bioretention areas require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, bioretention maintenance requirements are typical landscape care procedures and include:

1) Watering: Plants should be selected to be drought-tolerant and not require watering after establishment (2 to 3 years). Watering may be required during prolonged dry periods after plants are established.

2) Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred (see Appendix I for a bioretention inspection and maintenance checklist). Properly designed facilities with appropriate flow velocities should not have erosion problems except perhaps in extreme events. If erosion problems occur, the following should be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the pretreatment area and flow entrance. If sediment is deposited in the bioretention area, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.

3) Plant material: Depending on aesthetic requirements, occasional pruning and removing of dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants have been excluded.

4) Nutrient and pesticides: The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the bioretention area, as well as contribute pollutant loads to receiving waters. By design, bioretention facilities are located in areas where phosphorous and nitrogen levels are often

elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

5) Mulch: Replace mulch annually in bioretention facilities where high trash, sediment load, and heavy metal deposition is likely (e.g., heavy metal contributing areas include industrial and auto dealer/repair parking lots and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.

6) Soil: Soil mixes for bioretention facilities are designed to maintain long-term fertility and pollutant processing capability. Replacing mulch in bioretention facilities where high trash, sediment load, and heavy metal deposition are likely provides an additional level of protection for prolonged performance. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in bioretention systems. However, the saturated hydraulic conductivity should be assessed at least annually to ensure that the design water quality event is being treated. If in question, have soil analyzed for fertility and pollutant levels.

BIO-2: Planter Box

Planter boxes are bioretention treatment control measures that are completely contained within an i mpermeable structure with an underdrain (they do not infiltrate). These facilities function as a soil and plant based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. The facilities normally consist of a ponding area, mulch layer, planting soils, plantings, and an underdrain within the planter box. As stormwater passes down through the planting soil, pollutants are filtered, adsorbed, and biodegraded by the soil and plants. Planter boxes are comprised of a variety of materials, usually chosen to be the same material as the adjacent building or sidewalk.

Planter boxes may be placed adjacent to or near buildings, other structures, or sidewalks. Planter boxes can be used directly adjacent to buildings beneath downspouts as long as the boxes are properly lined on the building side and the overflow outlet discharges away from the building to ensure water does not percolate into footings or foundations. They can also be placed further away from buildings by conveying roof runoff in shallow engineered open conveyances, shallow pipes, or other innovative drainage structures.

Planter boxes extending along a building wall

Photo Credit: Geosyntec Consultants

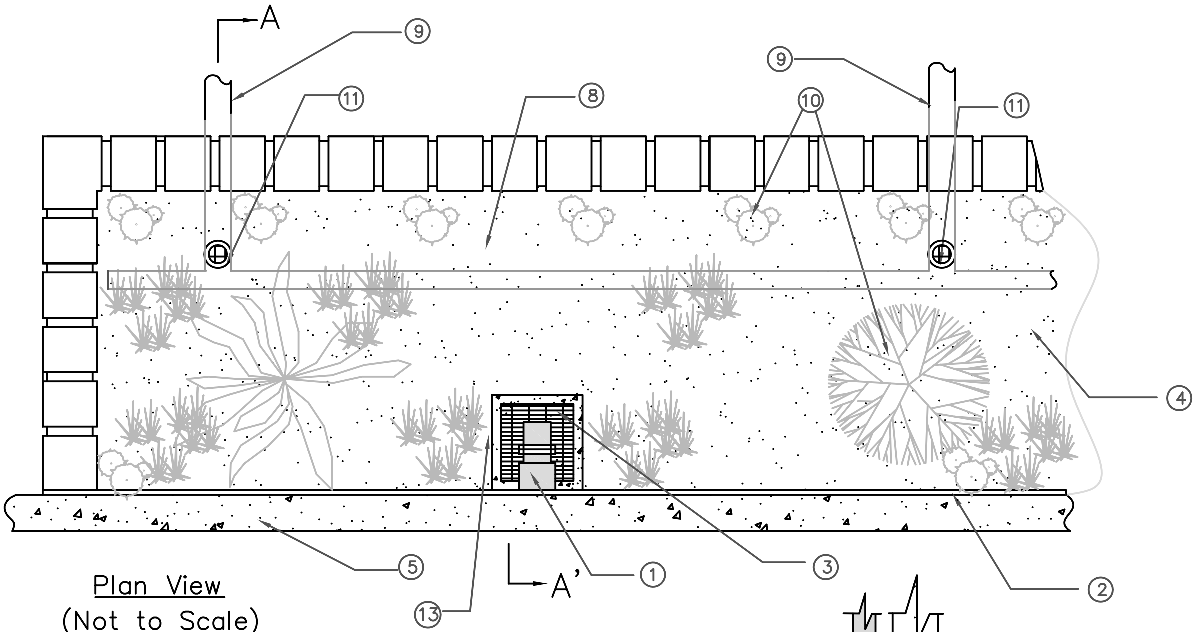
Application

- Areas adjacent to buildings and sidewalks
- Building entrances, courtyards, and walkways

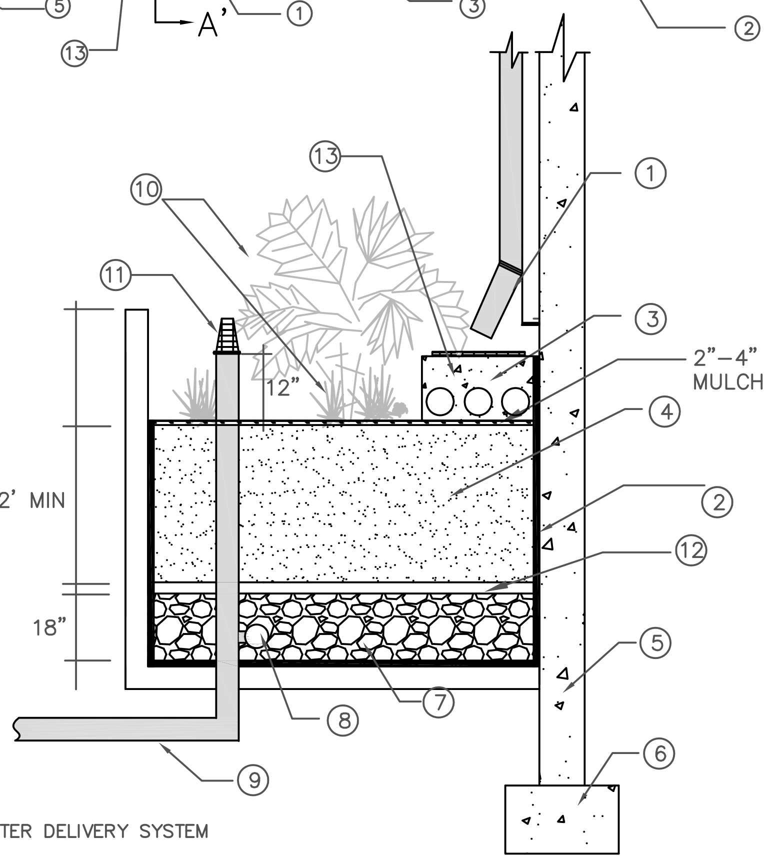
Preventative Maintenance

- Repair small eroded areas
- Remove trash and debris and rake surface soils
- Remove accumulated fine sediments, dead leaves, and trash
- Remove weeds and prune back excess plant growth
- Remove sediment and debris accumulation near inlet and outlet structures

Periodically observe function under wet weather conditions



Plan View
(Not to Scale)



Section A – A'
(Not to Scale)

NOTES:

1. ROOF DOWNSPOUT OR OTHER STORMWATER DELIVERY SYSTEM
2. WATERPROOF BARRIER
3. SHALLOW ENERGY DISSIPATOR BASIN DISPERSES FLOW AT SOIL SURFACE
4. SOIL MIX (SEE PLANTING MEDIA SECTION)
5. BUILDING
6. FOUNDATION. INSTALL FOUNDATION DRAINS AS NEEDED
7. GRAVEL BEDDING (SEE UNDERDRAIN)
8. PERFORATED PIPE SHALL RUN ENTIRE LENGTH OF PLANTER
9. CONNECTION TO DOWNSTREAM CONVEYANCE SYSTEM
10. PLANTS
11. SET OVERFLOW 2" BELOW THE TOP OF THE PLANTER
12. OPTIONAL CHOKING GRAVEL LAYER

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Figure 6-11: Planter Box

Limitations

The applicability of stormwater planter boxes is limited by the following site characteristics:

1) The tributary area (area draining to the planter box area) should be less than 15,000 ft^2.

2) Groundwater levels should be at least 2 ft lower than the bottom of the planter box.

3) Site must have adequate vertical relief between land surface and the stormwater conveyance system to permit connection of the underdrain to the stormwater conveyance system.

4) Planter boxes should not be located in areas with excessive shade to avoid poor vegetative growth. For moderately shaded areas, shade tolerant plants should be used.

Design Criteria

Planter boxes should be designed according to the requirements listed in Table 6-19 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-19: Planter Box Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Drawdown time of planting soil	hours	12
Maximum ponding depth	inches	12
Minimum soil depth	feet	2; 3 preferred
Stabilized mulch depth	inches	2 to 3
Planting soil composition	-	60 to 70% sand, 30 to 40% compost
Underdrain	-	6 inch minimum diameter; 0.5% minimum slope; slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent)
Overflow device	-	Required

Sizing Criteria

See Sizing Criteria section in the BIO-1: Bioretention with underdrains fact sheet.

Geometry and Size

1) Planter boxes areas should be sized to capture and treat the SQDV with a 12 inch maximum ponding depth. The mulch layer should be included as part of the ponding depth.

2) Minimum soil depth should be 2 feet, although 3 feet is preferred. *The intention is that a minimum soil depth should provide a beneficial root zone for the chosen plant palette and adequate water storage for the SQDV. A deeper planting soil depth will provide a smaller surface area footprint.*

3) Planter boxes should be designed to drain to below the planting soil depth in less than 48 hours. *The intention is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, prevent long periods of saturation for plant health, maintain adequate soil oxygen levels for healthy soil biota and vegetation, reduce potential for vector breeding, and provide proper soil conditions for biodegradation and retention of pollutants.*

4) Any planter box shape configuration is possible as long as other design criteria are met.

5) The distance between the downspouts and the overflow outlet should be maximized. *The intention is to increase the opportunity for stormwater retention and filtration.*

6) Off-line configurations should be considered to minimize the possibility of scouring and resuspension of previously captured pollutants during large storms.

Structural Materials

1) Planter boxes should be constructed out of stone, concrete, brick, recycled plastic, or other permanent materials. Pressure-treated wood or other materials that may leach pollutants (e.g., arsenic, copper, zinc, etc.) should not be allowed.

2) The structure should be adequately sealed or a waterproof membrane installed to ensure water only exits the structure via the underdrain.

Flow Entrance and Energy Dissipation

The following types of flow entrance can be used for planter boxes:

1) Pipe flow entrance: Piped entrances, such as roof downspouts, should include rock, splash blocks, or other appropriate measures at the entrance to dissipate energy and disperse flows.

2) Woody plants (e.g., trees, shrubs, etc.) can restrict or concentrate flows and can be damaged by erosion around the root ball and should not be placed directly in the entrance flow path.

Underdrains

Underdrains are required and should meet the following criteria:

1) 6-inch minimum diameter.

2) Underdrains should be made of slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent). *The intention is that in comparison to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

3) Slotted pipe should have 2 to 4 rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inch and should have a length of 1 to 1.25 inches. Slots should be longitudinally spaced such that the pipe has a minimum of one square inch opening per lineal foot and should face down.

4) Underdrains should be sloped at a minimum of 0.5%.

5) Rigid non-perforated observation pipes with a diameter equal to the underdrain diameter should be connected to the underdrain every 100 feet to provide a clean-out port as well as an observation well to monitor dewatering rates. The wells/cleanouts should be connected to the perforated underdrain with the appropriate manufactured connections. The wells/cleanouts should extend 6 inches above the top elevation of the bioretention facility mulch, and should be capped with a lockable screw cap. The ends of underdrain pipes not terminating in an observation well/cleanout should also be capped.

6) The following aggregate should be used to provide a gravel blanket and bedding for the underdrain pipe. Place the underdrain on a bed of washed aggregate at a minimum thickness of 6 inches and cover it with the same aggregate to provide a 1 foot minimum depth around the top and sides of the slotted pipe.

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

7) At the option of the designer/geotechnical engineer, a geotextile fabric may be placed between the planting media and the drain rock. If a geotextile fabric is used, it should

meet a minimum permittivity rate of 75 $gal/min/ft^2$, should not impede the infiltration rate of the soil medium, and should meet the following minimum materials requirements.

Geotextile Property	Value	Test Method
Trapezoidal Tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

Preferably, aggregate should be used in place of filter fabric to reduce the potential for clogging. This aggregate layer should consist of 2 to 4 inches of washed sand underlain with 2 inches of choking stone (Typically #8 or #89 washed).

8) The underdrain should be elevated from the bottom of the bioretention facility by 6 inches within the gravel blanket to create a fluctuating anaerobic/aerobic zone below the drain pipe. *The intention is that denitrification within the anaerobic/anoxic zone is facilitated by microbes using forms of nitrogen (NO_2 and NO_3) instead of oxygen for respiration.*

9) The underdrain must drain freely to an acceptable discharge point. The underdrain can be connected to a downstream open conveyance (vegetated swale), to another bioretention cell as part of a connected treatment system, to a storm drain, daylight to a vegetated dispersion area using an effective flow dispersion device, or to a storage facility for rainwater harvesting.

Overflow

An overflow device is required to be set at 2 inches below the top of the planter and no more than 12 inches above the soil surface. The most common option is a vertical riser, described below.

Vertical riser

1) A vertical PVC pipe (SDR 35) should be connected to the underdrain.

2) The overflow riser(s) should be 6 inches or greater in diameter, so it can be cleaned without damage to the pipe. The vertical pipe will provide access to cleaning the underdrains.

3) The inlet to the riser should be a maximum of 12 inches above the planting soil, and be capped with a spider cap. Spider caps should be screwed in or glued (i.e., not removable).

Hydraulic Restriction Layers

A waterproof barrier should be provided to restrict moisture away from foundations. Geomembrane liners should have a m inimum thickness of 30 mils. Equivalent waterproofing measures may be used.

Planting/Storage Media

1) The planting media placed in the cell should achieve a long-term, in-place infiltration rate of at least 1 inch per hour. Higher infiltration rates are permissible. If the design long-term, in-place infiltration rate of the soil exceeds 12 inches per hour, documentation should be provided to demonstrate that the media will adequately address pollutants of concern at a higher flowrate. Planter box soil shall also support vigorous plant growth.

2) Planting media should consist of 60 to 80% fine sand and 20 to 40% compost.

3) Sand should be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size should be non-plastic. Sand for the planter box should be analyzed by an ac credited lab using #200, #100, #40, #30, #16, #8, #4, and 3/8 sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation (Note: all sands complying with ASTM C33 for fine aggregate comply with the gradation requirements below):

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
3/8 inch	100	100
#4	90	100
#8	70	100
#16	40	95
#30	15	70
#40	5	55
#100	0	15
#200	0	5

Note: the gradation of the sand component of the media is believed to be a major factor in the hydraulic conductivity of the media mix. If the desired hydraulic conductivity of the media cannot be achieved within the specified proportions of sand and compost (#2), then it may be necessary to utilize sand at the coarser end of the range specified in above ("minimum" column).

4) Compost should be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes, or other organic materials not including manure or biosolids meeting standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal

of Testing Assurance (STA) Program (a compost testing and information disclosure program). Compost quality should be verified via a lab analysis to be:

- Feedstock materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.
- Organic matter: 35-75% dry weight basis.
- Carbon and Nitrogen Ratio: 15:1 < C:N < 25:1
- Maturity/Stability: shall have dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120 F) upon delivery or rewetting is not acceptable.
- Toxicity: any one of the following measures is sufficient to indicate non-toxicity:
  - NH4:NH3 < 3
  - Ammonium < 500 ppm, dry weight basis
  - Seed Germination > 80% of control
  - Plant trials > 80% of control
  - Solvita® > 5 index value
- Nutrient content:
  - Total Nitrogen content 0.9% or above preferred
  - Total Boron should be <80 ppm, soluble boron < 2.5 ppm
- Salinity: < 6.0 mmhos/cm
- pH between 6.5 and 8 (may vary with plant palette)

Compost for planter box should be analyzed by an ac credited lab using #200, ¼ inch, ½ inch, and 1 inch sieves (ASTM D 422 or as approved by the local permitting authority) and meet the following gradation:

Sieve Size (ASTM D422)	% Passing (by weight)	
	Minimum	Maximum
1 inch	99	100
½ inch	90	100
¼ inch	40	90
#200	2	10

Tests should be sufficiently recent to represent the actual material that is anticipated to be delivered to the site. If processes or sources used by the supplier have changed significantly since the most recent testing, new tests should be requested.

Note: the gradation of compost used in planter box media is believed to play an important role in the saturated hydraulic conductivity of the media. To achieve a higher saturated hydraulic conductivity, it may be necessary to utilize compost at the coarser end of this range ("minimum" column). The percent passing the #200 sieve (fines) is believed to be the most important factor in hydraulic conductivity.

In addition, a coarser compost mix provides more heterogeneity of the planter box media, which is believed to be advantageous for more rapid development of soil structure needed to support health biological processes. This may be an advantage for plant establishment with lower nutrient and water input.

5) The planter box should be covered with 2 to 4 inches (average 3 inches) of mulch at the start and an ad ditional placement of 1 to 2 inches of mulch should be added annually. *The intention is that to help sustain the nutrient levels, suppress weeds, retain moisture, and maintain infiltration capacity.*

Plants

1) Plant materials should be tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 96 hours.

2) It is recommended that a minimum of three types of tree, shrubs, and/or herbaceous groundcover species be incorporated to protect against facility failure due to disease and insect infestations of a single species.

3) Native plant species and/or hardy cultivars that are not invasive and do not require chemical inputs should be used to the maximum extent practicable.

4) Plants should be selected carefully to minimize maintenance and function properly.

Operations and Maintenance

Planter boxes require annual plant, soil, and mulch layer maintenance to ensure optimum infiltration, storage, and pollutant removal capabilities. In general, planter box maintenance requirements are typical of landscape care procedures and include:

1) Watering: Plants should be selected to be drought-tolerant and do not require watering after establishment (2 to 3 years). Watering may be required during prolonged dry periods after plants are established.

2) Erosion control: Inspect flow entrances, ponding area, and surface overflow areas periodically, and replace soil, plant material, and/or mulch layer in areas if erosion has occurred (see Appendix I for an inspection and maintenance checklist). Properly designed facilities with appropriate flow velocities should not have erosion problems

except perhaps in extreme events. If erosion problems occur, the following should be reassessed: (1) flow velocities and gradients within the cell, and (2) flow dissipation and erosion protection strategies in the flow entrance. If sediment is deposited in the planter box, immediately determine the source within the contributing area, stabilize, and remove excess surface deposits.

3) Plant material: Depending on aesthetic requirements, occasional pruning and removing of dead plant material may be necessary. Replace all dead plants and if specific plants have a high mortality rate, assess the cause and, if necessary, replace with more appropriate species. Periodic weeding is necessary until plants are established. The weeding schedule should become less frequent if the appropriate plant species and planting density have been used and, as a result, undesirable plants have been excluded.

4) Nutrients and pesticides: The soil mix and plants are selected for optimum fertility, plant establishment, and growth. Nutrient and pesticide inputs should not be required and may degrade the pollutant processing capability of the planter box area, as well as contribute pollutant loads to receiving waters. By design, planter boxes are located in areas where phosphorous and nitrogen levels are often elevated and these should not be limiting nutrients. If in question, have soil analyzed for fertility.

5) Mulch: Replace mulch annually in planter boxes where high trash, sediment load, and heavy metal deposition is likely (e.g., heavy metal contributing areas include industrial, auto dealer/repair, parking lots, and roads). In residential lots or other areas where metal deposition is not a concern, replace or add mulch as needed to maintain a 2 to 3 inch depth at least once every two years.

6) Soil: Soil mixes for planter boxes are designed to maintain long-term fertility and pollutant processing capability. Replacing mulch in planter boxes where high trash, sediment load, and heavy metal deposition are likely provides an additional level of protection for prolonged performance. Estimates from metal attenuation research suggest that metal accumulation should not present an environmental concern for at least 20 years in planter boxes. However, the saturated hydraulic conductivity should be assessed at least annually to ensure that the design water quality event is being treated. If in question, have soil analyzed for fertility and pollutant levels.

BIO-3: Vegetated Swale

Vegetated swales are open, shallow channels with low-lying vegetation covering the side slopes and bottom that collect and slowly convey runoff to downstream discharge points. Vegetated swales provide pollutant removal through settling and filtration in the vegetation (usually grasses) lining the channels, provide the opportunity for stormwater volume reduction through infiltration and evapotranspiration, reduce the flow velocity, and conveying stormwater runoff. An effective vegetated swale achieves uniform sheet flow through a densely vegetated area for a period of several minutes. The vegetation in the swale can vary depending on its location and is the choice of the designer, depending on the design criteria outlined in this section.

Vegetated swale captures flow from a residential street

Photo Credit: Geosyntec Consultants

Application

- Open areas adjacent to parking lots
- Open spaces adjacent to athletic fields
- Roadway medians and shoulders

Preventative Maintenance

- Remove excess sediment, trash, and debris
- Clean and reset flow spreaders
- Mow regularly
- Remove sediment and debris build-up near inlets and outlets
- Repair minor erosion and scouring

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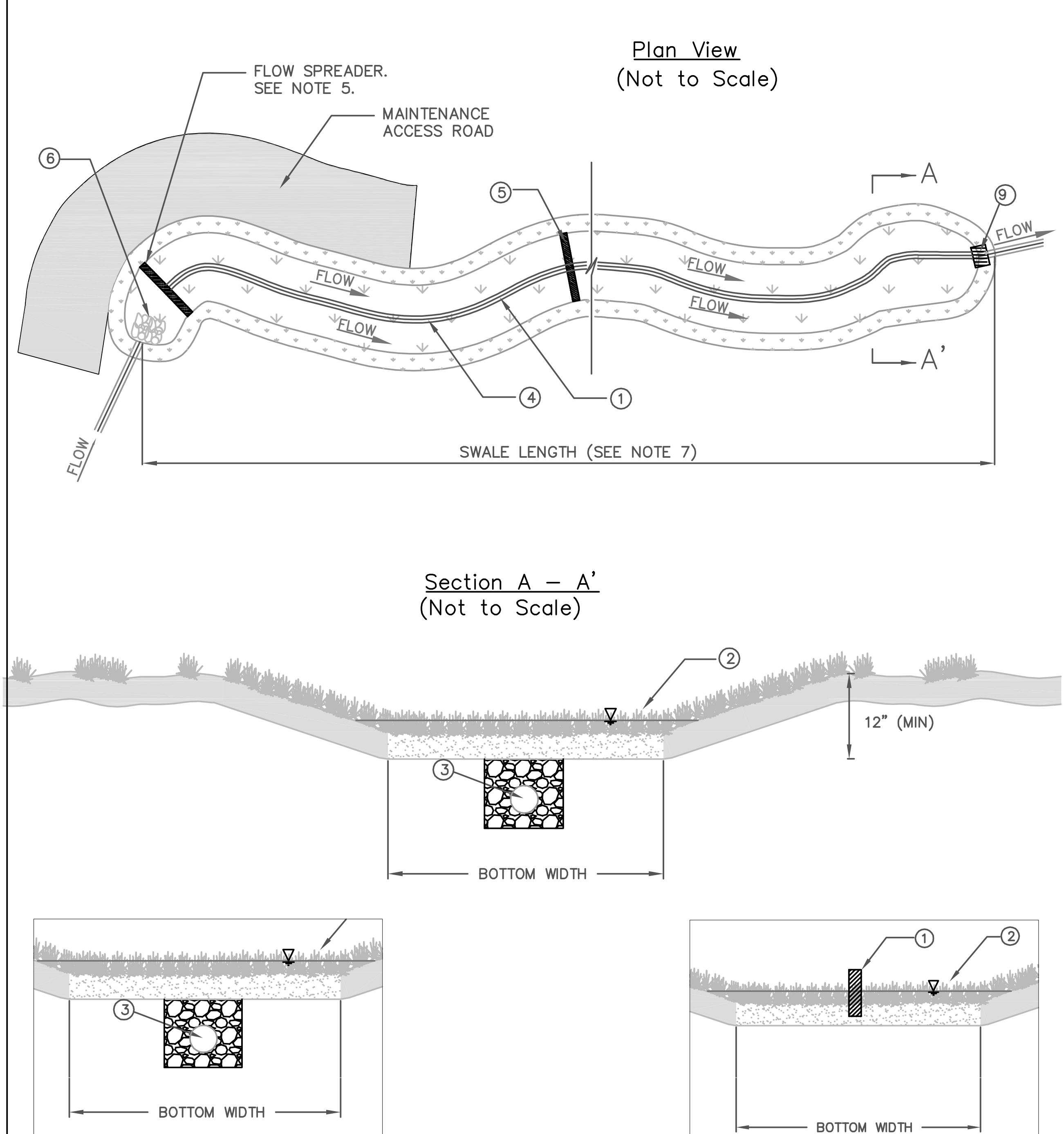

NOTES:

① SWALE DIVIDER REQUIRED FOR BOTTOM WIDTHS > 10'. MINIMUM REQUIRED BOTTOM WIDTH IS 2' EXCLUDING WIDTH OF LOW FLOW CHANNEL. MAXIMUM BOTTOM WIDTH WITH DIVIDER IS 16'.

② DEPTH OF FLOW FOR WATER QUALITY TREATMENT MUST NOT EXCEED TWO–THIRDS OF VEGETATION HEIGHT OR NOT GREATER THAN 2" FOR FREQUENTLY MOWED TURF.

③ IF AN UNDERDRAIN IS REQUIRED, IT MUST CONSIST OF AN AT LEAST 6" DIAMETER PERFORATED PIPE IN COARSE AGGREGATE BED CONNECTED TO STORM DRAIN. GRAVEL BED MUST EXTEND 6" BELOW AND 12" TO THE SIDE AND TOP OF THE PIPE.

④ IF NO UNDERDRAIN, LOW FLOW DRAIN SHALL EXTEND ENTIRE LENGTH OF SWALE AND SHALL HAVE A DEPTH OF 6" MINIMUM AND WIDTH NO MORE THAN 5% SWALE BOTTOM WIDTH. ANCHORED PLATE FLOW SPREADER IF USED, SHALL HAVE V–NOTCHES (MAX TOP WIDTH = 5% OF SWALE WIDTH) OR HOLES TO ALLOW PREFERENTIAL EXIT OF LOW FLOWS.

⑤ INSTALL CHECK DAMS OR GRADE CONTROL STRUCTURES FOR SLOPES > 2% AT 50' MAXIMUM SPACING TO ACHIEVE A MAXIMUM EFFECTIVE LONGITUDINAL SLOPE OF 2%. FLOW SPREADERS SHALL BE PROVIDED AT INLET AND AT THE BASE OF EACH CHECK DAM.

⑥ INSTALL ENERGY DISSIPATOR AT THE INLET OF VEGETATED SWALE.

⑦ SWALE LENGTH SHALL LENGTH REQUIRED TO PROVIDE 7 MINUTES RESIDENCE TIME.

⑧ INSTALL APPROPRIATE OUTLET STRUCTURE. ACCOMODATE LOW FLOW CHANNEL AND/OR UNDERDRAIN (IF PRESENT).

⑨ AMEND SOILS WITH 2" OF COMPOST TILLED INTO 6" OF NATIVE SOIL UNLESS NATIVE SOIL ORGANIC CONTENT > 10%.

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Figure 6-12: Vegetated Swale

Limitations

1) Compatibility with flood control - swales should not interfere with flood control functions of existing conveyance and detention structures.
2) Vegetation - select vegetation appropriately based on irrigation requirements and exposure (shady versus sunny areas). A thick vegetative cover is needed for vegetated swales to function properly. Native and drought tolerant plants are recommended.
3) Drainage area - each vegetated swale can treat a relatively small drainage area. Large areas should be divided and treated using multiple swales.

Design Criteria

Vegetated swales should be designed according to the requirements listed in Table 6-20 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-20: Vegetated Swale Filter Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design flow rate (SQDF)	cfs	See Section 2 and Appendix E for calculating SQDF.
Swale Geometry	-	Trapezoidal
Minimum bottom width	feet	2
Maximum bottom width	feet	10; if greater than 10 must use swale dividers; with dividers, max is 16
Minimum length	feet	sufficient length to provide minimum contact time
Minimum slope in flow direction	%	0.2 (provide underdrains for slopes less < 0.5%)
Maximum slope in flow direction	%	2.0 (provide grade-control checks for slopes > 2.0)
Maximum flow velocity	ft/sec	1.0 (water quality treatment); 3.0 (flood conveyance)
Maximum depth of flow for water quality treatment	inches	3 to 5 (1 inch below top of grass)
Minimum residence (contact) time	minutes	7 (provide sufficient length to yield minimum residence time)
Vegetation type	--	Varies (see vegetation section below); Native and drought tolerant plants are recommended
Vegetation height	inches	4 to 6 (trim or mow to maintain height)

Sizing Criteria

The flow capacity of a vegetated swale is a function of the longitudinal slope (parallel to flow), the resistance to flow (i.e. Manning's roughness), and the cross sectional area. The cross section is normally approximately trapezoidal and the area is a function of the bottom width and side slopes. The flow capacity of vegetated swales should be such that the SQDF will not exceed a flow depth of 2/3 the height of the vegetation within the swale or 4 inches at the SQDF. Once design criteria have been selected, the resulting flow depth for the SQDF is checked. If the depth restriction is exceeded, swale parameters (e.g. longitudinal slope, width) are adjusted to reduce the flow depth.

Procedures for sizing vegetated swales are summarized below. A vegetated swale sizing worksheet and example are also provided.

Step 1: Select design flows

The swale sizing is based on the SQDF (see Section 2 and Appendix E).

Step 2: Calculate swale bottom width

The swale bottom width (b) is calculated based on Manning's equation for open-channel flow. This equation can be used to calculate discharges (Q) as follows:

$$Q = \frac{1.49AR^{0.67}S^{0.5}}{n} \qquad \text{(Equation 6-27)}$$

Where:

Q	=	flow rate (cfs)
n	=	Manning's roughness coefficient (unitless)
A	=	cross-sectional area of flow (ft2)
R	=	hydraulic radius (ft) = area divided by wetted perimeter
S	=	longitudinal slope (ft/ft)

For shallow flow depths in swales, channel side slopes are ignored in the calculation of bottom width. Use the following equation (a simplified form of Manning's formula) to estimate the swale bottom width (b):

$$b = \frac{SQDF * n_{wq}}{1.49y^{0.67}s^{0.5}} \qquad \text{(Equation 6-28)}$$

Where:

b	=	bottom width of swale (ft)

$SQDF$	=	stormwater quality design flow (cfs)
n_{wq}	=	Manning's roughness coefficient for shallow flow conditions = 0.2 (unitless)
y	=	design flow depth (ft)
s	=	longitudinal slope (along direction of flow) (ft/ft)

Proceed to Step 3 if the bottom width is calculated to be between 2 and 10 feet. A minimum 2-foot bottom width is required. Therefore, if the calculated bottom width is less than 2 feet, increase the width to 2 feet and recalculate the design flow depth y using the Equation 6-18, where $SQDF$, n_{wq}, and s are the same values as used above, but b = 2 feet.

The maximum allowable bottom width is 10 feet. Therefore, if the calculated bottom width exceeds 10 feet, then one of the following steps is necessary to reduce the design bottom width:

1) Increase the longitudinal slope (s) to a maximum of 2 feet in 100 feet (0.02 feet per foot).
2) Increase the design flow depth (y) to a maximum of 4 inches.
3) Place a divider lengthwise along the swale bottom (Figure 6-11) at least three-quarters of the swale length (beginning at the inlet), without compromising the design flow depth and swale lateral slope requirements. The swale width can be increased to an absolute maximum of 16 feet if a divider is provided.

Step 3: Determine design flow velocity

To calculate the design flow velocity (V_{wq}) through the swale, use the flow continuity equation:

$$V_{wq} = SQDF/A_{wq} \qquad \text{(Equation 6-29)}$$

Where:

V_{wq}	=	design flow velocity (fps)
$SQDF$	=	stormwater quality design flow (cfs)
A_{wq}	=	$by + Zy^2$ = cross-sectional area (ft^2) of flow at design depth, where Z = side slope length per unit height (e.g., Z = 3 if side slopes are 3H:1V)

If the design flow velocity exceeds 1 foot per second, go back to Step 2 and modify one or more of the design parameters (longitudinal slope, bottom width, or flow depth) to reduce the design flow velocity to 1 foot per second or less. If the design flow velocity is calculated to be less than 1 foot per second, proceed to Step 4. *Note: It is desirable to have the design velocity as low as possible, both to improve treatment effectiveness and to reduce swale length requirements.*

Step 4: Calculate swale length

Use the following equation to determine the necessary swale length (L) to achieve a hydraulic residence time of at least 7 minutes:

$$L = 60 t_{hr} V_{wq} \quad \text{(Equation 6-30)}$$

Where:

L	=	minimum allowable swale length (ft)
t_{hr}	=	hydraulic residence time (min)
V_{wq}	=	design flow velocity (fps), calculated by Equation 6-19

If there is adequate space on the site to accommodate a larger swale, consider using a greater length to increase the hydraulic residence time and improve the swale's pollutant removal capability. If the calculated length is too long for the site, or if it would cause layout problems, such as encroachment into shaded areas, proceed to Step 5 to further modify the layout. If the swale length can be accommodated on the site (meandering may help), proceed to Step 6.

Step 5: Adjust swale layout to fit on site

If the swale length calculated in Step 4 is too long for the site, the length can be reduced (to a minimum of 100 feet) by increasing the bottom width up to a maximum of 16 feet, as long as the 10 minute retention time is retained. However, the length cannot be increased in order to reduce the bottom width because Manning's depth-velocity-flow rate relationships would not be preserved. If the bottom width is increased to greater than 10 feet, a low flow dividing berm is needed to split the swale cross section in half to prevent channelization.

Length can be adjusted by calculating the top area of the swale and providing an equivalent top area with the adjusted dimensions.

1) Calculate the swale treatment top area (A_{top}), based on the swale length calculated in Step 4:

$$A_{top} = (b_i + b_{slope}) L_i \quad \text{(Equation 6-31)}$$

Where:

A_{top} = top area (ft^2) at the design treatment depth

b_i = bottom width (ft), calculated in Step 2 using Equation 6-18

b_{slope} = the additional top width (ft) above the side slope for the design water depth (for 3:1 side slopes and a 4-inch water depth, b_{slope} = 2 feet)

L_i = initial length (ft) calculated in Step 4 using Equation 6-30

2) Use the swale top area and a reduced swale length (L_f) to increase the bottom width, using the following equation:

$$L_f = A_{top} / (b_f + b_{slope}) \quad \text{(Equation 6-32)}$$

Where:

L_f = reduced swale length (ft)

b_f = increased bottom width (ft)

3) Recalculate V_{wq} according to Step 3 using the revised cross-sectional area A_{wq} based on the increased bottom width (b_f). Revise the design as necessary if the design flow velocity exceeds 1 foot per second.

4) Recalculate to ensure that the 10 minute retention time is retained.

Step 6: Provide conveyance capacity for flows higher than SQDF

Vegetated swales may be designed as flow-through channels that convey flows higher than the SQDF, or they may be designed to incorporate a high-flow bypass upstream of the swale inlet. A high-flow bypass usually results in a smaller swale size. If a high-flow bypass is provided, this step is not needed. If no high-flow bypass is provided, proceed with the procedure below. A flow splitter structure design is described in Appendix F.

1) Check the swale size to determine whether the swale can convey the flood control design storm peak flow (Refer to Ventura County Hydrology Manual, revised 2006).

2) The peak flow velocity of the flood control design storm (see Ventura County Hydrology Manual revised 2006) should be less than 3.0 feet per second. If this velocity exceeds 3.0 feet per second, return to Step 2 and increase the bottom width or flatten the longitudinal slope as necessary to reduce the flood control design storm peak flow velocity to 3.0 feet per second or less. If the longitudinal slope is flattened, the swale bottom width must be recalculated (Step 2) and must meet all design criteria.

Geometry and Size

1) In general, a trapezoidal channel shape should be assumed for sizing calculations above, but a more naturalistic channel cross-section is preferred.

2) Swales designed for water quality treatment purposes only are usually fairly shallow, generally less than 1 ft. Therefore, a side slope of 2:1 (H:V) can be used and is acceptable.

3) Swales shall be greater than 100 feet in length. The vegetated swale can be shorter than 100 feet if it is used for pretreatment only (i.e., prior to infiltration). Length can be increased by meandering the swale.

4) The minimum swale bottom width shall be 2 feet to allow for ease of mowing.

5) The maximum swale bottom width shall be limited to 10 feet, unless a swale divider is provided, then the maximum bottom width can be a maximum of 16 feet wide. The swale width is calculated without the swale diving berm. *The intention is that experience shows that when the width exceeds about 10 feet, it is difficult to keep the water from concentrating in low flow channels. It is also difficult to construct the bottom level without sloping to one side. Vegetated swales are best constructed by leveling the bottom after excavating. A single-width pass with a front-end loader produces a better result than a multiple-width pass.*

6) Swales that are required to convey flood flow as well as the SQDF should be sized to convey the flood control design storm and include a provision of freeboard as required by the local approval authority.

7) Gradual meandering bends in the swale are desirable for aesthetic purposes and to promote slower flow.

Bottom Slope

1) The longitudinal slope (along the direction of flow) should be between 1% and 6%.

2) If longitudinal slopes are less than 1.5% and the soils are poorly drained (e.g., silts and clays), then underdrains should be provided. A s oils report to verify soils properties should be provided for swales less than 1.5%.

3) If longitudinal slope exceeds 2%, check dams with vertical drops of 12 inches or less should be provided to achieve a bottom slope of 2% or less between the drop structures.

4) The lateral (horizontal) slope at the bottom of the swale should be zero (flat) to discourage channeling.

Water Depth and Dry Weather Flow Drain

1) Water depth should not exceed 4 inches (or 2/3 of the expected vegetation height), except for frequently mowed turf swales, in which the depth should not exceed 2 inches.

2) The swale length must provide a minimum hydraulic residence time of 7 minutes.

3) A low flow drain should be provided if the potential for dry weather flows exists. The low flow drain should extend the entire length of the swale. The drain should have a minimum depth of 6 inches, and a width no more than 5% of the calculated swale bottom width. The width of the drain should be in addition to the required bottom width. The flow spreader at the swale inlet should have v-notches (maximum top width = 5% of swale width) or holes to allow preferential exit of low flows into the drain, if applicable. If an underdrain or gravel drainage layer is installed as discussed below, the low flow drain should be omitted.

Swale Inflow and Design Capacity

1) Whenever possible, inflow should be directed towards the upstream end of the swale and should, at a minimum, occur evenly over the length of the swale. Swale inflow design should provide for positive drainage into the swale to function on the long-term with minimal maintenance.

2) On-line vegetated swales should be designed to convey flow rates up to the post-development peak stormwater runoff discharge rate (flow rate) for the 100-yr 24-hour storm event, with appropriate freeboard (see Ventura County Hydrology Manual, revised 2006).

3) Off-line vegetated swales should be designed to convey the flow-based SQDF by using a flow diversion structure (e.g., flow splitter) which diverts the SQDF to the off-line vegetated swale designed to handle SQDF. Freeboard for off-line swales is not required, but should be provided if space is available. Flow splitter design specifications are described in Appendix F.

Energy Dissipation

1) Vegetated swales may be designed either on-line or off-line. If the facility is on-line, velocities should be maintained below the maximum design flow velocity of 3 feet per second to prevent scour and resuspension of deposited sediments.

2) The maximum flow velocity under the stormwater quality design flow rate should not exceed 1.0 foot per second. *The intention is that this maximum SQDV promotes settling and keeps vegetation upright.*

3) This velocity limitation combined with a maximum depth of 4 inches and bottom width of 10 feet results in a recommended maximum flow capacity of about 3.3 cfs,

after accounting for the side slopes. The contributory drainage area to each swale is limited so as not to exceed this recommended maximum flow capacity.

4) The maximum flow velocity during the 100-yr 24-hr storm event should not exceed 3.0 foot per second. This can be accomplished by:

   a. Splitting roadside swales near high points in the road so that flows drain in opposite directions, mimicking flow patterns on the road surface.

   b. Limiting tributary areas to long swales by diverting flows throughout the length of the swale at regular intervals, to the downstream stormwater conveyance system.

5) A flow spreader (see "Flow Spreaders" below) should be used at the inlet so that the entrance velocity is quickly dissipated and the flow is uniformly distributed across the whole swale. Energy dissipation controls should be constructed of sound materials such as stones, concrete, or proprietary devices that are rated to withstand the energy of the influent flows.

6) If check dams are used to reduce the longitudinal slope, a flow spreader should be provided at the toe of each vertical drop, with specifications described below.

7) If flow is to be introduced through curb cuts, place pavement approximately one inch above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.

Flow Spreaders

1) An anchored plate flow spreader or similar device should be provided at the inlet to the swale. Equivalent methods for spreading flows evenly throughout the width of the swale are acceptable.

2) The top surface of the flow spreader plate should be level, projecting a minimum of 2 inches above the ground surface of the water quality facility, or v-notched with notches 6 to 10 inches on center and 1 to 4 inches deep (use shallower notches with closer spacing).

3) A flow spreader plate should extend horizontally beyond the bottom width of the facility to prevent water from eroding the side slope. The plate should have a row of horizontal perforations at its base to prevent ponding for long durations. The horizontal extent should be such that the bank is protected for all flows up to the 100-yr 24-hr storm event (on-line swales) or the maximum flow that will enter the water quality facility (off-line swales).

4) Flow spreader plates should be securely fixed in place.

5) Flow spreader plates may be made of either concrete, stainless steel, or other durable material.

6) Anchor posts should be 4-inch square concrete, tubular stainless steel, or other material resistant to decay.

Check Dams

If check dams are required, they can be designed using a number of different materials, including riprap, earthen berms, or removal stop logs. Where vegetated swales parallel urban streets, the check dam can double as a crossing walk so that pedestrians have a pathway from the parked car to the building.

Check dams must be placed as to achieve the desired slope (1 to 6%) at a maximum of 50 feet apart. Check dams should be no higher than 12 inches. If riprap is used, the material should consist of well-graded stone consisting of a mixture of rock sizes. The following is an example of an acceptable gradation:

Particle Size	% Passing
24 inch	100
15 inch	75
9 inch	50
4 inch	10

Underdrains

If underdrains (not to be confused with a dry weather flow drain) are required, then they should meet the following criteria:

1) Underdrains should be made of slotted, polyvinyl chloride (PVC) pipe (PVC SDR 35 or approved equivalent). *The intention is that in comparison to round-hole perforated pipe, slotted underdrains provide greater intake capacity, clog resistant drainage, and reduced entrance velocity into the pipe, thereby reducing the chances of solids migration.*

2) Slotted pipe should have 2 to 4 rows of slots cut perpendicular to the axis of the pipe or at right angles to the pitch of corrugations. Slots should be 0.04 to 0.1 inch and should have a length of 1 to 1.25 inches. Slots should be longitudinally spaced such that the pipe has a minimum of one square inch of opening per linear foot of pipe.

3) Underdrains should be sloped at a minimum of 0.5%.

4) The underdrain pipe should be 6 inches or greater in diameter, so it can be cleaned without damage to the pipe. Clean-out risers with diameters equal to the underdrain pipe should be placed at the terminal ends of the underdrain and can be incorporated into the flow spreader and outlet structure to minimize maintenance obstacles in the swale. Intermediate clean-out risers may also be placed in the check dams or grade control structures. The cleanout risers should be capped with a lockable screw cap.

5) The underdrain should be placed parallel to the swale bottom and backfilled and underbedded with six inches of drain rock. The following coarse aggregate should be used to provide a gravel blanket and bedding for the underdrain pipe to provide a 1 foot minimum depth around the top and sides of the slotted pipe.

Sieve size	Percent Passing
¾ inch	100
¼ inch	30-60
US No. 8	20-50
US No. 50	3-12
US No. 200	0-1

6) At the option of the designer/geotechnical engineer, the drain rock may be wrapped in a geotextile fabric meeting the following minimum materials requirements. If a geotextile fabric is used, it should pass 75 gal/min/ft^2, should not impede the infiltration rate of the soil medium, and should meet the following minimum materials requirements.

Geotextile Property	Value	Test Method
Trapezoidal Tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

Preferably, aggregate should be used in place of geotextile fabric to reduce the potential for clogging. This aggregate layer should consist of 2 to 4 inches of washed sand underlain with 2 inches of choking stone (Typically #8 or #89 washed).

7) The underdrain should drain freely to an acceptable discharge point. The underdrain can be connected to a downstream open conveyance (vegetated swale), to another bioretention cell as part of a connected treatment system, daylight to a vegetated dispersion area using an effective flow dispersion device, stored for rainwater harvesting, or to a storm drain.

Gravel Drainage Layer

To increase volume reduction and if soil conditions allow (infiltration rate > 0.5 in/hr), omit the low flow drain or underdrain and install an appropriately sized gravel drainage layer (typically a washed 57 stone) beneath the swale to achieve desired volume reduction goals. Where slopes are greater than 1%, the gravel drainage layer should be installed in combination with check dams (e.g., drop structures) to slow the flow in the swale and allow for infiltration into the gravel drainage layer and then into the subsurface. The base of the drainage layer should have zero slope. The drawdown time in the gravel drainage layer should not exceed 72 hours. The soil and gravel layers should be separated with a geotextile filter fabric or a thin, 2 to 4 inch layer of pure sand and a thin layer (nominally two inches) of choking stone (such as #8). Sizing of the gravel drainage layer is based on volume reduction requirements.

Swale Divider

1) If a swale divider is used, the divider should be constructed of a firm material that will resist weathering and not erode, such as concrete, plastic, or compacted soil seeded with grass. Treated timber should not be used. Selection of divider material should take into account maintenance activities, such as mowing.

2) The divider should have a minimum height of 1 inch greater than the stormwater quality design water depth.

3) Earthen berms should be no steeper than 2H:1V.

4) Material other than earth should be embedded to a depth sufficient to be stable.

Soils

Swale soils should be amended with 2 inches of compost, unless the organic content is already greater than 10%. The compost should be mixed into the native soils to a depth of 6 inches to prevent soil layering and washout of compost. The compost will contain no sawdust, green or under-composted material, or any other toxic or harmful substance. It should contain no un-sterilized manure, which can lead to high levels of pathogen indictors (coliform bacteria) in the runoff.

Vegetation

Swales must be vegetated in order to provide adequate treatment of runoff via filtration. Vegetation, when chosen and maintained appropriately, also improves the aesthetics of a site. It is important to maximize water contact with vegetation and the soil surface.

1) The swale area should be appropriately vegetated with a mix of erosion-resistant plant species that effectively bind the soil. A diverse selection of low growing plants that thrive under the specific site, climatic, and watering conditions should be specified. A mixture of dry-area and wet-area grass species that can continue to grow through silt deposits is most effective. Native or adapted grasses are preferred because they generally require less fertilizer, limited maintenance, and are more drought-resistant than exotic plants. When appropriate, swales that are integrated within a project may use turf or other more intensive landscaping, while swales that are located on the project perimeter, within a park, or close to an open space area are encouraged to be planted with a more naturalistic plant palette.

2) Trees or shrubs may be used in the landscape as long as they do not over-shade the turf.

3) Above the design treatment elevation, a typical lawn mix or landscape plants can be used provided they do not shade the swale vegetation.

4) Irrigation is required if the seed is planted in the spring or summer. Use of a permanent irrigation system may help provide maximal water quality performance. Drought-tolerant grasses should be specified to minimize irrigation requirements.

5) Vegetative cover should be at least 4 inches in height, ideally 6 inches. Swale water depth should ideally be 2/3 of the height of the shortest plant species.

6) Locate the swale in an area without excessive shade to avoid poor vegetative growth. For moderately shaded areas, shade tolerant plants should be used.

7) Locate the swale away from large trees that may drop excessive leaves or needles, which may smother the grass or impede the flow through the swale. Landscape planter beds should be designed and located so that soil does not erode from the beds and enter a nearby swale.

Maintenance Access

1) Access to the swale inlet and outlet should be safely provided, with ample room for maintenance and operational activities.

Operations and Maintenance

1) Inspect vegetated swales for erosion or damage to vegetation after every storm greater than 0.75 inches for on-line swales and at least twice annually for off-line swales, preferably at the end of the wet season to schedule summer maintenance and in the fall to ensure readiness for winter. Additional inspection after periods of heavy runoff is recommended. Each swale should be checked for debris and litter and areas of sediment accumulation (see Appendix I for a v egetated swale inspection and maintenance checklist).

2) Swale inlets (curb cuts or pipes) should maintain a calm flow of water entering the swale. Remove sediment as needed at the inlet, if vegetation growth is inhibited in greater than 10% of the swale or if the sediment is blocking even distribution and entry of the water. Following sediment removal activities, replanting and/or reseeding of vegetation may be required for reestablishment.

3) Flow spreaders should provide even dispersion of flows across the swale. Sediments and debris should be removed from the flow spreader if blocking flows. Splash pads should be repaired if needed to prevent erosion. Spreader level should be checked and releveled if necessary.

4) Side slopes should be maintained to prevent erosion that introduces sediment into the swale. Slopes should be stabilized and planted using appropriate erosion control measures when native soil is exposed or erosion channels are formed.

5) Swales should drain within 48 hours of the end of a storm. Till the swale if compaction or clogging occurs and revegetate. If a perforated underdrain pipe is present, it should be cleaned if necessary.

6) Vegetation should be healthy and dense enough to provide filtering, while protecting underlying soils from erosion:

   - Mulch should be replenished as needed to ensure survival of vegetation.
   - Vegetation, large shrubs or trees that interfere with landscape swale operation should be pruned.
   - Fallen leaves and debris from deciduous plant foliage should be removed.
   - Grassy swales should be mowed to 4 to 6 inches height. Grass clippings should be removed.
   - Invasive vegetation, such as Alligatorweed (*Alternanthera philoxeroides*), Halogeton (*Halogeton glomeratus*), Spotted Knapweed (*Centaurea maculosa*), Giant Reed (*Arundo donax*), Castor Bean (*Ricinus communis*), Perennial Pepperweed (*Lepidium latifolium*), and Yellow Starthistle (*Centaurea solstitalis*) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 10% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.
   - Dead vegetation should be removed if greater than 10% of area coverage or when swale function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.

7) Check dams (if present) should control and distribute flow across the swale. Causes for altered water flow and/or channelization should be identified and obstructions cleared. Check dams and swale should be repaired if damaged.

8) The vegetated swale should be well maintained. Trash and debris, sediment, visual contamination (e.g., oils), noxious or nuisance weeds, should all be removed.

RB-AR34769

BIO-4: Vegetated Filter Strip

Filter strips are vegetated areas designed to treat sheet flow runoff from adjacent impervious surfaces or intensive landscaped areas such as golf courses. Filter strips decrease runoff velocity, filter out total suspended solids and associated pollutants, and provide some infiltration into underlying soils. While some assimilation of dissolved constituents may occur, filter strips are generally more effective in trapping sediment and particulate-bound metals, nutrients, and pesticides. Filter strips are more effective when the runoff passes through the vegetation and thatch layer in the form of shallow, uniform flow. Biological and chemical processes may help break down pesticides, uptake metals, and use nutrients that are trapped in the filter.

Vegetated filter strip captures runoff from freeway

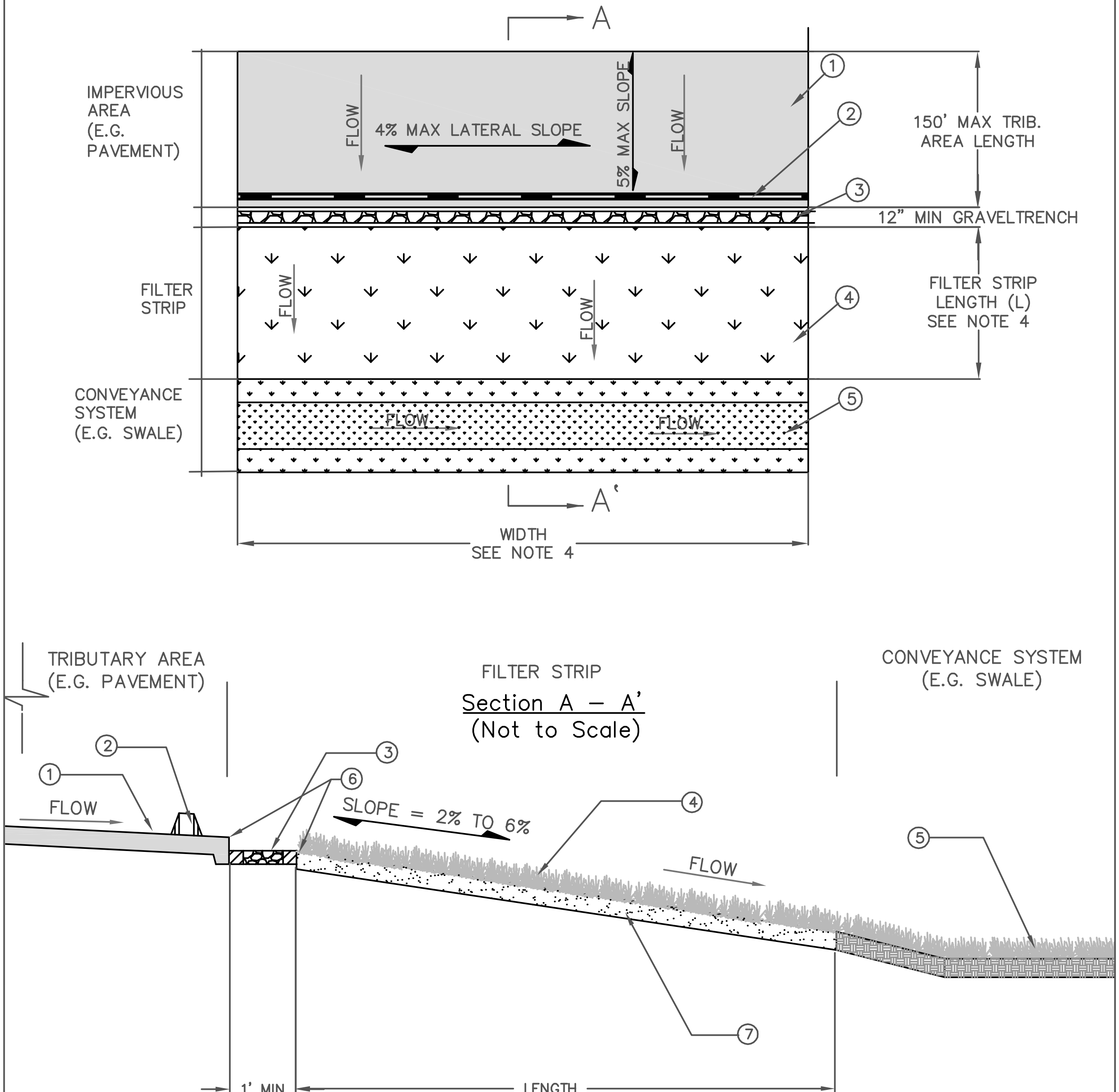
Photo Credit: Washington Department of Transportation

Applications

- Areas adjacent to parking lots and driveways
- Road medians and shoulders

Preventative Maintenance

- Remove excess sediment
- Stabilize/repair minor erosion and scouring
- Remove trash and debris
- Mow regularly



NOTES:

1. MAXIMUM LENGTH OF IMPERVIOUS TRIBUTARY AREA (PER UNIT WIDTH OF FILTER STRIP) SHALL BE 150'.
2. OPTIONAL NOTCHED CURB SPREADERS MAY BE USED IN CONJUNCTION WITH GRAVEL FLOW SPREADER.
3. GRAVEL FLOW SPREADER 6" DEEP BY 12" WIDE MIN SHALL BE PROVIDED.
4. VEGETATED FILTER STRIP SURFACE. SLOPE SHALL BE BETWEEN 2–4%. LENGTH OF STRIP MUST BE BETWEEN 15' AND 150'. WIDTH MUST BE EQUAL OR GREATER THAN THE WIDTH OF THE TRIBUTARY AREA.
5. INSTALL SWALE OR OTHER CONVEYANCE SYSTEM DOWNSTREAM OF FILTER STRIP.
6. TOP OF FILTER STRIP SHALL BE >1" BELOW TOP OF ADJACENT PAVEMENT.
7. AMEND SOILS WITH 2" OF COMPOST TILLED INTO 6" OF NATIVE SOIL UNLESS NATIVE SOIL ORGANIC CONTENT > 10%.

Geosyntec consultants

Figure 6-13: Vegetated Filter Strip

Limitations

The following describes limitations for vegetated filter strips:

- High flow velocity - steep terrain and/or large tributary area may cause concentrated, erosive flows.
- Sheet flow - shallow, evenly-distributed flow across the entire width of the filter strip is required. Filter strips are designed to treat small areas. The maximum flow path from a contributing impervious surface should not exceed 150 feet. Flows should enter as sheet flow and not exceed a depth of 1 inch.
- Shallow grades – a limited site slope may cause ponding.
- Availability of pervious area adjacent to impervious area - filter strips require sheet flow from impervious areas.

Design Criteria

The main challenge associated with filter strips is maintaining sheet flow, which is critical to the performance of this BMP. If flows are concentrated, then little or no treatment of stormwater runoff is achieved and erosive rilling is likely. The use of a flow spreading device (e.g., gravel trench or level spreader) to deliver shallow, evenly-distributed sheet flow to the strip is required. Vegetated filter strips should be designed according to the requirements listed in Table 6-21 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-21: Vegetated Filter Strip Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design flow (SQDF)	cfs	See Section 2 and Appendix E for calculating SQDF.
Maximum design flow depth	inches	1
Design residence time	minutes	7
Design flow velocity	ft/sec	< 1 ft/sec
Minimum length in flow direction	feet	15 (25 preferred); If sized for pretreatment only, filter strip can be a minimum of 4.
Maximum length (parallel to flow) of tributary area per unit width (perpendicular to flow) of filter strip	feet	150
Minimum slope in flow direction	%	2

Design Parameter	Unit	Design Criteria
Maximum slope in flow direction	%	4
Maximum lateral slope	%	4
Vegetation	-	Turf grass (irrigated) or approved equal
Minimum grass height	inches	2
Maximum grass height	inches	4 (typical) or as required to prevent shading
Elevation of flow spreader	inches	> 1 inch below the pavement surface

Sizing Criteria

The flow capacity of a vegetated filter strips (filter strips) is a function of the longitudinal slope (parallel to flow), the resistance to flow (e.g., Manning's roughness), and the width and length of the filter strip. The slope should be shallow enough to ensure that the depth of water will not exceed 1 inch over the filter strip. Similarly, the flow velocity should be less than 1 ft/sec. Procedures for sizing filter strips are summarized below. A filter strip sizing example is also provided.

Step 1: Calculate the design flow rate

The design flow is calculated based on the SQDF (see Section 2).

Step 2: Calculate the minimum width

Determine the minimum width (W_{min}), perpendicular to flow, allowable for the filter strip and design for that width or larger.

$$Wmin = (SQDF) / (qa,min) \qquad \text{(Equation 6-33)}$$

Where

W_{min} = minimum width of filter strip (and tributary area)

$SQDF$ = design flow (cfs)

$q_{a,min}$ = minimum linear unit application rate, 0.005 cfs/ft

Step 3: Calculate the design flow depth

The design flow depth (d_f) is calculated based on the width and the slope, parallel to the flow path, using a modified Manning's equation as follows:

$$d_f = 12 \times [SQDF * n_{wq} / 1.49 W_{trib} s^{0.5}]^{0.6} \qquad \text{(Equation 6-34)}$$

Where:

d_f	=	design flow depth (inches)
$SQDF$	=	design flow (cfs)
W	=	width of strip (perpendicular to flow = width of impervious surface contributing area (ft))
s	=	slope (ft/ft) of strip parallel to flow, average over the whole width
n_{wq}	=	Manning's roughness coefficient (0.25-0.30)

If d_f is greater than 1 inch (0.083 ft), then a shallower slope is required, or a filter strip cannot be used.

Step 4: Calculate the design velocity

The design flow velocity (V_{wq}) is based on the design flow, design flow depth, and width of the strip:

$$Vwq = SQDF / (df\ W) \qquad \text{(Equation 6-35)}$$

Where:

$d_{f,ft}$	=	design flow depth (ft) (d_f/12)
$SQDF$	=	stormwater quality design flow (cfs)
W	=	width of strip (perpendicular to flow = width of impervious surface contributing area (ft))

Step 5: Calculate the desired length of the filter strip

Determine the required length (L) to achieve a desired minimum residence time of 7 minutes using:

$$L = 60t_{hr} * V_{wq} \qquad \text{(Equation 6-36)}$$

Where:

L	=	minimum allowable strip length (ft)
t_{hr}	=	hydraulic residence time (min)
V_{wq}	=	design flow velocity (fps) calculated by Equation 6-35

Geometry and Size

1) The width of the filter strip shall extend across the full width of the tributary area. The upstream boundary of the filter should be located contiguous to the developed tributary area.

2) The length (in direction of flow) should be between 15 and 150 feet. A minimum length of 25 feet is preferred. Filter strips used for pretreatment shall be at least 4 feet long (in direction of flow).

3) Filter strips shall be designed on slopes (parallel to the direction of flow) between 2% and 4%; steeper slopes tend to result in concentrated flow. Slopes less than 2% could pond runoff, and in poorly permeable soils, create a mosquito breeding habitat.

4) The lateral slope of strip (parallel to the edge of the pavement, perpendicular to the direction of flow) should be 4% or less.

5) Grading should be even: a filter strip with uneven grading perpendicular to the flow path will develop flow channels over time.

6) The top of the strip should be installed 2 to 5 inches below the adjacent pavement to allow for vegetation and sediment accumulation at the edge of the strip. A beveled transition is acceptable and may be required per roadside design specifications.

7) Both the top and toe of the slope should be as flat as possible to encourage sheet flow and prevent channeling and erosion. For engineered filter strips, the facility surface should be graded flat prior to placement of vegetation.

Energy Dissipation / Level Spreading

Runoff entering a filter strip must not be concentrated. A flow spreader should be installed at the edge of the pavement to uniformly distribute the flow along the entire width of the filter strip.

1) At a minimum, a gravel flow spreader (gravel-filled trench) should be placed between the impervious area contributing flows and the filter strip, and meet the following requirements:

    a. The gravel flow spreader should be a minimum of 6 inches deep and should be 12 inches wide.

    b. The gravel should be a minimum of 1 inch below the pavement surface. *The intention is that this allows sediment from the paved surface to be accommodated without blocking drainage onto the strip.*

2) The gravel flow spreader should be a minimum of 6 inches deep and should be 12 inches wide.

a. Where the ground surface is not level, the gravel spreader must be installed so that the bottom of the gravel trench and the outlet lip are level.

b. Along roadways, gravel flow spreaders must be placed and designed in accordance with County road design specifications for compacted road shoulders.

3) Curb ports and interrupted curbs may only be used in conjunction with a gravel spreader to better ensure that water sheet flows onto the strip, provided:

a. Curb ports use fabricated openings that allow concrete curbing to be poured or extruded while still providing an opening through the curb to admit water to the filter strip. Interrupted curbs are sections of curb placed to have gaps spaced at regular intervals along the total width of the treatment area. Openings or gaps in the curb should be at regular intervals but at least every 6 feet. The width of each opening should be a minimum of 11 inches.

b. At a minimum, gaps should be every 6 feet to allow distribution of flows into the treatment facility before they become too concentrated. The opening should be a minimum of 11 inches. Approximately 15 percent or more of the curb section length should be in open ports, and as a general rule, no opening should discharge more than 10 percent of the overall flow entering the facility.

4) Energy dissipaters are needed in a filter strips if sudden slope drops occur, such as locations where flows in a filter strip pass over a rockery or retaining wall aligned perpendicular to the direction of flow. Adequate energy dissipation at the base of a drop section can be provided by a riprap pad.

Access

1) Access should be provided at the upper edge of a filter strip to enable maintenance of the inflow spreader throughout the strip width and allow access for mowing equipment.

Water Depth and Velocity

1) The design water depth shall not exceed 1 inch.

2) Runoff flow velocities should not exceed approximately 1 foot per second across the filter strip surface.

Soils

Filter strip soils should be amended with 2 inches of compost, unless the organic content is already greater than 10%. The compost should be mixed into the native soils to a depth of 6 inches to prevent soil layering and washout of compost. The compost will contain no sawdust, green or under-composted material, or any other toxic or harmful substance. It should contain no un-sterilized manure which can lead to high levels of potentially pathogenic bacteria in the runoff.

Vegetation

Filter strips must be uniformly graded and densely vegetated with erosion-resistant grasses that effectively bind the soil. Native or adapted grasses are preferred because they generally require less fertilizer and are more drought-resistant than exotic plants. The following vegetation guidelines should be followed for filter strips:

1) Sod (turf) can be used instead of grass seed, as long as there is complete coverage.

2) Irrigation should be provided to establish the grasses.

3) Grasses or turf should be maintained at a height of 2 to 4 inches. Regular mowing is often required to maintain the turf grass cover.

4) Trees or shrubs should not be used in abundance because they shade the turf and impede sheet flow.

Operations and Maintenance

Filter strips mainly require vegetation management. Therefore little special training is needed for maintenance crews. Typical maintenance activities and frequencies include:

1) Inspect strips at least twice annually for erosion or damage to vegetation, preferably at the end of the wet season to schedule summer maintenance and in the fall to ensure the strip is ready for winter. However, additional inspection after periods of heavy runoff is most desirable. The strip should be checked for debris and litter and areas of sediment accumulation (see Appendix I for a vegetated filter strip inspection and maintenance checklist).

2) Mow as frequently as necessary (at least twice a year) for safety and aesthetics or to suppress weeds and woody vegetation.

3) Trash tends to accumulate in strip areas, particularly along roadways. The need for litter removal should be determined through periodic inspection. Litter should always be removed prior to mowing.

4) Regularly inspect vegetated buffer strips for pools of standing water. Vegetated filter strips can become a nuisance due to mosquito breeding in level spreaders (unless designed to dewater completely in less than 72 hours), in pools of standing water if obstructions develop (e.g. debris accumulation, invasive vegetation), and/or if proper drainage slopes are not implemented and maintained.

5) Activities that lead to ruts or depressions on the surface of the filter strip should be prevented or the integrity of the strip should be restored by leveling and reseeding. Examples are vehicle tracks, utility maintenance, and pedestrian (short-cut) tracks.

6) Vegetation should be healthy and dense enough to provide filtering, while protecting underlying soils from erosion:

   - Mulch should be replenished as needed to ensure survival of vegetation.

   - Vegetation, large shrubs or trees that interfere with landscape swale operation should be pruned.

   - Fallen leaves and debris from deciduous plant foliage should be removed.

   - Filter strips should be mowed to 4 to 6 inches height. Grass clippings should be removed.

   - Invasive vegetation, such as Alligatorweed (*Alternanthera philoxeroides*), Halogeton (*Halogeton glomeratus*), Spotted Knapweed (*Centaurea maculosa*), Giant Reed (*Arundo donax*), Castor Bean (*Ricinus communis*), Perennial Pepperweed (*Lepidium latifolium*), and Yellow Starthistle (*Centaurea solstitalis*) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 10% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

   - Dead vegetation should be removed if greater than 10% of area coverage or when filter strip function is impaired. Vegetation should be replaced and established before the wet season to maintain cover density and control erosion where soils are exposed.

BIO-5: Proprietary Biotreatment

Proprietary biotreatment devices are manufactured treatment BMPs that incorporate plants, soil, and microbes engineered to provide treatment at higher flow rates or volumes and with smaller footprints than their non-proprietary counterparts. Incoming flows are typically pretreated to remove larger particles/debris, filtered through a planting media (mulch, compost, soil, and plants), collected by an underdrain, and delivered to the stormwater conveyance system.

Proprietary Biotreatment Examples

Photo Credits: 1. Filterra®; 2. Stormtreat™

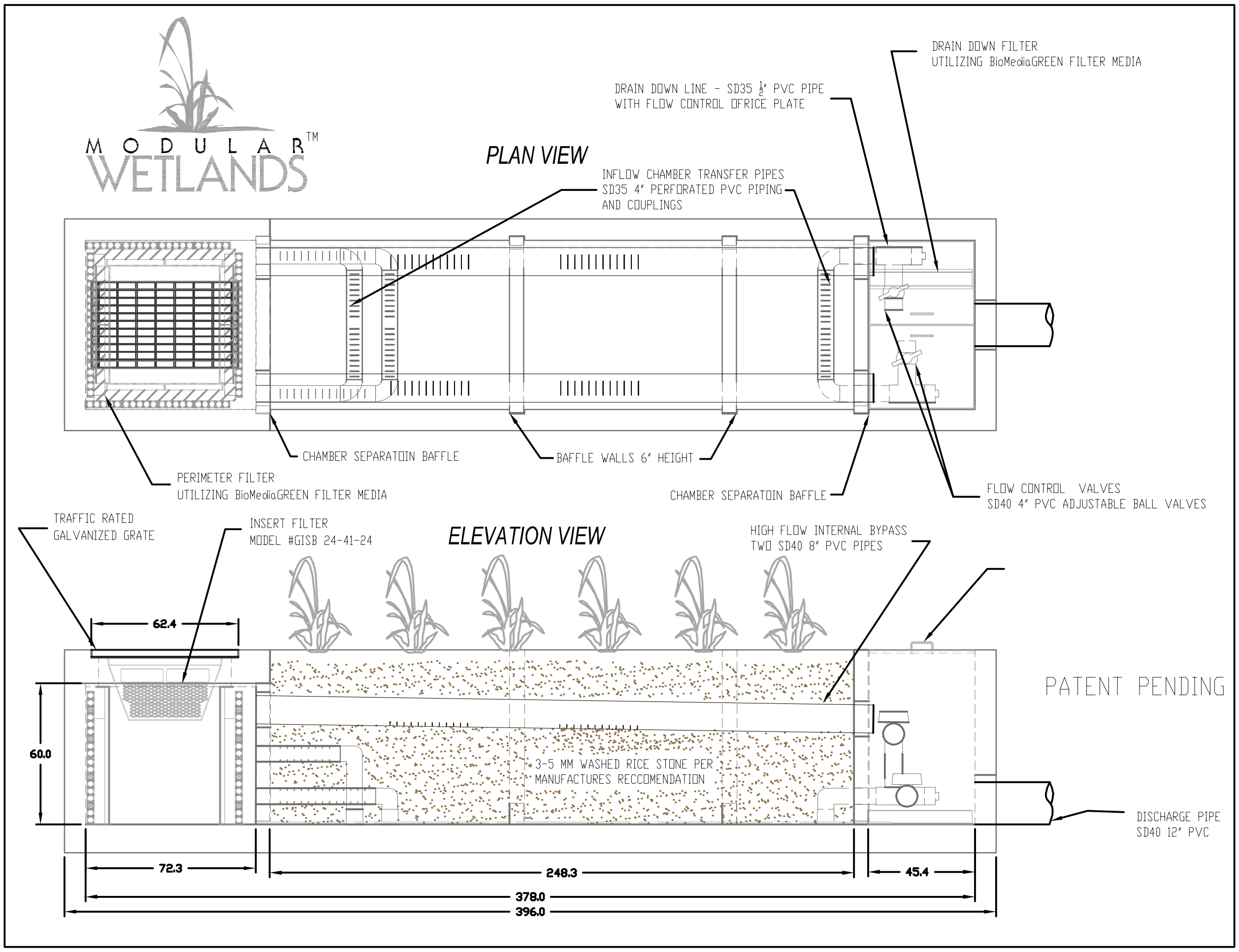
Application

- Parking lot islands
- Pickup/drop off turnarounds
- Roadway curbs

Maintenance

- Filter media replacement
- Sediment, trash, and debris removal
- Mulch replacement
- Vegetation upkeep and replacement

RB-AR34779



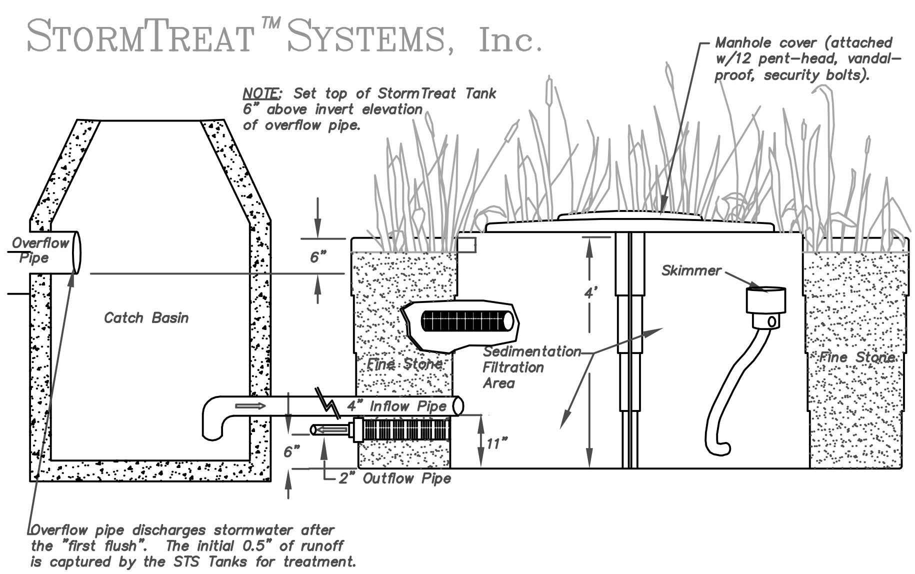


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Figure 6-14: Biotreatment Device

Table 6-22: Proprietary Biotreatment Device Manufacturer Websites

Device	Manufacturer	Website
DeepRoot® Silva Cell	DeepRoot® Urban Landscape Products	www.deeproot.com
Filterra®	Filterra® Bioretention Systems	www.filterra.com
Modular Wetlands (MWS-LINEAR)	Modular Wetlands Systems Inc.	www.modularwetlands.com
StormTreat™	StormTreat Systems Inc.	www.stormtreat.com
UrbanGreen BioFilter	Contech® Construction Products Inc.	www.contech-cpi.com/stormwater/13

Design Criteria

As proprietary biotreatment BMP vendors are constantly updating and expanding their product lines, refer to the specific vendor for the latest design and sizing guidance.

TCM-1: Dry Extended Detention Basin

Dry extended detention (ED) basins are basins whose outlets have been designed to detain the SQDV for 36 to 48 hours to allow sediment particles and associated pollutants to settle and be removed. Dry ED basins do not have a permanent pool. They are designed to drain completely between storm events. They can also be used to provide hydromodification and/or flood control by modifying the outlet control structure and providing additional detention storage. The slopes, bottom, and forebay of dry ED basins are typically vegetated. Without the addition of a s and filter beneath the basin, considerable stormwater volume reduction can still occur, depending on the infiltration capacity of the subsoil.

Extended Detention Basin Application

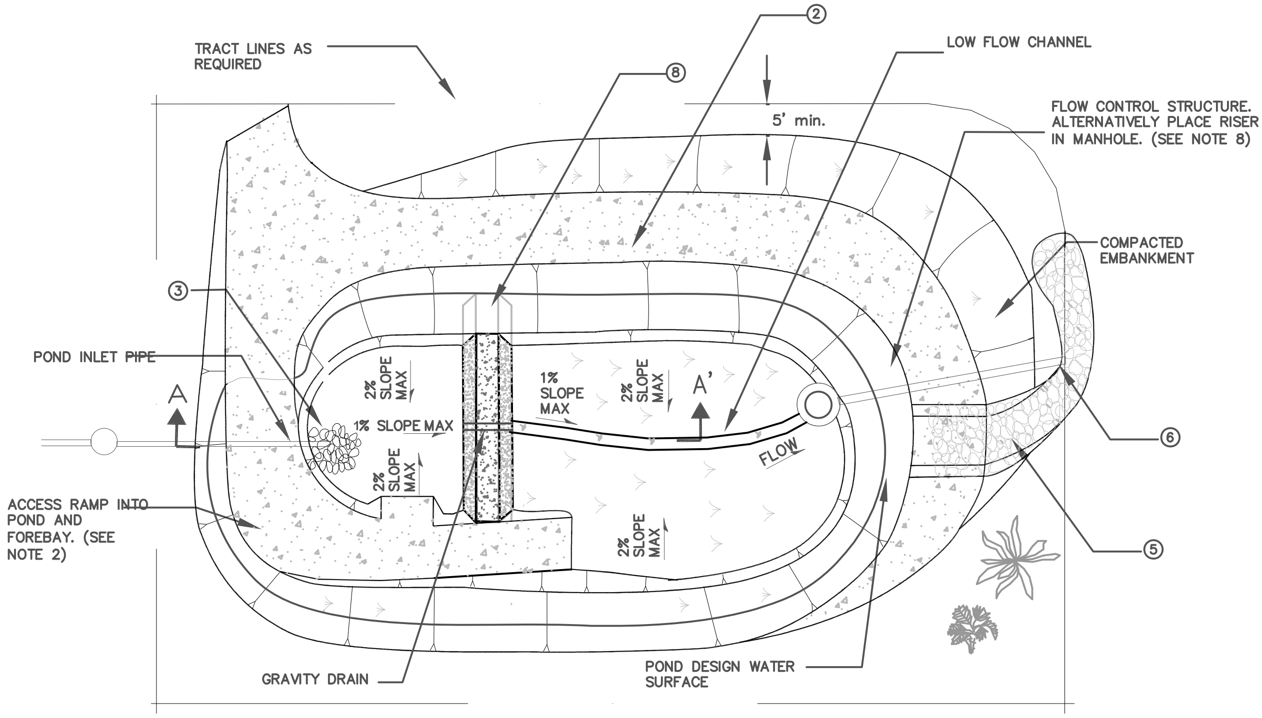
Photo Credit: Geosyntec Consultants

Application

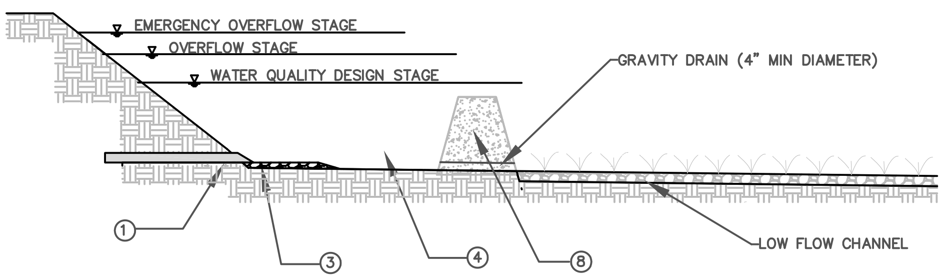
- Adjacent to parking lots
- Road medians and shoulders
- Within open areas or play fields

Preventative Maintenance

- Remove trash and debris, minor sediment accumulation, and obstructions near inlet and outlet structures
- Replace top 2 to 4 inch of sand
- Mow or weed surface of filter



Plan View
(Not to Scale)



Section A – A'
(Not to Scale)

NOTES:

1. INLET PIPE SHALL BE DESIGNED AND LOCATED SO THAT NON–EROSIVE VELOCITIES OCCUR IN THE FOREBAY
2. MAINTENANCE RAMP SHOULD PROVIDE ACCESS TO BOTH THE FOREBAY AND MAIN BASIN.
3. RIP RAP APRON OR OTHER INLET ENERGY DISSIPATION SHALL BE PROVIDED SUCH THAT VELOCITIES IN THE FOREBAY ARE < 4 FT/S.
4. SEDIMENT FOREBAY SHOULD BE SIZED TO PROVIDE 5–15% OF THE TOTAL BASIN VOLUME.
5. EMERGENCY SPILLWAY MUST BE SIZED TO PASS 100–YEAR PEAK FLOW FOR ON–LINE BASINS, AND WATER QUALITY DESIGN FLOW FOR OFF–LINE BASINS.
6. OUTLET PIPE. ENERGY DISSIPATION SHALL BE PROVIDED UNLESS DISCHARGE IS TO PIPE OR HARDENED CHANNEL.
7. OUTLET STRUCTURE SHOULD BE SIZED TO DRAIN WATER QUALITY VOLUME IN 36 – 48 HOURS (SEE FIGURE 2–2 FOR PERFORATED RISER DETAILS). ALTERNATIVELY PLACE RISER STRUCTURE IN A MANHOLE (SEE FIGURE 2–3).
8. INSTALL EARTHEN BERM OR EQUIVALENT. TOP OF BERM SHALL BE 2' MINIMUM BELOW DESIGN WATER QUALITY STAGE. BERM SHALL BE KEYED INTO EMBANKMENT A MINIMUM OF 1' ON BOTH SIDES.

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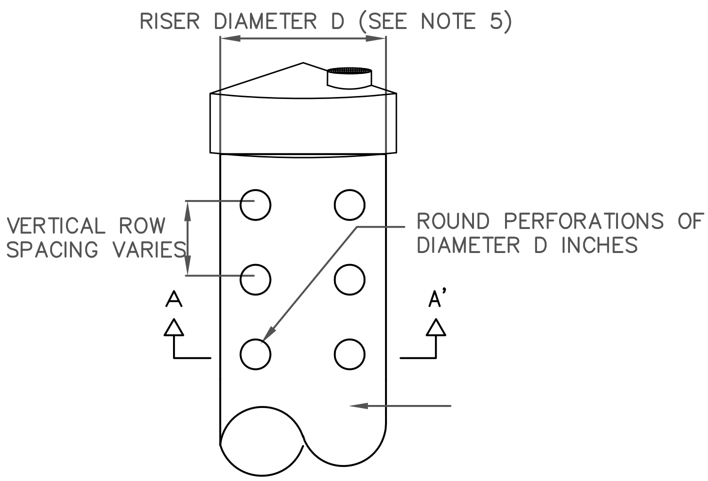
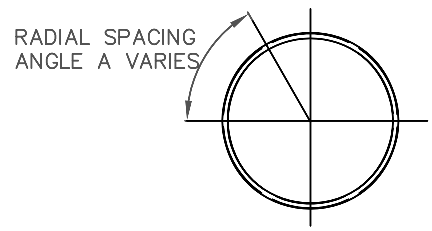
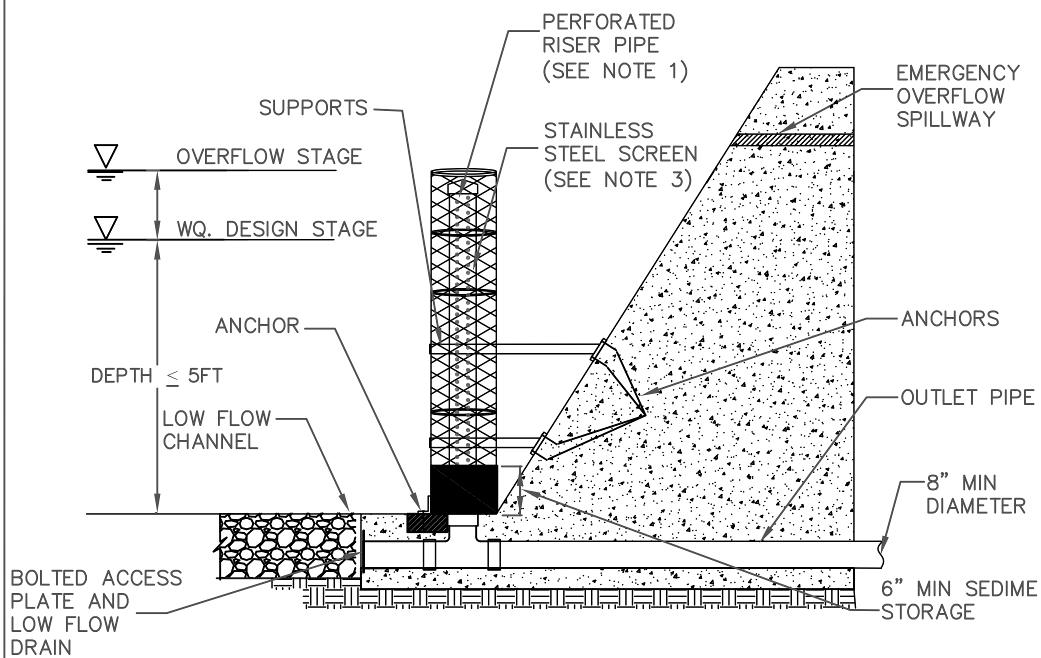
Figure 6-15: Extended Detention Basin



Perforated Riser Detail
(Not to Scale)



Section A – A'
(Not to Scale)



Perforated Riser Outlet Structure
(Not to Scale)

NOTES:

1. RISER PIPE SHALL BE SIZED TO PROVIDE 36 TO 48–HOUR FULL BRIM DRAW DOWN TIME.
2. TOTAL OUTLET CAPACITY: 100–YEAR PEAK FLOW FOR ON–LINE BASINS AND WATER QUALITY DESIGN FLOW FOR OFF–LINE BASINS.
3. SCREEN OPENINGS SHALL BE AT LEAST ¼" AND SHALL NOT EXCEED THE DIAMETER OF THE PERFORATIONS ON THE RISER.
4. RISER PIPE PERFORATION DIAMETER SHALL BE NO LESS THAN ½" AND NO MORE THAN 2"
5. MINIMUM PIPE DIAMETER (D) IS 2'
6. RISER PIPE MATERIAL IS CMP

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Figure 6-16: Perforated Riser Outlet

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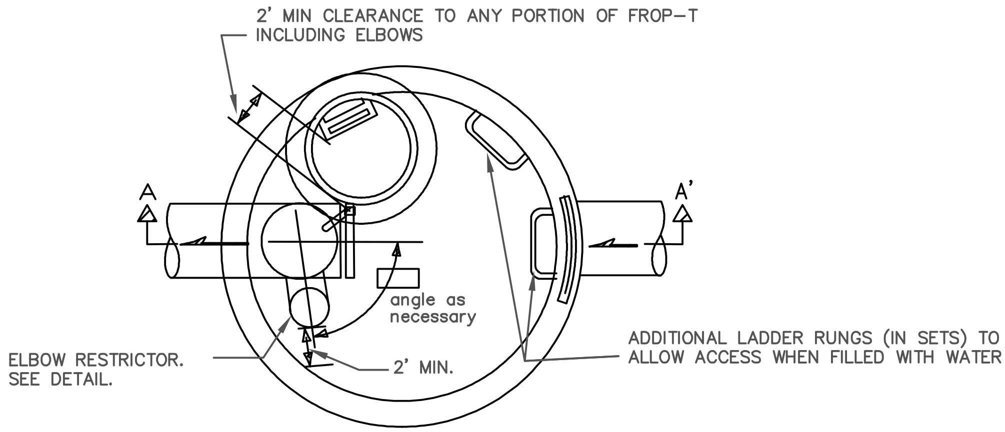
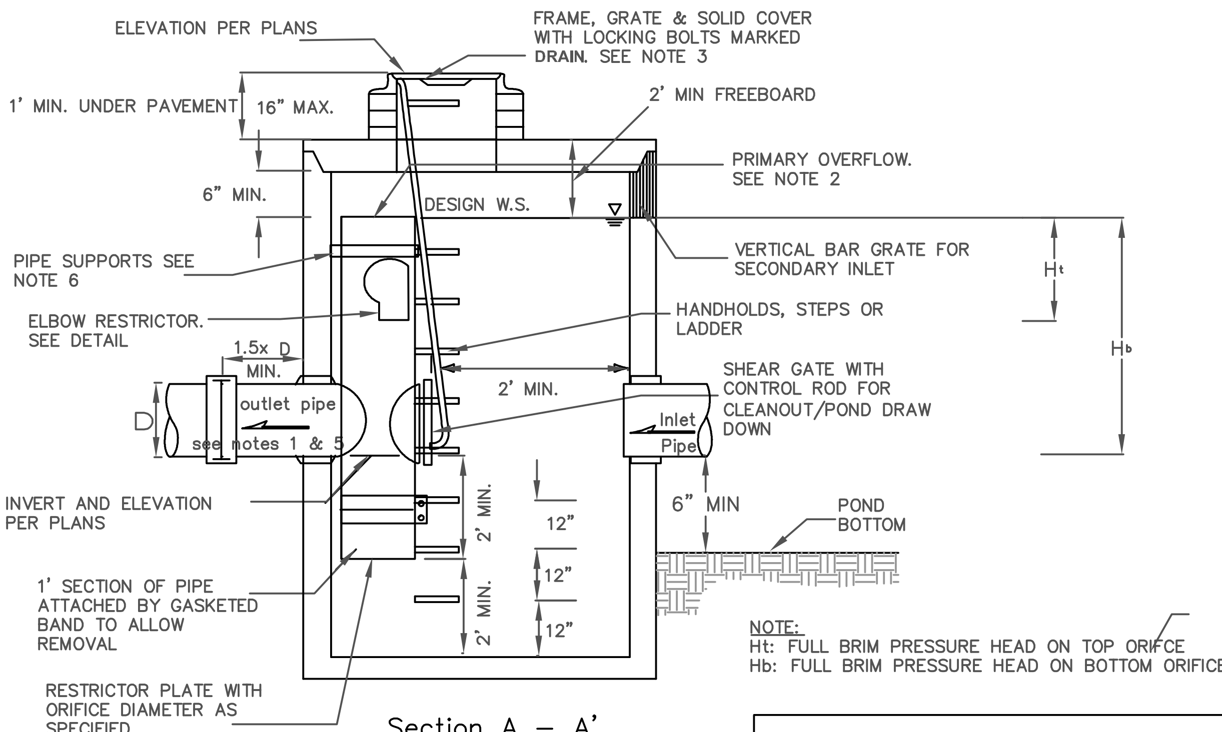
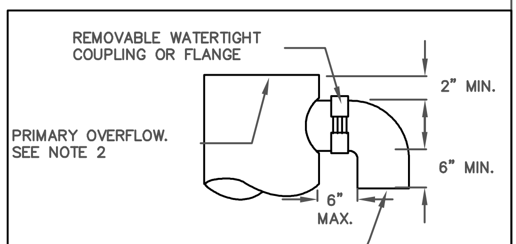


Plan View
(Not to Scale)



Section A – A'
(Not to Scale)



Detail
(Not to Scale)

NOTES:

1. USE A MINIMUM OF A 54" DIA TYPE 2 CATCH BASIN
2. OUTLET CAPACITY: 100-YEAR PEAK FLOW FOR ON-LINE BASINS.
3. METAL PARTS: CORROSION RESISTANT. NON-GALVANIZED PARTS PERFERRED. GALVANIZED PIPE PARTS TO HAVE ASPHALT TREATMENT.
4. FRAME AND LADDER OR STEPS OFFSET SO:
   A. CLEANOUT GATE IS VISIBLE FROM TOP.
   B. CLIMB-DOWN SPACE IS CLEAR OF RISER AND
   C. FRAME IS CLEAR OF CURB.
5. IF METAL OUTLET PIPE CONNECTS TO CEMENT CONCRETE PIPE: OUTLET PIPE TO HAVE SMOOTH O.D. EQUAL TO CONCRETE PIPE I.D. LESS ¼"
6. PROVIDE AT LEAST ONE 3 X .090 GAGE SUPPORT BRACKET ANCHORED TO CONCRETE WALL. (MAXIMUM 3' VERTICAL SPACING)
7. LOCATE ADDITIONAL LADDER RUNGS IN STRUCTURES USED AS ACCESS TO TANKS OR VAULTS TO ALLOW ACCESS WHEN CATCH BASIN IS FILLED WITH WATER

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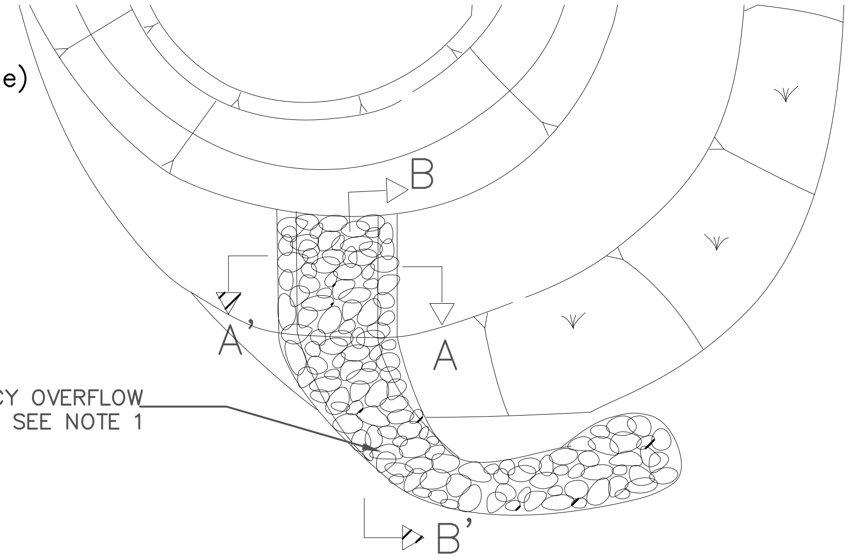
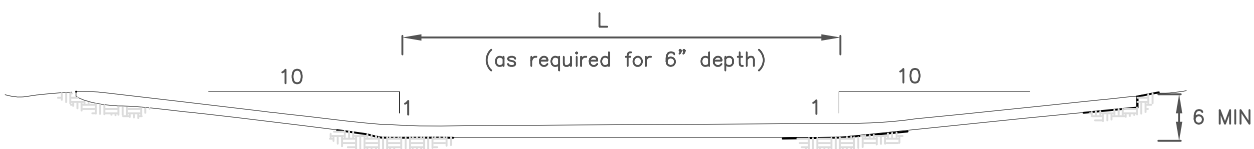
Figure 6-17: Multiple Orifice Outlet

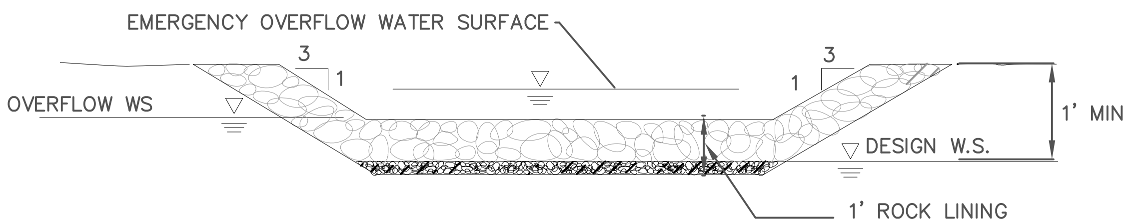
Plan View
(Not to Scale)



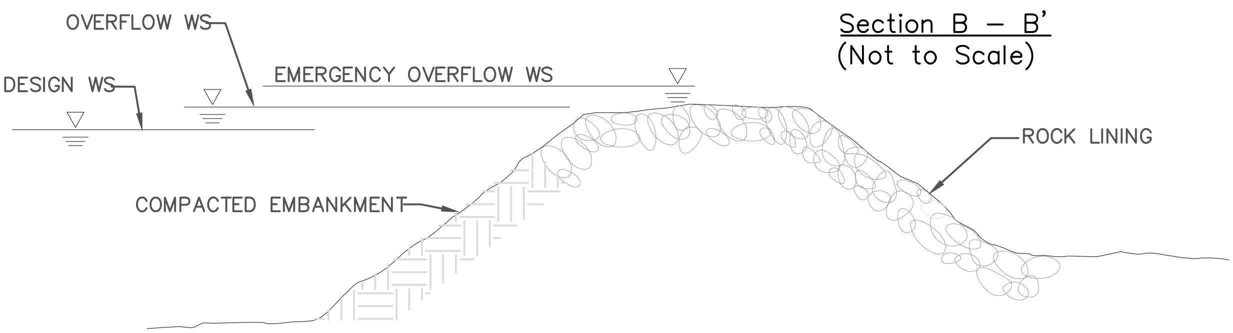
Section A – A' Option 1
(Not to Scale)



Section A – A' Option 2
(Not to Scale)



Section B – B'
(Not to Scale)



NOTES:

1. ALTERNATIVE SPILLWAY DESIGNS BASED ON THE CALIFORNIA DEPARTMENT OF WATER RESOURCES' GUIDELINES FOR THE DESIGN AND CONSTRUCTION OF SMALL EMBANKMENT DAMS OR AT THE DISCRETION OF THE DEPARTMENT

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Figure 6-18: Spillway

Limitations

Limitations for dry extended detention basins include:

- Surface space availability - typically 0.5 to 2.0 percent of the total tributary development area required.
- Depth to groundwater - bottom of basin should be 2 feet higher than the seasonal high water table elevation.
- Steep slopes - basins placed above slopes greater than 15 percent or within 200 feet from the top of a hazardous slope or landslide area require a geotechnical investigation.
- Compatibility with flood control - basins must not interfere with flood control functions of existing conveyance and detention structures.

Design Criteria

Dry extended detention basins should be designed according to the requirements listed in Table 6-23 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-23: Dry Extended Detention Basin Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume (SQDV)	acre-feet	See Section 2 and Appendix E for calculating SQDV
Drawdown time for SQDV	hours	Top 50%: 12 hrs (minimum); Bottom 50%: 36 hrs
Basin Design Volume	acre-ft	1.2 * SQDV
Forebay basin size	acre-feet	5 to 15% of SQDV
Maximum forebay drain time	min	45
Low–flow channel depth	inches	9
Low-flow channel flow capacity		2*forebay outlet rate
Freeboard (minimum)	inches	12
Flow path length to width ratio	L:W	2:1, larger preferred; can be achieved using internal berms
Longitudinal slope	percentage	1 (forebay) and 0-2 (main basin)
Low flow channel geometry	feet	depth of 0.5 and width of 1
Minimum outflow device diameter	inches	18

Sizing Criteria

Dry extended detention (ED) basins are basins designed such that the SQDV is detained for 48 hours. This allows sediment particles and associated pollutants to settle and be removed from the stormwater. Procedures for sizing extended detention basins are summarized below. A sizing example is also provided.

Step 1: Calculate the design volume

Dry extended detention facilities shall be sized to capture and treat the SQDV (see Section E.1).

Step 2: Calculate the volume of the active basin

The total basin volume should be increased an additional 20% above the SQDV to account for sediment accumulation, at a minimum. If t he basin is designed only for water quality treatment then the basin volume would be 120% of the SQDV. Freeboard is in additional to the total basin volume. Calculate the volume of the active basin (ft²) (V_a):

$$V_a = 1.20 * SQDV \qquad \text{(Equation 6-37)}$$

Step 3: Determine detention basin location and preliminary geometry based on site constraints

Based on site constraints, determine the basin geometry (area and length) and the storage available by developing an e levation-storage relationship for the basin. The cross-sectional geometry across the width of the basin should be approximately trapezoidal. Shallow side slopes are necessary if the basin is designed to have recreational uses during dry weather conditions.

1) Calculate the width of the basin footprint (W_{tot}) as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}} \qquad \text{(Equation 6-38)}$$

Where:

A_{tot} = total surface area of the basin footprint (ft²)

L_{tot} = total length of the basin footprint (ft)

2) Calculate the length of the active volume surface area including the internal berm but excluding the freeboard, (L_{av-tot}):

$$L_{av-tot} = L_{tot} - 2Zd_{fb} \qquad \text{(Equation 6-39)}$$

Where:

Z = interior side slope as length per unit height (H:V)

d_{fb} = freeboard depth (ft)

3) Calculate the width of the active volume surface area including the internal berm but excluding freeboard (ft), ($W_{av\text{-}tot}$):

$$W_{av-tot} = W_{tot} - 2Zd_{fb}$$ (Equation 6-40)

4) Calculate the total active volume surface area including the internal berm and excluding freeboard, ($A_{av\text{-}tot}$):

$$A_{av-tot} = L_{av-tot} \times W_{av-tot}$$ (Equation 6-41)

5) Calculate the area of the berm, (A_{berm}):

$$A_{berm} = W_{berm} \times L_{berm}$$ (Equation 6-4243)

Where:

W_{berm} = width of the internal berm

L_{berm} = length of the internal berm (= width excluding freeboard, $W_{av\text{-}tot}$)

6) Calculate the surface area excluding the internal berm and freeboard, A_{av}:

$$A_{av} = A_{av=tot} - A_{berm}$$ (Equation 6-44)

Step 4: Determine Dimensions of Forebay

The forebay should be sized to at least 5 to 15% of the basin active volume (V_a). Calculate the active volume of the forebay, (V_1):

$$V_1 = \frac{V_a \times \%V_1}{100}$$ (Equation 6-45)

Where:

$\%V_1$ = percent of V_a in forebay (%)

V_a = total active volume (ft^3)

7) Calculate the surface area for the active volume of forebay (A_1):

$$A_1 = \frac{V_1}{d_1}$$ (Equation 6-46)

Where:

d_1 = average depth for the forebay (ft)

8) Calculate the length of forebay, (L_1):

$$L_1 = \frac{A_1}{W_1}$$ (Equation 6-47)

Where:

W_1 = width of forebay (ft)

Step 5: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

1) Calculate the active volume of Cell 2, (V_2):

$$V_2 = V_a - V_1$$ (Equation 6-48)

Where:

V_a = total basin active volume (ft^3)

V_1 = volume of forebay (ft^3)

2) Calculate the surface area, A_2, for the active volume of Cell 2:

$$A_2 = A_{av} - A_1$$ (Equation 6-49)

Where:

A_{av} = basin surface area excluding berm and freeboard (ft^2)

A_1 = surface area of forebay (ft^2)

3) Calculate the average depth (d_2) for the active volume of Cell 2:

$$d_2 = \frac{V_2}{A_2}$$ (Equation 6-50)

4) Calculate the length of Cell 2, (L_2):

$$L_2 = \frac{A_2}{W_2}$$ (Equation 6-51)

Where:

W_2 = width of Cell 2 (ft)

5) Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen. Calculate the length-to width (LW_{mid2}) ratio of Cell 2 at half of d_2 follows:

$$LW_{mid2} = \frac{L_{mid2}}{W_{mid2}} \quad \text{(Equation 6-52)}$$

Where:

W_{mid2} = $W_2 - Zd_2$ (Equation 6-53)

L_{mid2} = $L_2 - Zd_2$ (Equation 6-54)

W_{mid2} = width of Cell 2 at half of d_2 (ft)

L_{mid2} = length of Cell 2 at half of d_2 (ft)

Z = interior side slope as length per unit height (H:V)

d_2 = cell 2 average depth (ft)

Step 6: Ensure Design Requirements and Site Constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or alternative treatment BMP.

Step 7: Size Outlet Structure

The total drawdown time for the basin should be 48 hours. The outlet structure should be designed to release the bottom 50% of the detention volume (half-full to empty) over 36 hours, and the top half (full to half-full) in 12 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm. See Section 6 for outlet structure sizing methodologies.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak stormwater runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing and Geometry

1) The total basin volume should be increased an additional 20% of the SQDV to account for sediment accumulation, at a minimum. If the basin is designed only for water quality treatment then the basin volume would be 120% of the SQDV. Freeboard is in addition to the total basin volume.

2) The minimum freeboard should be at least 1 foot above the emergency overflow water surface for dry extended detention basins.

3) The minimum flow-path length to width ratio at half basin height should be a minimum of 3:1 (L:W) and can be achieved using internal berms or other means to prevent short-circuiting. Intent: a long flow length will improve fine sediment removal.

4) The cross-sectional geometry across the width of the basin should be approximately trapezoidal. Shallow side slopes are necessary if the basin is designed to have recreational uses during dry weather conditions.

5) All dry ED basins should be free draining and a low flow channel should be provided. A low flow channel is a narrow, shallow trench filled with pea gravel and encased with filter fabric that runs the length of the basin to drain dry weather flows. The low flow channel should be of sufficient size considering the natural characteristics of the soil and have a positive-draining gradient flowing toward the outlet structure (typically 1 ft wide by 6 inches deep). If infiltration rates of subsurface soils are insufficient, the low flow channel should tie into perforated pipe at the outlet structure. If a sand filter or planting media is provided beneath the dry ED basin for increased volume reduction, it may be designed to take the place of the low flow channel.

6) The basin bottom should have a 1% longitudinal slope (direction of flow) in the forebay, and may range from 0 to 2% longitudinal slope in the main basin. The bottom of the basin should slope 2% toward the center low flow channel.

7) A basin should be large enough to allow for equipment access via a graded ramp.

Soils Considerations

1) The slopes of the detention basin should be analyzed for slope stability using rapid drawdown conditions and should meet the minimum standards set by the Ventura County Flood Control District. A 1.5 static factor of safety should be used. Seismic analysis is not required due to the temporary storage of water in the basin.

2) The infiltration capability of the dry ED basin can be enhanced by incorporating soil amendments.

Energy Dissipation

1) Energy dissipation controls constructed of sound materials such as stones, concrete, or proprietary devices that are rated to withstand the energy of the influent flow should be installed at the inlet to the sediment forebay. Flow velocity into the basin forebay should be controlled to 4 feet per second (ft/sec) or less.

2) Energy dissipation controls must also be used at the outlet/spillway from the detention basin unless the basin discharges to a storm drain or hardened channel.

Sediment Forebay

As untreated stormwater enters the dry ED basin, it passes through a sediment forebay for coarse solids removal. The forebay may be constructed using an i nternal berm constructed out of earthen embankment material, grouted riprap, stop logs, or other structurally sound material.

1) The basin should be sized so that 5 to 15% of the total basin volume is in the forebay and 85 to 95% of the total basin volume is in the main portion of the basin.

2) A gravity drain outlet from the forebay (2 inch minimum diameter) should extend the entire width of the internal berm and be designed to completely drain to the main basin within 10 minutes.

3) The forebay outlet should be offset (horizontally) from the inflow streamline to prevent short-circuiting.

4) Permanent steel post depth markers should be placed in the forebay to define sediment removal limits at 50% of the forebay sediment storage depth.

Vegetation

Vegetation within the dry ED basin provides erosion protection from wind and water and biofiltration of stormwater. The local permitting authority should review and approve any proposed basin landscape plan prior to implementation and following guidelines should be followed:

1) The bottom and slopes of the dry ED basin should be vegetated. A mix of erosion-resistant plant species that effectively bind the soil should be used on the slopes and a diverse selection of plants that thrive under the specific site, climatic, and watering conditions should be specified for the basin bottom. The basin bottom should not be planted with trees, shrubs, or other large woody plants that may interfere with sediment removal activities. The basin should be free of floating objects. Only native perennial grasses, forbs, or similar vegetation that can be replaced via seeding should be used on the basin bottom.

    a. Landscaping outside of the basin is required for all dry ED basins and should adhere to the following criteria so as not to hinder maintenance operations:

b. No trees or shrubs may be planted within 15 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, should not be used within 50 feet of pipes or manmade structures. Weeping willow (Salix babylonica) should not be planted in or near detention basins.

2) Prohibited non-native plant species will not be permitted. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website- or the California Invasive Plant Council website at www.cal-ipc.org.

3) A plant list provided by a landscape professional should be used as a guide only and should not replace project-specific planting recommendations, including recommendations on appropriate plants, fertilizer, mulching applications, and irrigation requirements (if any) to ensure healthy vegetation growth.

Sand Filter or Planting Media Layer

For increasing the volume reduction capability of a dry ED basin, an appropriately sized sand filter or planting media layer can be placed beneath the dry ED basin to achieve desired volume reduction goals if soil and slope conditions allow (i.e., infiltration rate greater than 0.5 in/hr but less than 2.4 in/hr; site slope less than 15%). The drawdown time of the sand filter or planting media layer should be less than 72 hours. The base of the sand filter or planting media layer should be level (i.e., zero slope). If a s and filter/planting media layer is provided over the length of the basin, it can take the place of the low-flow channel so long as it is designed to adequately infiltrate dry weather flows. Sizing of the sand filter and planting media layer for dry ED basins is the same as for sand filters and bioretention areas, respectively. The depth of water in the dry ED basin should not exceed 6 feet.

Outlet Structure and Drawdown Time

A drawdown time of 36 to 48 hours shall be provided for the SQDV. This drawdown time is for the volume in the basin above the sand filter layer (if provided) and serves the purpose of water quality treatment. An outflow device should be designed to release the bottom 50% of the detention volume (half-full to empty) over 24 to 32 hours, and the top half (full to half-full) in 12 to 16 hours. *The intention is that the drawdown schemes that detain low flows for longer periods than high flows have the following advantages over outlets that drain the basin evenly:*

- Greater flood control capabilities
- Enhanced treatment of low flows which make up the bulk of incoming flows.

Additional storage, detention, and outlet control is required to achieve pre-development stormwater runoff discharge rates for hydromodification control. The outlet structure can be designed to achieve flow control for meeting the multiple objectives of water quality and flow attenuation.

The outflow device (i.e., outlet pipe) should be oversized (18 inch minimum diameter). There are two options that can be used for the outlet structure:

1) Uniformly perforated riser structures.

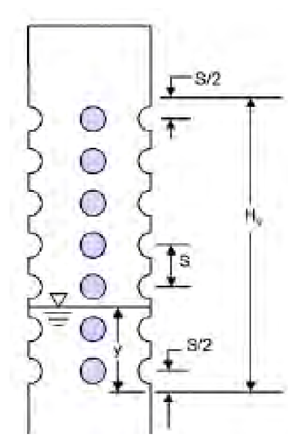
2) Multiple orifice structures (orifice plate).

The outlet structure can be placed in the basin with a debris screen (Figure 6-15) or housed in a standard manhole (Figure 6-16). If a multiple orifice structure is used, an orifice restriction (if necessary) should be used to limit orifice outflow to the maximum discharge rates allowable for achieving the desired water quality and flow control objectives. Orifice restriction plates should be removable for emergency situations. A removable trash rack should be provided at the outlet.

Note that a primary overflow (typically a riser pipe connected to the outlet works) should be sized to pass flows larger than the stormwater quality design storm (if the ED basin is sized only for water quality) or to pass flows larger than the peak flow rate of the maximum design storm to be detained in the basin (e.g., 100-yr, 24-hr). The primary overflow is intended to protect against overtopping or breaching of a basin embankment.

Perforated Risers Outlet Sizing Methodology

The following attributes influence the perforated riser outlet sizing calculations**:**



Perforated Riser Outlet

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- Shape of the basin (e.g., trapezoidal)
- Depth and volume of the basin
- Elevation / depth of first row of holes
- Elevation / depth of last row of holes
- Size of perforations
- Number of rows or perforations and number of perforations per row
- Desired drawdown time (e.g., 16 hour and 32 hour draw down for top half and bottom half respectively, 48 hour total drawdown time for the stormwater quality design volume)

The governing rate of discharge from a perforated riser structure can be calculated using Equation 6-44 below:

$$Q = C_p \frac{2A_p}{3H_s} \sqrt{2g} H^{3/2}$$

(Equation 6-55)

Where:

Q	=	riser flow discharge (cfs)
C_p	=	discharge coefficient for perforations (use 0.61)
A_p	=	cross-sectional area of all the holes (ft^2)
s	=	center to center vertical spacing between perforations (ft)
H_s	=	distance from s/2 below the lowest row of holes to s/2 above the top row of holes (McEnroe 1988).
H	=	effective head on the orifice (measured from center of orifice to water surface)

For the iterative computations needed to size the perforations in the riser and determine the riser height, a simplified version of Equation 6-44 may be used as shown below in Equation 6-45 and Equation 6-46:

$$Q = kH^{3/2}$$

(Equation 6-56)

Where:

H	=	effective head on the orifice (measured from center of orifice to water surface)

$$k = C_p \frac{2A_p}{3H_s} \sqrt{2g}$$

(Equation 6-57)

Where:

C_p	=	discharge coefficient for perforations (use 0.61)
A_p	=	cross-sectional area of all the holes (ft^2)
s	=	center to center vertical spacing between perforations (ft)

H_s	=	distance from s/2 below the lowest row of holes to s/2 above the top row of holes.
g	=	32.17 ft/sec^2

Uniformly perforated riser designs are defined by the depth or elevation of the first row of perforations, the length of the perforated section of pipe, and the size or diameter of each perforation.

Multiple Orifice Outlet Sizing Methodology

The following attributes influence multiple orifice outlet sizing calculations**:**

- Shape of the basin (e.g., trapezoidal)
- Depth and volume of the basin
- Elevation of each orifice
- Desired draw-down time (e.g., 16 hour and 32 hour draw down times for top half and bottom half respectively, 48 hour drawdown time for stormwater quality design volume)

The rate of discharge from a single orifice can be calculated using Equation 6-22.

$$Q = CA(2gH)^{0.5}$$ (Equation 6-58)

Where:

Q	=	orifice flow discharge
C	=	discharge coefficient
A	=	cross-sectional area of orifice or pipe (ft2)
g	=	acceleration due to gravity (32.2 ft/s2)
H	=	effective head on the orifice (measured from center of orifice to water surface)

Multiple orifice designs are defined by the depth (or elevation) and the size (or diameter) of each orifice. The steps needed to size a dual orifice outlet are outlined in Appendix E; multiple orifices may be provided and sized using a similar approach.

Emergency Spillway

An emergency overflow spillway in addition to the primary overflow outlet (as described above) is required. The emergency spillway should be sized for flows greater than the peak 100-year 24-hour storm if the basin is designed on-line or, if the basin is designed on-line, the spillway should be sized for flows greater than the basin design volume (e.g., stormwater quality design volume). The spillway should provide for adequate energy dissipation downstream. The spillway should allow for at least 12 inches of freeboard above the emergency overflow water surface elevation if the basin is on-line. If the basin is on-line, 2 feet of freeboard is preferable.

Spillways shall meet the California Department of Water Resources, Division of Safety of Dams Guidelines for the Design and Construction of Small Embankment Dams (http://damsafety.water.ca.gov/docs/GuidelinesSmallDams.pdf). *Intent: Emergency overflow spillways are intended to control the location of basin overtopping and safely direct overflows back into the downstream conveyance system or other acceptable discharge point.*

On-line Basins

1) On-line basins must have an emergency overflow spillway to prevent overtopping of walls or berms should blockage of the primary outlet occur based on a downstream risk assessment.

2) The overflow spillway must be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm.

3) The minimum freeboard should be 1 foot (but preferably at least 2 feet) above the maximum water surface elevation over the emergency spillway.

Off-line Basins

1) Off-line basins must have either an emergency overflow spillway or an emergency overflow riser. The emergency overflow must be designed to pass the 100-yr 24-hr post-development peak stormwater runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. Where an emergency overflow spillway would discharge to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

2) The emergency overflow spillway shall be armored to withstand the energy of the spillway flows.

3) The minimum freeboard should be 1 foot above the maximum water surface elevation over the emergency spillway.

Side Slopes

1) Interior side slopes above the stormwater quality design depth and up to the emergency overflow water surface steeper than 4:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

2) Exterior side slopes steeper than 2:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

3) For any slope (interior or exterior) greater than 2:1 (H:V), a geotechnical investigation and report must be submitted and approved by the local permitting authority.

4) Landscaped slopes should be no greater than 3:1 (H:V) to allow for maintenance.

5) Basin walls may be vertical retaining walls, provided: (a) they are constructed of reinforced concrete, (b) a fence is provided along the top of the wall (see fencing below) or further back, and (c) the design is stamped by a licensed civil engineer and approved by the Local permitting authority.

Embankments

1) Earthworks and berm embankments should be performed in accordance with the latest edition of the "Greenbook Standard Specifications for Public Works Construction".

2) Embankments are earthen slopes or berms used for detaining or redirecting the flow of water.

3) Top of berm separating forebay and main basin should be 2 feet minimum below the stormwater quality design water surface and should be keyed into embankment a minimum of 1 foot on both sides.

4) Typically, the top width of berm embankments are at least 20 f eet, but narrower embankments may be plausible if approved by the civil engineer and the Local permitting authority.

5) Basin berm embankments should be constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a licensed civil engineer) free of loose surface soil materials, roots, and other organic debris.

6) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

7) Basin berm embankments greater than 4 feet in height should be constructed by excavating a key equal to 50% of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed civil engineer.

8) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

9) Low growing native or non-invasive perennial grasses should be planted on downstream embankment slopes. See vegetation section below.

Fencing

1) Safety is provided either by fencing of the facility or by managing the contours of the basin to eliminate drop-offs and other hazards.

2) If fences are required, fences should be designed and constructed in accordance with relevant standards and should typically be located at or above the overflow water surface elevation. Shrubs (approved, California-adapted species) can be used to hide the fencing. See vegetation section above.

Right-of-Way

1) Dry extended detention basins and associated access roads to be maintained by a public agency should be dedicated in fee or in an easement to the public agency with appropriate access.

Maintenance Access

1) Ownership of the basin and maintenance thereof is the responsibility of the developer/applicant. A maintenance agreement with the Local permitting authority is required to ensure adequate performance and allow emergency access to the facilities.

2) Maintenance access road(s) should be provided to the control structure and other drainage structures associated with the basin (e.g., inlet, emergency overflow or bypass structures). Manhole and catch basin lids should be in or at the edge of the access road.

3) A ramp into the basin should be constructed near the basin outlet. An access ramp is required for removal of sediment with a backhoe or loader and truck. The ramp should extend to the basin bottom to avoid damage to vegetation planted on the basin slope.

4) All access ramps and roads should be provided in accordance with the current policies of the Ventura County Flood Control District or local approval authority.

Construction Considerations

The use of treated wood or galvanized metal anywhere inside the facility is prohibited.

Operations and Maintenance

Maintenance is of primary importance if extended detention basins are to continue to function as originally designed. A maintenance agreement must be developed with the local approval authority to ensure adequate performance and allow emergency access. Maintenance of the basin is the responsibility of the development, unless otherwise agreed upon.

A specific maintenance plan shall be formulated for each facility outlining the schedule and scope of maintenance operations, as well as the data handling and reporting requirements. The following are general maintenance requirements:

1) The basin should be inspected semiannually or more frequently, and inspections after major storm events are encouraged (see Appendix I for guidance on facility maintenance inspections). Trash and debris should be removed as needed, but at least annually prior to the beginning of the wet season (see Appendix I for dry extended detention basin inspection and maintenance checklist).

2) Site vegetation should be maintained as follows:

   - Vegetation, large shrubs, or trees that limit access or interfere with basin operation should be pruned or removed.

   - Slope areas that have become bare should be revegetated and eroded areas should be regraded prior to being revegetated.

   - Grass should be mowed to 4 to 9 inch high and grass clippings should be removed.

   - Fallen leaves and debris from deciduous plant foliage should be raked and removed.

   - Invasive vegetation, such as Alligatorweed (Alternanthera philoxeroides), Halogeton (Halogeton glomeratus), Spotted Knapweed (Centaurea maculosa), Giant Reed (Arundo donax), Castor Bean (Ricinus communis), Perennial Pepperweed (Lepidium latifolium), and Yellow Starthistle (Centaurea solstitalis) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 25% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

   - Dead vegetation should be removed if it exceeds 10% of area coverage. Vegetation should be replaced immediately to maintain cover density and control erosion where soils are exposed.

   - No herbicides or other chemicals should be used to control vegetation.

3) Sediment buildup exceeding 50% of the forebay capacity should be removed. Sediment from the remainder of the basin should be removed when 6 inches of sediment accumulates. Sediments should be tested for toxic substance accumulation in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed. If toxic substances are encountered at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations,

the sediment must be disposed of in a hazardous waste landfill. It is recommended to clean the forebay frequently to reduce frequency of main basin cleaning.

4) Remove sediment from basin when accumulation reaches 25% of original design depth. C leaning is recommended to occur in early spring to allow vegetation to reestablish.

5) Repair erosion to banks and bottom of basin as required.

6) Following sediment removal activities, replanting, and/or reseeding of vegetation may be required for reestablishment.

7) Control vectors as needed.

TCM-2: Wet Detention Basin

Wet detention basins are constructed, naturalistic ponds with a permanent or seasonal pool of water (also called a "wet pool" or "dead storage"). Aquascape facilities, such as artificial lakes, are a special form of wet pool facility that can incorporate innovative design elements to allow them to function as a stormwater treatment facility in addition to an aesthetic water feature. Wetponds require base flows to exceed or match losses through evaporation and/or infiltration and they must be designed with the outlet positioned and/or operated in such a way as to maintain a permanent pool. Wetponds can be designed to provide extended detention of incoming flows using the volume above the permanent pool surface.

Wet Detention Basin

Photo Credit: Geosyntec Consultants

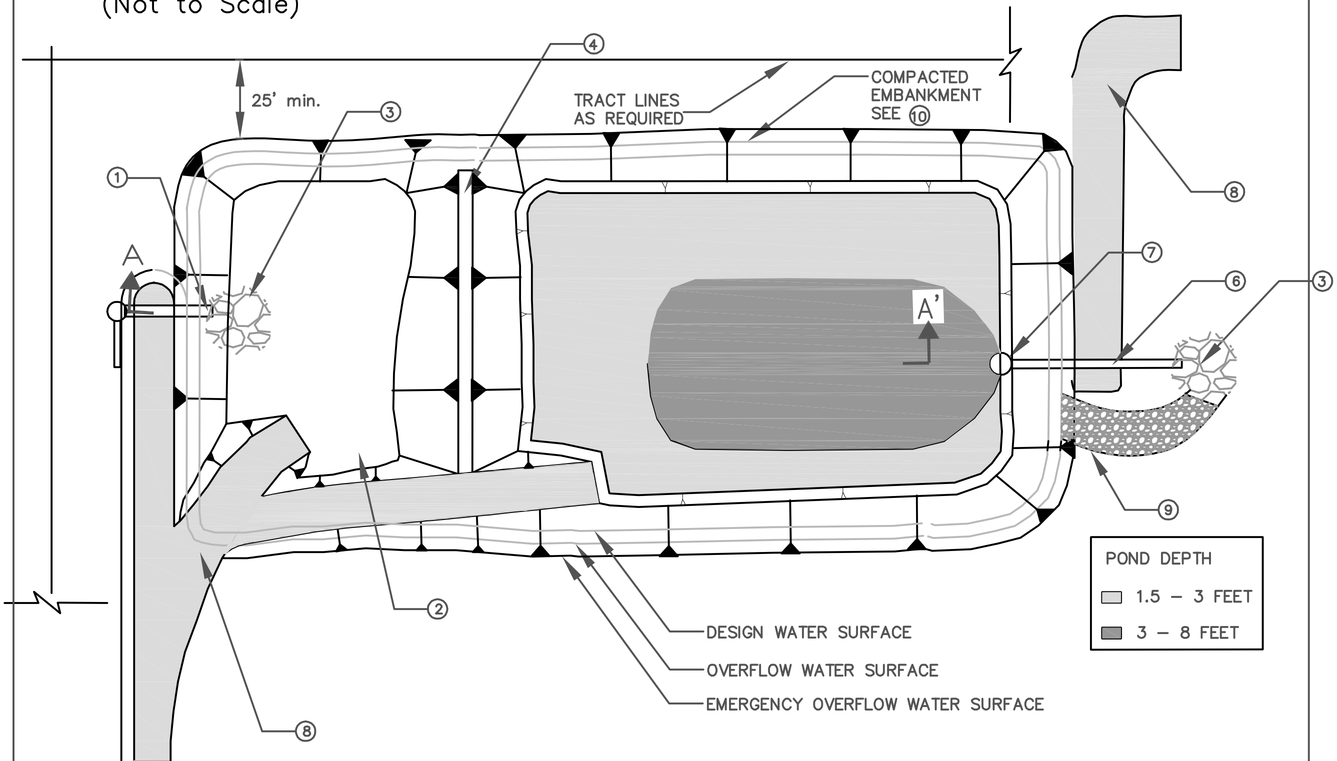
Application

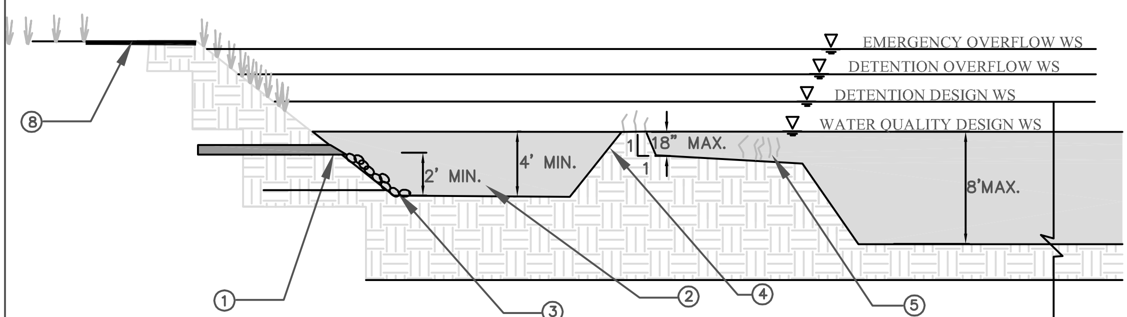
- Regional detention & treatment
- Roads, highways, parking lots, commercial, residential
- Parks, open spaces, and golf courses

Preventative Maintenance

- inspected at a minimum annually and inspections after major storm events
- Pruned or remove vegetation, large shrubs, or trees that limit access or interfere with basin operation
- Remove sediment buildup at inlets and outlets

Plan View
(Not to Scale)





Section A - A'
(Not to Scale)

NOTES:

1. INLET PIPE SHOULD BE SUBMERGED WITH A MINIMUM OF 2' DISTANCE FROM THE BOTTOM
2. FIRST CELL VOLUME SHALL EQUAL 25% TO 35% OF TOTAL WETPOND VOLUME. DEPTH SHALL BE 4' MIN TO 8' MAX PLUS AN ADDITIONAL 1' MIN SEDIMENT STORAGE DEPTH.
3. RIP RAP APRON OR OTHER ENERGY DISSIPATION.
4. BERM SHALL EXTEND ACROSS ENTIRE WIDTH OF THE WETPOND.
5. EMERGENT VEGETATION SHALL BE PLANTED IN REGIONS OF THE POND THAT ARE 3' DEEP OR LESS.
6. SIZE OUTLET PIPE TO PASS 100-YEAR PEAK FLOW FOR ON-LINE PONDS AND WATER QUALITY PEAK FLOW FOR OFF-LINE PONDS.
7. WATER QUALITY OUTLET STRUCTURE. SEE FIGURE 8-2 AND FIGURE 8-3 FOR DETAILS.
8. MAINTENANCE ACCESS ROAD SHOULD PROVIDE ACCESS TO BOTH THE FIRST CELL AND MAIN BASIN.
9. INSTALL EMERGENCY OVERFLOW SPILLWAY AS NEEDED. SEE FIGURE 2-4 FOR DETAILS

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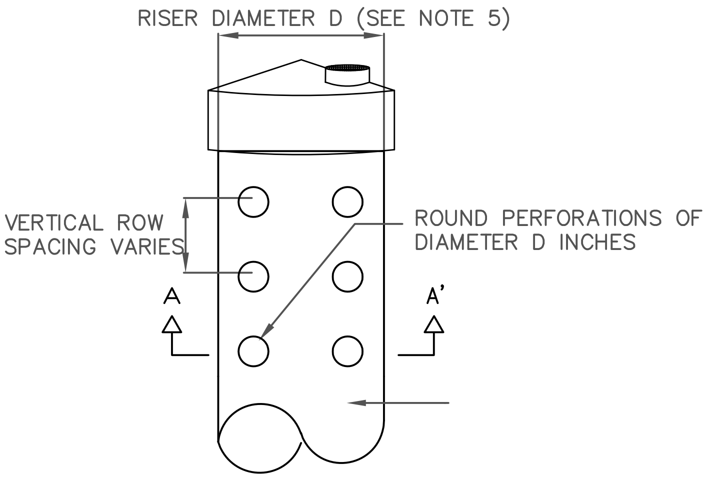
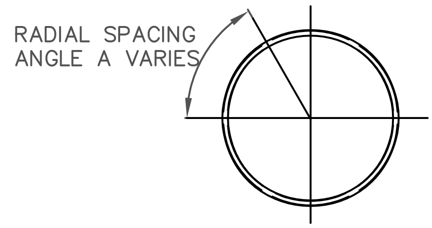
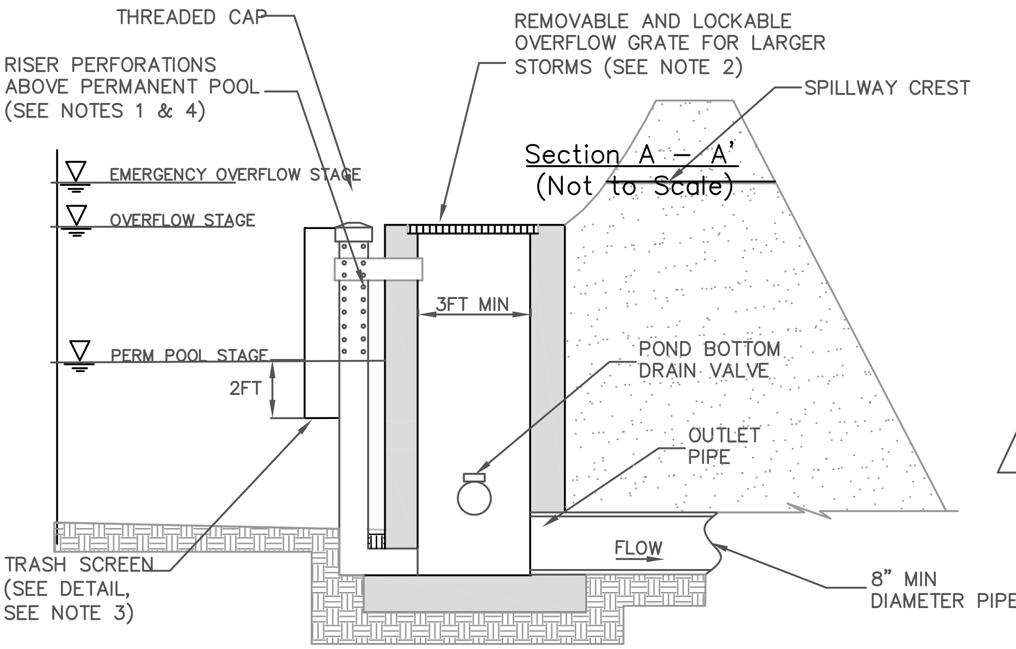
Figure 6-19: Wet Detention Basin

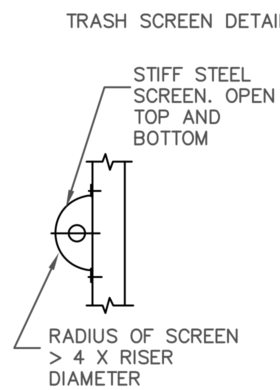


Perforated Riser Detail
(Not to Scale)



Section A – A'
(Not to Scale)





Perforated Riser Outlet Structure
(Not to Scale)

NOTES:

1. RISER PIPE SHALL BE SIZED TO PROVIDE 36 TO 48–HOUR FULL BRIM DRAW DOWN TIME.
2. TOTAL OUTLET CAPACITY: 100–YEAR PEAK FLOW FOR ON–LINE BASINS AND WATER QUALITY DESIGN FLOW FOR OFF–LINE BASINS.
3. SCREEN OPENINGS SHALL BE AT LEAST ¼" AND SHALL NOT EXCEED THE DIAMETER OF THE PERFORATIONS ON THE RISER.
4. RISER PIPE PERFORATION DIAMETER SHALL BE NO LESS THAN ½" AND NO MORE THAN 2"
5. MINIMUM PIPE DIAMETER (D) IS 2'
6. RISER PIPE MATERIAL IS CMP

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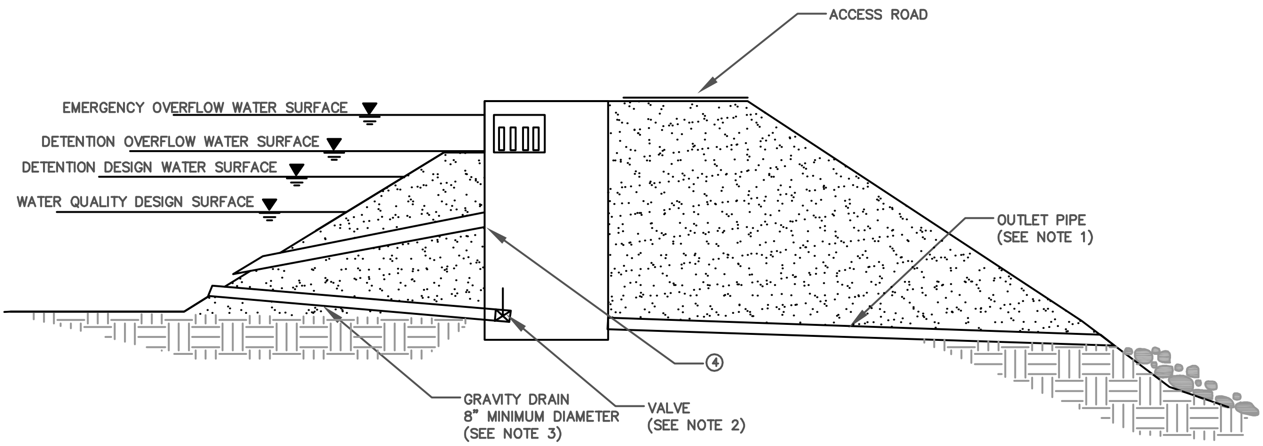
Figure 6-20: Riser Outlet



Inverted Pipe Outlet Structure
(Not to Scale)

NOTES:

1. SIZE OUTLET PIPE SYSTEM TO PASS 100–YEAR FLOW FOR ON–LINE PONDS AND WATER QUALITY PEAK FLOW FOR OFF–LINE PONDS.
2. VALVE MAY BE LOCATED INSIDE MANHOLE OR OUTSIDE WITH APPROVED OPERATIONAL ACCESS
3. INVERT OF DRAIN SHALL BE 6" MINIMUM BELOW TOP OF INTERNAL BERM. LOWER PLACEMENT IS DESIRABLE. INVERT SHALL BE 6" MINIMUM ABOVE BOTTOM OF POND.
4. OUTLET PIPE INVERT SHALL BE AT WETPOOL WATER SURFACE ELEVATION

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Figure 6-21: Inverted Pipe Outlet

Limitations

Limitations for wet detention basins include:

- Wet detention basins typically are used for treating areas larger than 10 acres and less than 10 square miles. They are especially applicable for regional water quality treatment and flow control.
- Off-line wet detention basins must not interfere with flood control functions of existing conveyance and detention structures.
- If wet detention basins are located in areas with site slopes greater than 15% or within 200 feet of a hazardous steep slope or mapped landslide area (on the uphill side), a geotechnical investigation and report must be provided to ensure that the basin does not compromise the stability of the site slope or surrounding slopes.
- Wet detention basins require a regular source of base flow if water levels are to be maintained. If base flow is insufficient during summer months, supplemental water may be necessary to maintain water levels.

Design Criteria

The main challenge associated with wet detention basins is maintaining desired water levels. A wet detention basin should be designed according to the requirements listed in Table 6-24 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-24: Wet Detention Basin Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume, SQDV	acre-ft	See Section 2 and Appendix E for calculating SQDV.
Permanent Pool Volume		SQDV
Forebay Volume		5 to 10% of SQDV
Maximum Forebay Drain Time	min	45
Depth without sediment storage	feet	0.5-12 (littoral zone, 25-40% permanent pool) 4 (first cell minimum) 8 (any cell maximum) Deeper zone: 4-8 feet average; 12 feet maximum depth
Maximum residence time	Days	7 (dry weather)
Freeboard (minimum)	inches	12

Flow path length to width ratio	L:W	2:1 (larger preferred)
Side slope (maximum)	H:V	4:1 (H:V) Interior and 3:1 (H:V) Exterior
Longitudinal slope	percentage	1 (forebay) and 0-2 (main basin)
Vegetation Type	--	Varies see vegetation section below
Vegetation Height	--	Varies see vegetation section below
Buffer zone (minimum)	feet	25
Minimum outflow device diameter	inches	18

Sizing Criteria

Wet Detention basins may be designed with or without extended detention above the permanent pool. The extended detention portion of the wet detention basin above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin). If there is no extended detention provided, wet detention basins shall be sized to provide a minimum wet pool volume equal to the stormwater quality design volume plus an additional 5% for sediment accumulation. If extended detention is provided above the permanent pool, the sizing is dependent of the functionality of the basin; the basin may function as water quality treatment only or water quality plus peak flow attenuation.

If the basin is designed for water quality treatment only, then the permanent pool volume should be a minimum of 10 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) should make up the remaining 90 percent. If extended detention is provided above the permanent pool and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume should be equal to the water quality treatment volume, and the surcharge volume should be sized to attenuate peak flows in order to meet the peak runoff discharge requirements. The extended detention portion of the wet detention basin above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin).

Step 1: Calculate the design volume

Wet detention basins shall be sized with a permanent pool volume equal to the SQDV volume (see Section 2 and Appendix E).

Step 2: Determine the active design volume for the wet detention basin without extended detention

The active volume of the wet detention basin, V_a, shall be equal to the SQFV plus an additional 5% for sediment accumulation.

$$V_a = 1.05 \times SQDV \qquad \text{(Equation 6-59)}$$

Step 3: Determine pond location and preliminary geometry based on site constraints

Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. Note that a more natural geometry may be used and is in many cases recommended; the preliminary basin geometry calculations should be used for sizing purposes only.

1) Calculate the width of the pond footprint, W_{tot}, as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}} \qquad \text{(Equation 6-60)}$$

Where:

A_{tot} = total surface area of the pond footprint (ft^2)

L_{tot} = total length of the pond footprint (ft)

1) Calculate the length of the active volume surface area including the internal berm but excluding the freeboard, $L_{av\text{-}tot}$:

$$L_{av-tot} = L_{tot} - 2Zd_{fb} \qquad \text{(Equation 6-61)}$$

Where:

Z = interior side slope as length per unit height

d_{fb} = freeboard depth

2) Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot}$:

$$W_{av-tot} = W_{tot} - 2Zd_{fb} \qquad \text{(Equation 6-62)}$$

3) Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot}$:

$$A_{av-tot} = L_{av-tot} \times W_{av-tot} \qquad \text{(Equation 6-63)}$$

4) Calculate the area of the berm, A_{berm}:

$$A_{berm} = W_{berm} \times L_{berm} \qquad \text{(Equation 6-64)}$$

Where:

W_{berm} = width of the internal berm

L_{berm} = length of the internal berm

5) Calculate the active volume surface area excluding the internal berm and freeboard, A_{wq}:

$$A_{wq} = A_{wq\,=\,tot} - A_{berm}$$ (Equation 6-65)

Step 4: Determine Dimensions of Forebay

The wet detention basin should be divided into two cells separated by a berm or baffle. The forebay should contain between 5 and 10 percent of the total volume. The berm or baffle volume should not count as part of the total volume. Calculate the active volume of forebay, V_1:

$$V_1 = \frac{V_a \times \%V_1}{100}$$ (Equation 6-66)

Where:

$\%V_1$ = percent of SQDV in forebay (%)

1) Calculate the surface area for the active volume of forebay, A_1:

$$A_1 = \frac{V_1}{d_1}$$ (Equation 6-67)

Where:

d_1 = average depth fo rhte active volume of forebay (ft)

1) Calculate the length of forebay, L_1. N ote, inlet and outlet should be configured to maximize the residence time.

$$L_1 = \frac{A_1}{W_1}$$ (Equation 6-68)

Where:

W_1 = width of forebay (ft), $W_1 = W_{av\text{-}tot} = L_{berm}$

Step 5: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

1) Calculate the active volume of Cell 2, V_2:

$$V_2 = V_a - V_1$$ (Equation 6-69)

2) The minimum wetpool surface area includes 0.3 acres of wetpool per acre-foot of permanent wetpool volume. Calculate A_{min2}:

$$A_{min2} = (V_2 \times 0.3 \frac{acres}{acre-feet}) \quad \text{(Equation 6-70)}$$

3) Calculate the actual wetpool surface area, A_2:

$$A_2 = A_{av} - A_1 \quad \text{(Equation 6-71)}$$

Verify that A_2 is greater than A_{min2}. If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.

4) Calculate the top length of Cell 2, L_2:

$$L_2 = \frac{A_2}{W_2} \quad \text{(Equation 6-72)}$$

Where:

W_2 = width of Cell 2 (ft), $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$

5) Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen.

$$LW_2 = \frac{L_2}{W_2} \quad \text{(Equation 6-73)}$$

6) Calculate the emergent vegetation surface area, A_{ev}:

$$A_{ev} = \frac{A_2 \bullet \%A_{ev}}{100} \quad \text{(Equation 6-74)}$$

Where:

$\%A_{ev}$ = percent of surface area that will be planted with emergent vegetation

7) Calculate the volume of the emergent vegetation shallow zone (1.5 – 3 ft), V_{ev}:

$$V_{ev} = A_{ev} \bullet d_{ev} \quad \text{(Equation 6-75)}$$

Where:

d_{ev} = average depth of the emergent vegetation shallow zone (1.5 – 3 ft)

8) Calculate the length of the emergent vegetation shallow zone, L_{ev}:

$$L_{ev} = \frac{A_{ev}}{W_{ev}}$$ (Equation 6-76)

Where:

W_{ev} = width of the emergent vegetation shallow zone (ft), $W_{ev} = W_2$

9) Calculate the volume of the deep zone, V_{deep}:

$$V_{deep} = V_2 - V_{ev}$$ (Equation 6-77)

10) Calculate the surface area of the deep (>3 ft) zone, A_{deep}:

$$A_{deep} = A_2 - A_{ev}$$ (Equation 6-78)

11) Calculate the average depth of the deep zone (4-8 ft), d_{deep}:

$$d_{deep} = \frac{V_{deep}}{A_{deep}}$$ (Equation 6-79)

12) Calculate length of the deep zone, L_{deep}:

$$L_{deep} = \frac{A_{deep}}{W_{deep}}$$ (Equation 6-80)

Where:

W_{deep} = width of the deep zone (ft), $W_{deep} = W_2$

Step 6: Ensure design requirements and site constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the BMP.

Step 7: Size Outlet Structure

For extended detention wet detention basin, outlet structures should be designed to provide 12 to 48 hour emptying time for the water quality volume above the permanent pool.

The basin outlet pipe should be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing and Geometry

1) If there is no extended detention provided, wet detention basins shall be sized to provide a minimum wet pool volume equal to the stormwater quality design volume plus an additional 5% for sediment accumulation. If extended detention is provided above the permanent pool and the basin is designed for water quality treatment only, then the permanent pool volume should be a minimum of 10 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) should make up the remaining 90 percent. If extended detention is provided above the permanent pool and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume shall be equal to the water quality treatment volume and the surcharge volume should be sized to attenuate peak flows to meet the peak runoff discharge requirements. The extended detention portion of the wet detention basin above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see TCM-1: Dry Extended Detention Basin).

2) The wet detention basin should be divided into two cells separated by a berm or baffle. The first cell should contain between 25 to 35 percent of the total volume. The berm or baffle volume should not count as part of the total volume. Intent: The full-length berm or baffle reduces short-circuiting and promotes plug flow.

3) Wet detention basins with wetpool volumes less than or equal to 4,000 cubic feet may be single-celled (i.e., no baffle or berm is required).

4) Sediment storage should be provided in the first cell. The sediment storage should have a minimum depth of 1 foot. This volume should not be included as part of the required water quality volume.

5) The minimum depth of the first cell should be 4 feet, exclusive of sediment storage requirements. The depth of the first cell may be greater than the depth of the second cell. Average depth should be between 4 feet and 8 feet.

6) For wet detention basin depths in excess of 6 feet, some form of recirculation should be provided, such as a fountain or aerator, to prevent stratification, stagnation and low dissolved oxygen conditions.

7) The edge of the basin should slope from the surface of the permanent pool to a depth of 12 to 18 inches at a slope of 1:1 or greater. If soil conditions will not support a 1:1 (H:V) slope then the steepest slope that can be supported should be used or a shallow retaining wall constructed (18 inch max). Beyond the edge of the basin, a bench sloped at 4:1 (H:V) maximum should extend into the basin to a depth of at least 3 feet. A steeper slope may be used beyond the 3 foot depth to a maximum of 8 feet. Intent: steep slopes at water's edge will minimize very shallow areas that can support mosquitoes.

8) At least 25% of the basin area should be deeper than 3 feet to prevent the growth of emergent vegetation across the entire basin. If greater than 50% of the wet pool area is in excess of 6 feet deep, some form of recirculation should be provided, such as a fountain or aerator, to prevent stratification, stagnation and low dissolved oxygen conditions.

9) A wet detention basin should have a surface area of not less than 0.3 acres for each acre-foot of permanent pool volume. In addition, extra area needed to provide a design that meets all other provisions of this section should be provided. Additional surface area in excess of the minimum may be provided. There is no maximum surface area provided that all provisions of this section are met.

10) Inlets and outlets should be placed to maximize the flowpath through the facility. The flowpath length-to-width ratio should be a minimum of 1.5:1, but a flowpath length-to-width ratio of 2:1 or greater is preferred. The flowpath length is defined as the distance from the inlet to the outlet, as measured at mid-depth. The width at mid-depth can be found as follows: width = (average top width + average bottom width)/2. Intent: a long flowpath length will improve fine sediment removal.

11) All inlets should enter the first cell. If there are multiple inlets, the length-to-width ratio should be based on the average flowpath length for all inlets.

12) The minimum freeboard should be 1 foot above the maximum water surface elevation (2 feet preferred) for on-line basins and 1 foot above the maximum water surface elevation for on-line basins.

13) The maximum residence time for dry weather flows should be 7 days. Intent: Vector control.

Internal Berms and Baffles

1) A berm or baffle should extend across the full width of the wet detention basin and be keyed into the basin side slopes. If the berm embankments are greater than 4 feet in height, the berm should be constructed by excavating a key equal to 50% of the embankment cross-sectional height and width. This requirement may be waived if recommended by a licensed civil engineer for the specific site conditions. The geotechnical investigation must consider the situation in which one of the two cells is empty while the other remains full of water.

2) The top of the berm should extend to the permanent pool surface or be one foot below the permanent pool surface to discourage public access. If the top of the berm is at the water permanent pool surface, the side slopes should be 4H:1V. Berm side slopes may be steeper (up to 3:1) if the berm is submerged one foot.

3) If good vegetation cover is not established on the berm, erosion control measures should be used to prevent erosion of the berm back-slope when the basin is initially filled.

4) The interior berm or baffle may be a retaining wall provided that the design is prepared and stamped by a l icensed civil engineer. If a b affle or retaining wall is used, it should be submerged one foot below the permanent pool surface to discourage access by pedestrians.

5) Internal earthen berms 6 feet high or less should have a minimum top width 6 feet or as recommended by a civil engineer.

Water Supply

1) Water balance calculations should be provided to demonstrate that adequate water supply will be present to maintain a pool of water during a drought year when precipitation is 50% of average for the site. Water balance calculations should include evapotranspiration, infiltration, precipitation, spillway discharge, and dry weather flow (where appropriate).

2) Where water balance indicates that losses will exceed inputs, a source of water should be provided to maintain the basin water surface elevation throughout the year. The water supply should be of sufficient quantity and quality to not have an adverse impact on the wet detention basin water quality. Water that meets drinking water standards should be assumed to be of sufficient quality.

3) Wet detention basin may be designed as seasonal ponds where the water balance and water supply conditions make it infeasible to sustain a permanent wet detention basin.

Soils Considerations

Wet detention basin implementation in areas with high permeability soils requires liners to increase the chances of maintaining a p ermanent pool in the basin. Liners can be either synthetic materials or imported lower permeability soils (i.e., clays). The water balance assessment should determine whether a liner is required.

If low permeability soils are used for the liner, a minimum of 18 inches of native soil amended with good topsoil or compost (one part compost mixed with 3 parts native soil) should be placed over the liner. If a synthetic material is used, a soil depth of 2 feet is recommended to prevent damage to the liner during planting.

Buffer Zone

A minimum of 25 feet buffer should be provided around the top perimeter of the wet detention basin. The portion of the access road outside of the maximum water level may be included as part of the buffer.

Stormwater Quality Design Features

1) Wet detention basins that are located in publicly-accessible or highly visible locations should include design features that will improve and maintain the quality of water within the BMP at a level suitable for the proposed location and uses of the surrounding area. Typical design features include aeration, pumped circulation, filters, biofilters, and other facilities that operate year-round to remove pollutants and nutrients. Stormwater quality design features will result in higher quality water in the BMP and lower discharges of pollutants downstream.

2) Wet detention basins in publicly-accessible or highly visible locations should have a maintenance plan that includes regular collection and removal of trash from the area within and surrounding the BMP.

3) If fencing is required for wet detention basins in publicly-accessible or highly visible locations, the fence can be designed to be aesthetically incorporated into the site and Shrubs (approved, California-adapted species) can be used to hide the fencing. See vegetation section below.

Energy Dissipation

1) The inlet to the wet detention basin should be submerged with the inlet pipe invert a minimum of two feet from the basin bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible. Intent: The inlet is submerged to dissipate energy of the incoming flow. The distance from the bottom is set to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.

2) Energy dissipation controls should also be used at the outlet from the wet detention basin unless the basin discharges to a stormwater conveyance system or hardened channel.

Vegetation

A plan should be prepared that indicates how aquatic, temporarily submerged areas (extended detention wet detention basins) and terrestrial areas will be stabilized with vegetation.

1) If the second cell of the wet detention basin is 3 feet or shallower, the bottom area should be planted with emergent wetland vegetation.

2) Emergent aquatic vegetation should be planted to cover 25-75% of the area of the permanent pool.

3) Outside of the basin, native vegetation adapted for site conditions should be used in non-irrigated sites.

4) The area surrounding a wet detention basin should be landscaped to minimize erosion and should adhere to the following criteria so as not to hinder maintenance operations:

5) No trees or shrubs may be planted within 15 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, should not be used within 50 feet of pipes or manmade structures. Weeping willow (Salix babylonica) should not be planted in or near detention basins.

6) Prohibited non-native plant species will not be permitted. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website- or the California Invasive Plant Council website at www.cal-ipc.org.

7) A landscape professional should provide recommendations on appropriate plants, fertilizer, mulching applications, and irrigation requirements (if any) to ensure healthy vegetation growth.

Outlet Structure

1) An outlet pipe and outlet structure should be provided. The outlet pipe may be a perforated standpipe strapped to a manhole or placed in an embankment, suitable for extended detention, or may be back-sloped to a catch basin with a grated opening (jail house window) or manhole with a cone grate (birdcage). The grate or birdcage openings provide an overflow route should the basin outlet pipe become clogged.

2) For extended detention wet detention basin, outlet structures should be designed to provide 12 to 48 hour emptying time for the water quality volume above the permanent pool.

3) The basin outlet pipe should be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Emergency Spillway

An emergency overflow spillway in addition to the primary overflow outlet (as described above) is required. The emergency spillway should be sized for flows greater than the peak 100-year 24-hour storm if the basin is designed on-line or, if the basin is designed off-line, the spillway should be sized for flows greater than the basin design volume (e.g., stormwater quality design volume). The spillway provide for adequate energy dissipation downstream. The spillway should allow for at least 12 inches of freeboard above the emergency overflow water surface elevation if the basin is on-line. If the basin is -line, 2 feet of freeboard is preferable.

Spillways shall meet the California Department of Water Resources, Division of Safety of Dams Guidelines for the Design and Construction of Small Embankment Dams (http://damsafety.water.ca.gov/docs/GuidelinesSmallDams.pdf). *Intent: Emergency overflow spillways are intended to control the location of basin overtopping and safely direct overflows back into the downstream conveyance system or ot her acceptable discharge point.*

On-line Basins

1) On-line basins must have an emergency overflow spillway to prevent overtopping of walls or berms should blockage of the primary outlet occur based on a downstream risk assessment.

2) The overflow spillway must be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm.

3) The minimum freeboard should be 1 foot (but preferably at least 2 feet) above the maximum water surface elevation over the emergency spillway.

Off-line Basins

1) Off-line basins must have either an emergency overflow spillway or an emergency overflow riser. The emergency overflow must be designed to pass flows greater than the basin design volume (e.g., stormwater quality design volume) directly to the downstream conveyance system or another acceptable discharge point. Where an emergency overflow spillway would discharge to a steep slope, an emergency overflow riser, in addition to the spillway should be provided. See Appendix E for basin/pond outlet sizing worksheets.

2) The emergency overflow spillway should be armored to withstand the energy of the spillway flows. The spillway should be constructed of grouted rip-rap.

3) The minimum freeboard should be 1 foot above the maximum water surface elevation over the emergency spillway.

Side Slopes

1) Interior side slopes above the stormwater quality design depth and up to the emergency overflow water surface steeper than 4:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

2) Exterior side slopes steeper than 2:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

3) For any slope (interior or exterior) greater than 2:1 (H:V), a geotechnical investigation and report must be submitted and approved by the local permitting authority.

4) Landscaped slopes should be no steeper than 3:1 (H:V) to allow for maintenance.

5) Basin walls may be vertical retaining walls, provided: (a) they are constructed of reinforced concrete, (b) a fence is provided along the top of the wall (see fencing below) or further back, and (c) the design is stamped by a licensed civil engineer.

Embankments

1) Earthworks and berm embankments should be performed in accordance with the latest edition of the "Greenbook Standard Specifications for Public Works Construction".

2) Embankments are earthen slopes or berms used for detaining or redirecting the flow of water.

3) Top of berm should be 2 feet minimum below the stormwater quality design water surface and should be keyed into embankment a minimum of 1 foot on both sides.

4) Typically, the top width of berm embankments are at least 20 feet, but narrower embankments may be plausible if approved by the civil engineer and the Local permitting authority.

5) Basin berm embankments should be constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a licensed civil engineer) free of loose surface soil materials, roots, and other organic debris.

6) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

7) Basin berm embankments greater than 4 feet in height should be constructed by excavating a key equal to 50% of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed civil engineer.

8) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

9) Low growing native or non-invasive perennial grasses should be planted on downstream embankment slopes. See vegetation section below.

Fencing

Safety is provided either by fencing of the facility or by managing the contours of the basin to eliminate drop-offs and other hazards.

1) If fences are required, fences should be designed and constructed in accordance with current and relevant policies and typically are required to be located at or above the overflow water surface elevation. Shrubs (approved, California-adapted species) can be used to hide the fencing. See vegetation section above.

Right-of-Way

2) Wet detention basins and associated access roads to be maintained by a public agency should be dedicated in fee or in an easement to the public agency with appropriate access.

Maintenance Access

1) Ownership of the basin and maintenance thereof is the responsibility of the developer/applicant. A maintenance agreement is required to ensure adequate performance and allow emergency access to the facilities.
2) Maintenance access road(s) should be provided to the control structure and other drainage structures associated with the basin (e.g., inlet, emergency overflow or bypass structures). Manhole and catch basin lids should be in or at the edge of the access road.
3) A ramp into the basin should be constructed near the basin outlet. An access ramp is required for removal of sediment with a backhoe or loader and truck. The ramp should extend to the basin bottom to avoid damage to vegetation planted on the basin slope.
4) All access ramps and roads should be provided in accordance with the current policies of the Flood Control District.

Vector Control

1) A Mosquito Management Plan or Service Contract should be approved or waived by the local Vector Control District for any facility that maintains a pool of water for 72 hours or more.

Operations and Maintenance

General Requirements

Maintenance is of primary importance if extended detention basins are to continue to function as originally designed. A maintenance agreement must be developed with the Flood Control District to ensure adequate performance and allow the County emergency access. Maintenance of the basin is the responsibility of the development, unless otherwise agreed upon.

A specific maintenance plan shall be formulated for each facility outlining the schedule and scope of maintenance operations, as well as the data handling and reporting requirements. The following are general maintenance requirements:

1) The basin should be inspected annually and inspections after major storm events are encouraged (see Appendix I for guidance on facility maintenance inspections). Trash and debris should be removed as needed, but at least annually prior to the beginning of the wet season (see Appendix I for dry extended detention basin inspection and maintenance checklist).

2) Site vegetation should be maintained as follows:

3) Vegetation, large shrubs, or trees that limit access or interfere with basin operation should be pruned or removed.

4) Slope areas that have become bare should be revegetated and eroded areas should be regraded prior to being revegetated.

5) Grass should be mowed to 4”-9” high and grass clippings should be removed.

6) Fallen leaves and debris from deciduous plant foliage should be raked and removed.

7) Invasive vegetation, such as Alligatorweed (Alternanthera philoxeroides), Halogeton (Halogeton glomeratus), Spotted Knapweed (Centaurea maculosa), Giant Reed (Arundo donax), Castor Bean (Ricinus communis), Perennial Pepperweed (Lepidium latifolium), and Yellow Starthistle (Centaurea solstitalis) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 25% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

8) Dead vegetation should be removed if it exceeds 10% of area coverage. Vegetation should be replaced immediately to maintain cover density and control erosion where soils are exposed.

9) No herbicides or other chemicals should be used to control vegetation.

10) Sediment buildup exceeding 50% of the forebay capacity should be removed. Sediment from the remainder of the basin should be removed when 6 inches of sediment accumulates. Sediments should be tested for toxic substance accumulation in compliance with current disposal requirements if land uses in the catchment include commercial or industrial zones, or if visual or olfactory indications of pollution are noticed. If toxic substances are encountered at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, the sediment must be disposed of in a hazardous waste landfill.

11) Following sediment removal activities, replanting, and/or reseeding of vegetation may be required for reestablishment.

Construction Considerations

The use of treated wood or galvanized metal anywhere inside the facility is prohibited. The use of galvanized fencing is permitted if in accordance with the Fencing requirement above.

TCM-3: Constructed Wetland

A constructed treatment wetland is a system consisting of a sediment forebay and one or more permanent micro-pools with aquatic vegetation covering a significant portion of the basin. Constructed treatment wetlands typically include components such as an inlet with energy dissipation, a sediment forebay for settling out coarse solids and to facilitate maintenance, a base with shallow sections (1 to 2 feet deep) planted with emergent vegetation, deeper areas or micro pools (3 to 5 feet deep), and a water quality outlet structure. The interactions between the incoming stormwater runoff, aquatic vegetation, wetland soils, and the associated physical, chemical, and biological unit processes are a fundamental part of constructed treatment wetlands.

Constructed Wetlands

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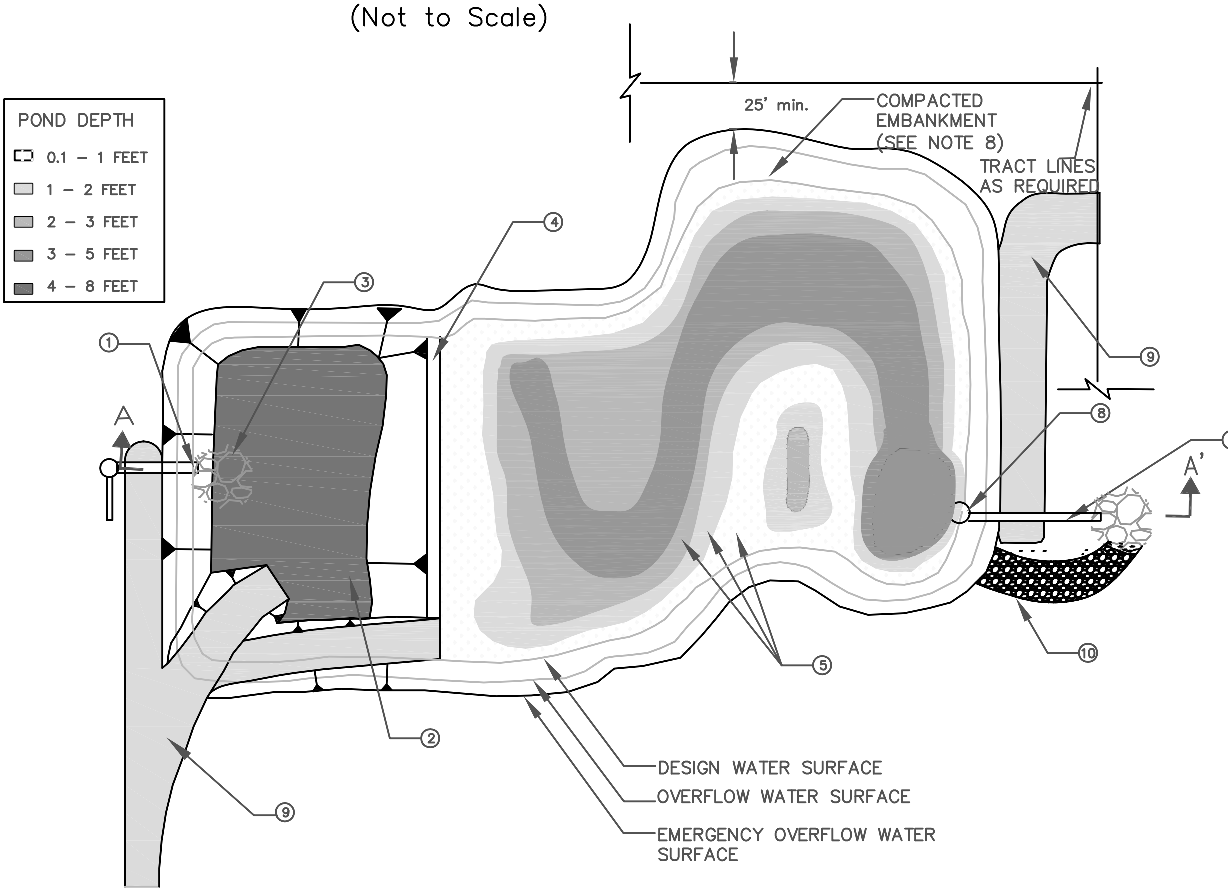
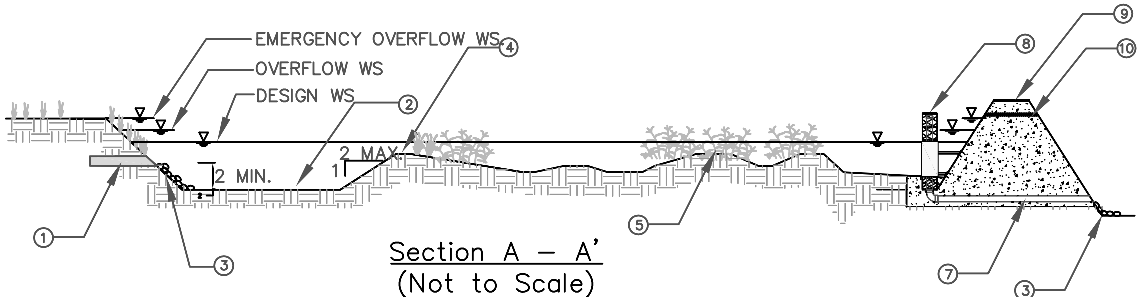
Application

- Regional detention & treatment
- Roads, highways, parking lots, commercial, residential
- Parks, open spaces, and golf courses

Preventative Maintenance

- inspected at a minimum annually and inspections after major storm events
- Pruned or remove vegetation, large shrubs, or trees that limit access or interfere with basin operation
- Remove sediment buildup at inlets and outlets





NOTES:

① INLET PIPE SHOULD BE SUBMERGED WITH A MINIMUM OF 2' DISTANCE FROM THE BOTTOM

② SEDIMENT FOREBAY. FORE BAY VOLUME SHALL EQUAL 10% TO 20% OF TOTAL WETLAND VOLUME. FOREBAY DEPTH SHALL BE 4' MIN TO 8' MAX PLUS AN ADDITIONAL I' MIN SEDIMENT STORAGE DEPTH.

③ RIP RAP APRON OR OTHER INLET ENERGY DISSIPATION.

④ BERM AT DESIGN WATER SURFACE ELEVATION OR SUBMERGED 1' BELOW DESIGN WATER SURFACE ELEVAVTION. EXTEND BERM ACROSS ENTIRE WIDTH OF THE WETLAND.

⑤ WETLAND VEGETATION. PLANTING SCHEME MUST BE DESIGNED BY A WETLAND ECOLOGIST.

⑥ EMBANKMENT SIDE SLOPES SHALL BE NO STEEPER THAN 2H:1V OUTSIDE AND 3H:1V INSIDE

⑦ SIZE OUTLET PIPE TO PASS 100-YEAR PEAK FLOW FOR ONLINE AND WATER QUALTIY PEAK FLOW FOR OFFLINE BASINS.

⑧ WATER QUALITY OUTLET STRUCTURE. SEE FIGURE 7-2 AND FIGURE 7-3 FOR DETAILS.

⑨ MAINTENANCE RAMP SHOULD PROVIDE ACCESS TO BOTH THE FOREBAY AND MAIN BASIN.

⑩ INSTALL EMERGENCY OVERFLOW SPILWAY AS NEEDED. SEE FIGURE 2-4 FOR DETAILS

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Figure 6-22: Constructed Wetland

Limitations

- In theory, there are no limitations on the tributary area size draining to a constructed treatment wetland; however, constructed treatment wetlands usually require considerable land area. Typically, treatment wetlands capture runoff from tributary areas larger than 10 acres and less than 10 square miles. Smaller "pocket" wetlands can be feasible in areas where space is restricted.
- If the constructed treatment wetland is not used for flow control, the wetland must not interfere with flood control functions of existing conveyance and detention structures.
- Constructed treatment wetlands should not be permitted in areas with site slopes greater than 7% or within 200 feet (on the uphill side) of a steep slope hazard area or a mapped landslide area unless a geotechnical investigation and report is completed by a licensed civil engineer.
- Constructed treatment wetlands require a regular source of water (base flow) to maintain wetland vegetation and associated treatment processes. If adequate base flow is not available year-round, supplemental water may be needed during the summer months to maintain adequate base flow.

Design Criteria

The main challenge associated with constructed treatment wetlands is maintaining base flow to support vegetation. Constructed wetlands should be designed according to the requirements listed in Table 6-25 and outlined in the section below. Constructed wetland BMP sizing worksheets are presented in Appendix E.

Table 6-25: Constructed Wetland Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume, SQDV	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Permanent pool volume	%	75% of SQDV
Drawdown time for extended detention (over permanent pool)	hours	48 ; 12 for 50% SQDV (minimum)
Sediment forebay volume	%	30 to 50% of permanent pool surface area
Depth of sediment forebay	feet	2-4 (1 foot of sediment storage required)
Wetland zone volume	%	50-70% of permanent pool surface area
Depth of wetland basin	feet	0.5 to 1.0 (30 to 50% should be 0.5 feet deep)

Design Parameter	Unit	Design Criteria
Wetland (littoral zone) bottom slope	%	10 maximum
Maximum residence time	Days	7 (dry weather)
Freeboard (minimum)	inches	12
Flow path length to width ratio	L:W	2:1, larger preferred
Side slope (maximum)	H:V	4:1 Interior; 3:1 Exterior
Vegetation Type	--	Varies see vegetation section below
Vegetation Height	--	Varies see vegetation section below
Buffer zone (minimum)	feet	25
Minimum outflow device diameter	inches	18

Sizing

In most cases, the constructed treatment wetland permanent pool should be sized to be greater than or equal to the stormwater quality design volume. If extended detention is provided above the permanent pool and the wetland is designed for water quality treatment only, then the permanent pool volume should be a minimum of 80 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) should make up the remaining 20 percent and provide at least 12 hours of detention. If extended detention is provided and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume should be equal to the water quality treatment volume and the surcharge volume should be sized to attenuate peak flows to meet the peak runoff discharge requirements. The extended detention portion of the wetland above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin).

Step 1: Calculate the design volume

Constructed wetlands shall be sized to be greater than or equal to the SQDV volume (see Section 2 and Appendix E).

Step 2: Determine the Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints

Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. The equations provided below assume a trapezoidal geometry for cell 1 (Forebay) and cell 2, and assumes that the wetland does not have extended detention.

1) Calculate the width of the wetland footprint, W_{tot}, as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}} \qquad \text{(Equation 6-81)}$$

Where:

A_{tot}	=	total surface area of the wetland footprint (ft^2)
L_{tot}	=	total length of the wetland footprint (ft)

2) Calculate the length of the water quality volume surface area including the internal berm but excluding the freeboard, $L_{wq\text{-}tot}$:

$$L_{wq-tot} = L_{tot} - 2Zd_{fb} \qquad \text{(Equation 6-82)}$$

Where:

Z	=	interior side slope as length per unit height
d_{fb}	=	freeboard depth

3) Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, $W_{wq\text{-}tot}$:

$$W_{wq-tot} = W_{tot} - 2Zd_{fb} \qquad \text{(Equation 6-83)}$$

4) Calculate the total water quality volume surface area including the internal berm and excluding freeboard, $A_{wq\text{-}tot}$:

$$A_{wq-tot} = L_{wq-tot} \times W_{wq-tot} \qquad \text{(Equation 6-84)}$$

5) Calculate the area of the berm, A_{berm}:

$$A_{berm} = W_{berm} \times L_{berm} \qquad \text{(Equation 6-85)}$$

Where:

W_{berm}	=	width of the internal berm
L_{berm}	=	length of the internal berm

6) Calculate the water quality surface area excluding the internal berm and freeboard, A_{wq}:

$$A_{wq} = A_{wq=tot} - A_{berm}$$ (Equation 6-86)

Step 3: Determine Dimensions of Forebay

30-50% of the SQDV is required to be within the active volume of forebay.

1) Calculate the active volume of forebay, V_1:

$$V_1 = \frac{SQDV \times \%V_1}{100}$$ (Equation 6-87)

Where:

$\%V_1$ = percent of SQDV in forebay (%)

2) Calculate the surface area for the active volume of forebay, A_1:

$$A_1 = \frac{V_1}{d_1}$$ (Equation 6-88)

Where:

d_1 = average depth fo rhte active volume of forebay (2 -4 ft) (ft)

3) Calculate the length of forebay, L_1. Note, inlet and outlet should be configured to maximize the residence time.

$$L_1 = \frac{A_1}{W_1}$$ (Equation 6-89)

Where:

W_1 = width of forebay (ft), $W_1 = W_{av\text{-}tot} = L_{berm}$

Step 4: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

1) Calculate the active volume of Cell 2, V_2:

$$V_2 = SQDV - V_1$$ (Equation 6-90)

2) Calculate the surface area of Cell 2, A_2:

$$A_2 = A_{wq} - A_1$$ (Equation 6-91)

3) Calculate the top length of Cell 2, L_2:

$$L_2 = \frac{A_2}{W_2}$$ (Equation 6-92)

Where:

W_2 = width of Cell 2 (ft), $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$

4) Verify that the length-to-width ratio of Cell 2, LW_2, is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen.

$$LW_2 = \frac{L_2}{W_2}$$ (Equation 6-93)

5) Calculate the very shallow zone surface area, A_{vs}:

$$A_{vs} = \frac{A_2 \bullet \%A_{vs}}{100}$$ (Equation 6-94)

Where:

$\%A_{VS}$ = percent of surface area of very shallow zone

6) Calculate the volume of the shallow zone, V_{vs}:

$$V_{vs} = A_{vs} \bullet d_{vs}$$ (Equation 6-95)

Where:

d_{VS} = average depth of the very shallow zone (0.1 – 1 ft)

7) Calculate the length of the very shallow zone, L_{vs}:

$$L_{vs} = \frac{A_{vs}}{W_{vs}}$$ (Equation 6-96)

Where:

W_{VS} = width of the very shallow zone (ft), $W_{VS} = W_2$

8) Calculate the surface area of the shallow zone, A_s:

$$A_s = \frac{A_2 \bullet \%A_s}{100}$$ (Equation 6-97)

Where:

$\%A_s$ = percent of surface area of shallow zone

9) Calculate the volume of the shallow zone, V_s:

$$V_s = A_s \bullet d_s \quad \text{(Equation 6-98)}$$

Where:

d_s = average depth of shallow zone (1 - 3 ft)

10) Calculate length of the shallow zone, L_s:

$$L_s = \frac{A_s}{W_s} \quad \text{(Equation 6-99)}$$

Where:

W_s = width of the shallow zone (ft), $W_s = W_2$

11) Calculate the surface area of the deep zone, A_{deep}:

$$A_{deep} = A_2 - A_{vs} - A_s \quad \text{(Equation 6-100)}$$

12) Calculate the volume of the deep zone, V_{deep}:

$$V_{deep} = V_2 - V_{vs} - V_s \quad \text{(Equation 6-101)}$$

13) Calculate the average depth of the deep zone (3-5 ft), d_{deep}:

$$d_{deep} = \frac{V_{deep}}{A_{deep}} \quad \text{(Equation 6-102)}$$

14) Calculate length of the deep zone, L_{deep}:

$$L_{deep} = \frac{A_{deep}}{W_{deep}} \quad \text{(Equation 6-103)}$$

Where:

W_{deep} = width of the deep zone (ft), $W_{deep} = W_2$

Step 5: Ensure design requirements and site constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or alternative treatment BMP.

Step 6: Size Outlet Structure

For wetlands with detention, the outlet structures should be designed to provide 12 hours emptying time for the water quality volume or the required detention necessary for achieving the peak runoff discharge requirements if the extended detention is designed for flow attenuation.

The wetland outlet pipe should be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for on-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing and Geometry

In most cases, the constructed treatment wetland permanent pool should be sized to be greater than or equal to the stormwater quality design volume. If extended detention is provided above the permanent pool and the wetland is designed for water quality treatment only, then the permanent pool volume should be a minimum of 80 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) should make up the remaining 20 percent and provide at least 12 hours of detention. If extended detention is provided and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume should be equal to the water quality treatment volume and the surcharge volume should be sized to attenuate peak flows to meet the peak runoff discharge requirements. A constructed treatment wetland design worksheets are presented in Appendix E. The extended detention portion of the wetland above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see TCM-1: Dry Extended Detention Basin).

1) Constructed treatment wetlands should consist of at least two cells including a sediment forebay and a wetland basin.

2) The sediment forebay must contain between 10 and 20 percent of the total basin volume.

3) The depth of the sediment forebay should be between 4 and 8 feet.

4) One foot of sediment storage should be provided in the sediment forebay.

5) The "berm" separating the two basins should be uniform in cross-section and shaped such that its downstream side gradually slopes to the main wetland basin.

6) The top of berm should be either at the stormwater quality design water surface or submerged 1 foot below the stormwater quality design water surface, as with wet retention basins. Correspondingly, the side slopes of the berm should meet the following criteria:

   a. If the type of the berm is at the stormwater quality design water surface, the berm side slopes should be no steeper than 4H:1V.

   b. If the top of berm is submerged 1 foot, the upstream side slope may be a max of 3H:1V.

7) The constructed treatment wetlands should be designed with a "naturalistic" shape and a range of depths intermixed throughout the wetland basin to a maximum of 5 feet.

Depth Range (feet)	Percent by Area
0.1 to 1	15
1 to 3	55
3 to 5	30

8) The flowpath length-to-width ratio should be a minimum of 2:1, but preferably at least 4:1 or greater. *Intent: a high flow path length to width ratio will maximize fine sediment removal.*

9) The minimum freeboard should be 1 foot above the maximum water surface elevation for on-line basins (2 feet preferable) and 1 foot above the maximum water surface elevation for on-line basins.

10) Wetland pools should be designed such that the residence time for dry weather flows is no greater than 7 days. *Intent: Minimize vector and stagnation issues.*

Water Supply

Water balance calculations should be provided to demonstrate that adequate water supply will be present to maintain a permanent pool of water during a drought year when precipitation is 50% of average for the site. Water balance calculations should include evapotranspiration, infiltration, precipitation, spillway discharge, and dry weather flow (where appropriate).

Where water balance indicates that losses will exceed inputs, a source of water should be provided to maintain the wetland water surface elevation throughout the year. The water supply should be of sufficient quantity and quality to not have an adverse impact on the wetland water quality. Water that meets drinking water standards should be assumed to be of sufficient quality.

Soils Considerations

1) Implementation of constructed treatment wetlands in areas with high permeability soils (>0.1 in/hr) requires liners to increase the chances of maintaining permanent pools and/or micro-pools in the basin. Liners can be either synthetic materials or imported lower permeability soils (i.e., clays). The water balance assessment should determine whether a liner is required. The following conditions can be used as a guideline.
2) The wetland basin should retain water for at least 10 months of the year.
3) The sediment forebay should retain at least 3 feet of water year-round.
4) Many wetland plants can adapt to periods of summer drought, so a limited drought period is allowed in the wetland basin. This may allow for a soil liner rather than a geosynthetic liner. The sediment forebay should retain water year-round for presettling to be effective.
5) If low permeability soils are used for the liner, a minimum of 18 inches of native soil amended with good topsoil or compost (one part compost mixed with 3 parts native soil) should be placed over the liner (see soil amendment Section 5.10). If a synthetic material is used, a soil depth of 2 feet is recommended to prevent damage to the liner during planting.

Buffer Zone

A minimum of 25 feet buffer should be provided around the top perimeter of the constructed treatment wetlands.

Energy Dissipation

1) The inlet to the constructed treatment wetland should be submerged with the inlet pipe invert a minimum of two feet from the cell bottom (not including sediment storage). The top of the inlet pipe should be submerged at least 1 foot, if possible. *Intent: the inlet is submerged to dissipate energy of the incoming flow. The distance from the bottom is set to minimize resuspension of settled sediments. Alternative inlet designs that accomplish these objectives are acceptable.*
2) Energy dissipation controls must also be used at the outlet/spillway from the constructed treatment wetlands unless the wetland discharges to a stormwater conveyance system or hardened channel.

Vegetation

1) The wetland cell(s) should be planted with emergent wetland plants following the recommendations of a wetlands specialist.

2) Landscaping outside of the basin is required for all constructed wetlands and should adhere to the following criteria so as not to hinder maintenance operations:

    a. No trees or shrubs may be planted within 15 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, should not be used within 50 feet of pipes or manmade structures. Weeping willow (*Salix babylonica*) should not be planted in or near detention basins.

    b. Prohibited non-native plant species will not be permitted. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

3) Project-specific planting recommendations should be provided by a wetland ecologist or a qualified landscape professional including recommendations on appropriate plants, fertilizer, mulching applications, and irrigation requirements (if any) to ensure healthy vegetation growth.

Outlet Structure

An outlet pipe and outlet structure should be provided. The outlet pipe may be a perforated standpipe strapped to a manhole or placed in an embankment, suitable for extended detention, or may be back-sloped to a catch basin with a grated opening (jail house window) or manhole with a cone grate (birdcage). The grate or birdcage openings provide an overflow route should the basin outlet pipe become clogged. The outlet should be protected from clogging by a skimmer shield that starts at the bottom of the permanent pool and extends above the SQDV depth. A trash rack is also required.

For wetlands with detention, the outlet structures should be designed to provide 12 hours emptying time for the water quality volume or the required detention necessary for achieving the peak runoff discharge requirements if the extended detention is designed for flow attenuation.

The wetland outlet pipe should be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for on-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

See the dry extended detention section (see ST-1: Dry Extended Detention Basin) and Appendix E for further detail on outlet sizing.

Emergency Spillway

An emergency overflow spillway in addition to the primary overflow outlet (as described above) is required. The emergency spillway should be sized for flows greater than the peak 100-year 24-hour storm if the basin is designed on-line or, if the basin is designed on-line, the spillway should be sized for flows greater than the basin design volume (e.g., stormwater quality design volume). The spillway provide for adequate energy dissipation downstream. The spillway should allow for at least 12 inches of freeboard above the emergency overflow water surface elevation if the basin is on-line. If the basin is on-line, 2 feet of freeboard is preferable.

Spillways shall meet the California Department of Water Resources, Division of Safety of Dams Guidelines for the Design and Construction of Small Embankment Dams (http://damsafety.water.ca.gov/docs/GuidelinesSmallDams.pdf). *Intent: Emergency overflow spillways are intended to control the location of basin overtopping and safely direct overflows back into the downstream conveyance system or ot her acceptable discharge point.*

On-line Basins

1) On-line basins must have an emergency overflow spillway to prevent overtopping of walls or berms should blockage of the primary outlet occur based on a downstream risk assessment.

2) The overflow spillway must be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm.

3) The minimum freeboard should be 1 foot (but preferably at least 2 feet) above the maximum water surface elevation over the emergency spillway.

Off-line Basins

1) Off-line basins must have either an emergency overflow spillway or an emergency overflow riser. The emergency overflow must be designed to pass the 100-yr 24-hr post-development peak stormwater runoff discharge rate (see Appendix E for further detail) directly to the downstream conveyance system or another acceptable discharge point. Where an emergency overflow spillway would discharge to a steep slope, an emergency overflow riser, *in addition* to the spillway should be provided.

2) The emergency overflow spillway should be armored to withstand the energy of the spillway flows. The spillway should be constructed of grouted rip-rap.

3) The minimum freeboard should be 1 foot above the maximum water surface elevation over the emergency spillway.

Side Slopes

1) Interior side slopes above the stormwater quality design depth and up to the emergency overflow water surface steeper than 4:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

2) Exterior side slopes steeper than 2:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

3) For any slope (interior or exterior) greater than 2:1 (H:V), a geotechnical investigation and report must be submitted and approved by the local permitting authority.

4) Landscaped slopes should be no steeper than 3:1 (H:V) to allow for maintenance.

5) Basin walls may be vertical retaining walls, provided: (a) they are constructed of reinforced concrete, (b) a fence is provided along the top of the wall (see fencing below) or further back, and (c) the design is stamped by a licensed civil engineer and approved by the local permitting authority.

Embankments

1) Earthworks and berm embankments should be performed in accordance with the latest edition of the "Greenbook Standard Specifications for Public Works Construction".

2) Embankments are earthen slopes or berms used for detaining or redirecting the flow of water.

3) Top of berm should be 2 feet minimum below the stormwater quality design water surface and should be keyed into embankment a minimum of 1 foot on both sides.

4) Typically, the top width of berm embankments are at least 20 f eet, but narrower embankments may be plausible if approved by the civil engineer and the local permitting authority.

5) Basin berm embankments should be constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a licensed civil engineer) free of loose surface soil materials, roots, and other organic debris.

6) Basin berm embankments greater than 4 feet in height should be constructed by excavating a key equal to 50% of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed civil engineer.

7) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

8) Low growing native or non-invasive perennial grasses should be planted on downstream embankment slopes. See vegetation section below.

Fencing

Safety is provided either by fencing of the facility or by managing the contours of the basin to eliminate drop-offs and other hazards.

1) Provide fencing in accordance with the local permitting agency's requirements Perimeter fencing (minimum height of 42 inches) should be required on all basins exceeding two feet in depth or where interior side slopes are steeper than 6:1 (H:V).

2) If fences are required, fences should be designed and constructed in accordance with current policies of the local permitting agency and should be located at or above the overflow water surface elevation. Shrubs (approved, California-adapted species) can be used to hide the fencing. See vegetation section above.

Right-of-Way

1) Constructed treatment wetlands and associated access roads to be maintained by a public agency should be dedicated in fee or in an easement to the public agency with appropriate access.

Maintenance Access

1) Ownership of the basin and maintenance thereof is the responsibility of the developer/applicant. A maintenance agreement is required to ensure adequate performance and allow emergency access to the facilities.

2) Maintenance access road(s) should be provided to the control structure and other drainage structures associated with the basin (e.g., inlet, emergency overflow or bypass structures). Manhole and catch basin lids should be in or at the edge of the access road.

3) An access ramp into the basin should be constructed near the basin outlet. An access ramp is required for removal of sediment with a backhoe or loader and truck. The ramp should extend to the basin bottom to avoid damage to vegetation planted on the basin slope.

4) All access ramps and roads should be provided in accordance with the current policies of the Flood Control District.

Vector Control

1) A Mosquito Management Plan or Service Contract should be approved or waived by the local Vector Control District for any facility that maintains a pool of water for 72 hours or more.

Construction Considerations

The use of treated wood or galvanized metal anywhere inside the facility is prohibited. The use of galvanized fencing is permitted if in accordance with the Fencing requirement above.

Operations and Maintenance

Maintenance is of primary importance if constructed treatment wetlands basins are to continue to function as originally designed. A specific maintenance plan shall be formulated for each facility outlining the schedule and scope of maintenance operations, as well as the data handling and reporting requirements. The following are general maintenance requirements:

1) The constructed treatment wetlands basin should be inspected twice annually or more frequently, and inspections after major storm events are encouraged (see Appendix I for a c onstructed treatment wetland inspection and maintenance checklist). Trash and debris should be removed as needed, but at least annually prior to the beginning of the wet season.

2) Site vegetation should be maintained as frequently as necessary to maintain the aesthetic appearance of the site and to prevent clogging of outlets, creation of dead volumes, and barriers to mosquito fish to access pooled areas, and as follows:

3) Vegetation, large shrubs, or trees that limit access or interfere with basin operation should be pruned or removed.

4) Slope areas that have become bare should be revegetated and eroded areas should be regraded prior to being revegetated.

5) Invasive vegetation, such as Alligatorweed (*Alternanthera philoxeroides*), Halogeton (*Halogeton* glomeratus), Spotted Knapweed (*Centaurea maculosa*), Giant Reed (*Arundo donax*), Castor Bean (*Ricinus communis*), Perennial Pepperweed (*Lepidium latifolium*), and Yellow Starthistle (*Centaurea solstitalis*) should be removed and replaced with non-invasive species. Invasive species should never contribute more than 25% of the vegetated area. For more information on invasive weeds, including biology and control of listed weeds, look at the encycloweedia located at the California Department of Food and Agriculture website or the California Invasive Plant Council website at www.cal-ipc.org.

6) Dead vegetation should be removed if it exceeds 10% of area coverage. This does not include seasonal die-back where roots would grow back later in colder areas. Vegetation should be replaced immediately to maintain cover density and control erosion where soils are exposed.

7) Sediment buildup exceeding 6 inches over the storage capacity in the first cell should be removed. Sediments should be tested for toxic substance accumulation in compliance with current disposal requirements if land uses in the catchment include

commercial or industrial zones, or if visual or olfactory indications of pollution are noticed. If toxic substances are encountered at concentrations exceeding thresholds of Title 22, Section 66261 of the California Code of Regulations, the sediment must be disposed of in a hazardous waste landfill. Clean forebay every two years at a minimum, to avoid accumulation in main wetland area. Environmental regulations and permits may be involved with the removal of wetland deposits. When the main wetland area needs to be cleaned, it is suggested that the main area be cleaned one half at a time with at least one growing season in between cleanings. This will help to preserve the vegetation and enable the wetland to recover more quickly from the cleaning.

8) Repair erosion to banks and bottom as required.

9) Inspect outlet for clogging a minimum of twice a year, before and after the rainy season, after large storms, and more frequently if needed. C orrect observed problems as necessary.

10) Following sediment removal activities, replanting, and/or reseeding of vegetation may be required for reestablishment.

TCM-4: Sand Filters

Sand filters operate much like bioretention facilities; however, instead of filtering stormwater through engineered soils, stormwater is filtered through a constructed sand bed with an underdrain system. Runoff enters the filter and spreads over the surface. As flows increase, water backs up on the surface of the filter where it is held until it can percolate through the sand. The treatment pathway is vertical (downward through the sand) to a perforated underdrain system that is connected to the downstream storm drainage system or to an infiltration facility. As stormwater passes through the sand, pollutants are trapped in the small pore spaces between sand grains or are adsorbed to the sand surface.

Sand filters connected to impervious surfaces

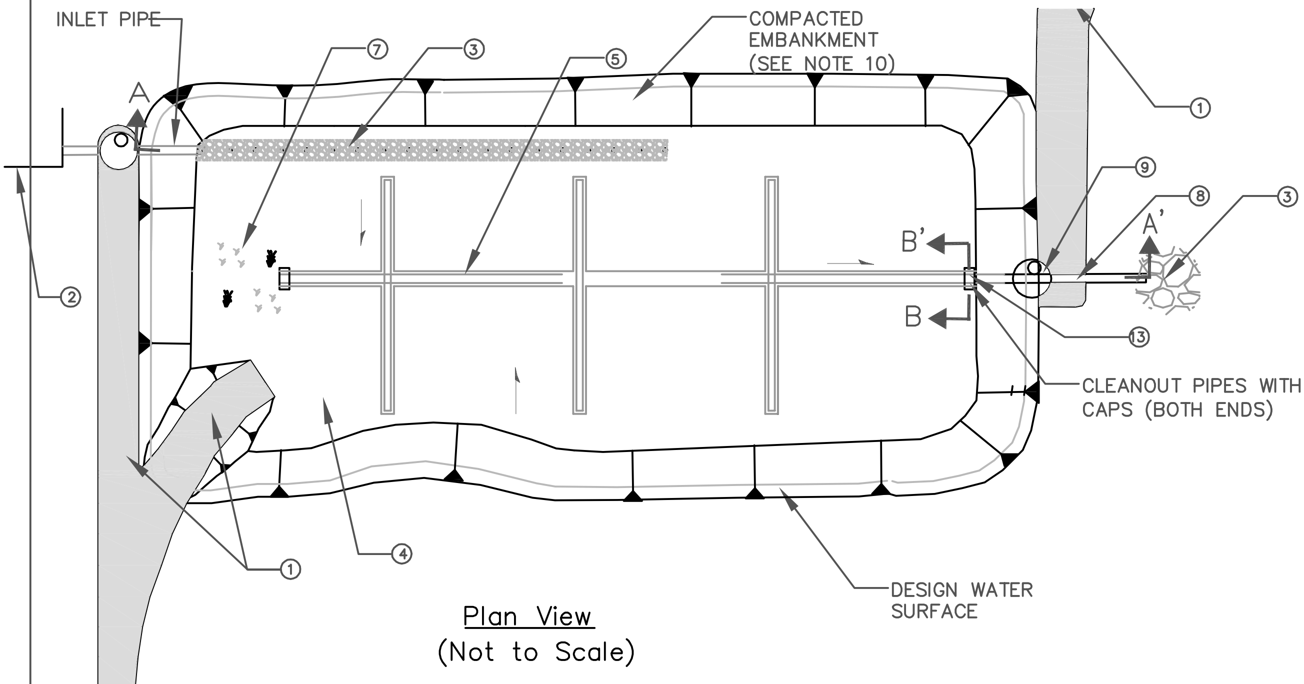
Photo Credits: Geosyntec Consultants

Application

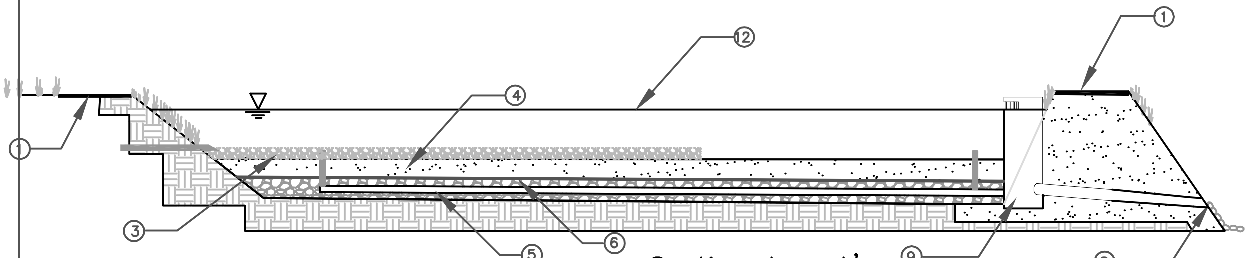
- Adjacent to parking lots
- Road medians and shoulders
- Within open areas or play fields

Preventative Maintenance

- Remove trash and debris, minor sediment accumulation, and obstructions near inlet and outlet structures
- Replace top 2” – 4” of sand
- Mow or weed surface of filter



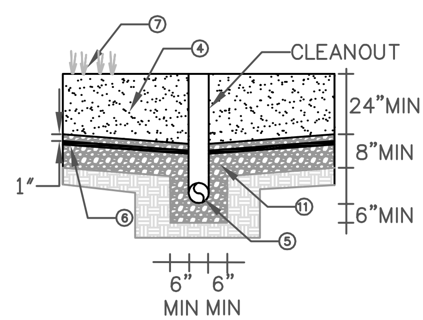
Plan View
(Not to Scale)



Section A – A'
(Not to Scale)

NOTES:

1. INSTALL MAINTENANCE ACCESS ROAD AND RAMP TO BOTTOM OF SAND FILTER.
2. UPSTREAM PRETREATMENT SHALL BE PROVIDED. IN THE ABSENCE OF PRETREATMENT, INCLUDE SEDIMENT FOREBAY WITH VOLUME EQUAL TO 10–20% OF TOTAL SAND FILTER VOLUME.
3. FLOW SPREADER TO EVENLY DISTRIBUTE FLOWS ALONG AT LEAST 20% OF PERIMETER.
4. FILTER BED SHALL BE A 24" MINIMUM SAND LAYER ON TOP OF 8" MINIMUM GRAVEL OR DRAIN ROCK BACKFILL.
5. 6" MINIMUM DIAMETER PERFORATED PIPE UNDERDRAIN SURROUNDED BY GRAVEL BEDDING. INSTALL AT 0.5% MINIMUM SLOPE
6. INSTALL GEOTEXTILE FABRIC OVERLAIN BY 1" OF DRAIN ROCK OR TRANSITIONALLY GRADED AGGREGRATE BETWEEN SAND AND GRAVEL LAYER.
7. VEGETATION MAY BE PLANTED ON TOP OF FILTER BED. NO TOP SOIL SHALL BE ADDED TO FILTER BED.
8. SIZE OUTLET PIPE STRUCTURE TO PASS WATER QUALITY DESIGN STORM AND INCLUDE AN EMERGENCY OVERFLOW.
9. EMERGENCY OVERFLOW STRUCTURE.
10. ¾" – 1½" WASHED DRAIN ROCK OR GRAVEL LAYER.
11. DESIGN WATER SURFACE. 6' MAX PONDING DEPTH.



Section B – B'
(Not to Scale)

Geosyntec consultants

Figure 6-23: Sand Filter

Limitations

Limitations for sand filters include:

- The sand filter should be located away from trees producing leaf litter or areas contributing significant eroded sediment to prevent clogging.
- Sand filters are should not be used in areas where heavy sediment loads are expected or in tributary areas that are not fully stabilized; high sediment loading rates may cause premature clogging of the filter. Pretreatment is essential.
- Site must have adequate relief between land surface and stormwater conveyance system to permit vertical percolation through the sand filter and collection and conveyance in the underdrain to stormwater conveyance system; four feet of elevation difference is recommended between the inlet and outlet of the filter.
- Not applicable in areas of high groundwater.
- Does not provide quantity control.

Design Criteria

The main challenge associated with sand filters is maintaining the filtration capacity, which is critical to the performance of this BMP. If flows entering the sand filter have high sediment concentrations, clogging of the sand filter is likely. Contribution of eroded soils or leaf litter may also reduce the infiltration and associated treatment capacity of the structure. Sand filters should be designed according to the requirements listed in Table 6-26 and outlined in the section below. BMP sizing worksheets are presented in Appendix E.

Table 6-26: Sand Filter Design Criteria

Design Parameter	Unit	Design Criteria
Stormwater quality design volume, SQDV	acre-feet	See Section 2 and Appendix E for calculating SQDV.
Max depth at SQDV	feet	3
Freeboard (minimum)	feet	1
Length to width ratio	L:W	2:1 (larger preferred)
Filter bed depth	inches	18 inches sand; 9 inches gravel
Max ponding depth above filter bed	feet	6
Drawdown time	Hours	?

Design Parameter	Unit	Design Criteria
Hydraulic conductivity of sand, k	in/hr	1 (equal to 2 ft/day)
Underdrains		6 inch minimum diameter; 0.5% minimum slope
Side slopes	H:V	4:1 (H:V) interior and 3:1 (H:V) exterior, unless stabilization has been approved by a licensed geotechnical engineer; or vertical concrete walls

Pretreatment

Pretreatment must be provided for sand filters in order to reduce the sediment load entering the filter. Pretreatment refers to design features that provide settling of large particles before runoff reaches the filter, easing the long-term maintenance burden. To ensure that pretreatment mechanisms are effective, designers shall incorporate pretreatment such as a biofiltration BMP, proprietary device, or sedimentation forebay. BMPs that are described in the 2011 TGM that may serve this purpose include:

For design specification of selected pre-treatment devices, refer to:

- VEG-3: Vegetated swale
- VEG-4: Vegetated filter strip
- PROP-1: Hydrodynamic separation device

Sizing Criteria

Background

Sand filter design is based on Darcy's law:

$$Q = KiA \qquad \text{(Equation 6-104)}$$

Where:

Q = water quality design flow (cfs)

K = hydraulic conductivity (fps)

A = surface area perpendicular to the direction of flow (ft^2)

i = hydraulic gradient (ft/ft) for a constant head and constant media depth, computed as follows:

$$i = \frac{h + l}{l} \qquad \text{(Equation 6-105)}$$

Where:

h	=	average depth of water above the filter (ft), defined for this design as $d/2$
d	=	maximum storage depth above the filter (ft)
l	=	thickness of sand media (ft)

Darcy's law underlies both the simple and the routing methods of design. The filtration rate V, or more correctly, $1/V$, is the direct input in the sand filter design. The relationship between the filtration rate V and hydraulic conductivity K is revealed by equating Darcy's law and the equation of continuity, $Q = VA$. Specifically:

$Q = KiA$ and $Q = VA$

So, $VA = KiA$

Or: $V = Ki$ (Equation 6-106)

Where,

V	=	filtration rate (ft/s)

Note that $V \neq K$. That is, the filtration rate is not the same as the hydraulic conductivity, but they do have the same units (distance per time). K can be equated to V by dividing V by the hydraulic gradient i, which is defined above.

The hydraulic conductivity K does not change with head nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. A design hydraulic conductivity of 1 inch per hour (2 feet per day) used in this simple sizing method is based on bench-scale tests of conditioned rather than clean sand (KCSWDM, 2005) and represents the average sand bed condition as silt is captured and held in the sand bed.

Unlike the hydraulic conductivity, the filtration rate V changes with head and media thickness, although the media thickness is constant in the sand filter design.

Simple Sizing Method

The simple sizing method does not route flows through the filter. It determines the size of the filter based on the simple assumption that inflow is immediately discharged through the filter as if there were no storage volume. An adjustment factor (0.7) is applied to compensate for the greater filter size resulting from this method. Even with the adjustment factor, the simple method generally produces a larger filter size than the routing method.

Step 1: Determine the water quality design volume

Sand filters should be sized to capture and treat the stormwater quality design volume (see Section E.1).

Step 2: Determine maximum storage depth of water

Determine the maximum water storage depth (d) above the sand filter. This depth is defined as the depth at which water begins to overflow the reservoir pond, and it depends on the site topography and hydraulic constraints. The depth is chosen by the designer, but should be 6 feet or less.

Step 3: Calculate the sand filter area

Determine the sand filter area using the following equation:

$$A_{sf} = \frac{V_{wq} R L}{K t (h + L)} \qquad \text{(Equation 6-107)}$$

Where,

A_{sf}	=	surface area of the sand filter bed (ft^2)
V_{wq}	=	water quality design volume (ft^3)
R	=	routing adjustment factor (use $R = 0.7$)
L	=	sand bed depth (ft)
K_{des}	=	design hydraulic conductivity of media (use 2 ft/day)
t	=	drawdown time (use 1 day)
h	=	average depth of water above the filter (ft), [use (d/2) with d from Step 2]

Routing Method

A continuous runoff model, such as US EPA's Stormwater Management Model (SWMM) Model, can be used to optimally size a sand filter. A continuous simulation model consists of three components: a representative long term period of rainfall data (≈ 20 years or greater) as the primary model input; a model component representing the tributary area to the sand filter that takes into account the amount of impervious area, soil types of the pervious area, vegetation, evapotranspiration, etc.; and a component that simulates the sand filter. Using this method, the filter should be sized to capture and treat the WQ design volume from the post-development tributary area.

The continuous simulation model routes predicted tributary runoff to the sand filter, where treatment is simulated as a function of the infiltrative (flow) capacity of the sand filter and the available storage volume above the sand filter. In a continuous runoff model such as SWMM, the physical parameters of the sand filter are represented with stage-storage-discharge relationships. Due to the computational power of ordinary desktop computers, long-term continuous simulations generally take only minutes to run. This allows the modeler to run several simulations for a range of sand filter sizes, varying either the surface area of the filter (and resulting flow capacity) or the storage capacity above the sand filter, or both. Sufficient continuous model simulations should be completed so that results encompass the WQ design volume capture goal.

Model results should be plotted for both varying storage depths above the filter and for varying filter surface area (and resulting flow capacity) while keeping all other parameters constant. The resulting relationship of percent capture as a function of sand filter flow and storage capacity can be used to optimally size a sand filter based on site conditions and restraints.

In addition to continuous simulation modeling, routing spreadsheets and/or other forms of routing modeling that incorporate rainfall-runoff relationships and infiltrative (flow) capacities of sand filters may be used to size facilities. Alternative sizing methodologies should be prepared with good engineering practices.

Sizing and Geometry

1) Sand filters shall be sized to capture and filter the Stormwater quality design volume, SQDV (See Section 2 and Appendix E for further detail).

2) Sand filters may be designed in any geometric configuration, but rectangular with a 2:1 length-to-width ratio or greater is preferred.

3) Filter bed depth must be at least 24 inches, but 36 inches is preferred.

4) Depth of water storage over the filter bed should be 6 feet maximum. Minimum freeboard is one foot.

5) Sand filters should be placed off-line to prevent scouring of the filter bed by high flows. The overflow structure must be designed to pass the stormwater quality design storm.

Sand Specification

Ideally the effective diameter of the sand, d_{10} (the diameter corresponding to the sieve size that passes 10% of sand grains), should be just small enough to ensure a good quality effluent while preventing penetration of stormwater particles to such a depth that they cannot be removed by surface scraping (~2-3 inches). This effective diameter usually lies in the range 0.20-0.35 mm. In addition, the coefficient of uniformity, $Cu = d_{60}/d_{10}$, should be less than 3.

The sand in a filter should consist of medium sand with few fines meeting ASTM C 33 size gradation (by weight) or equivalent as given in the table below.

U.S. Sieve Size	Percent Passing
3/8 inch	100
U.S. No. 4	95 to 100
U.S. No. 8	80 to 100
U.S. No. 16	50 to 85
U.S. No. 30	25 to 60
U.S. No. 50	5 to 30
U.S. No. 100	Less than 10

Finally, the silica (SiO_2) content of the sand should be greater than 95% by weight.

Underdrain

1) There are several underdrain system options which can be used in the design of a sand filter:

    a. A central underdrain collection pipe with lateral collection pipes in an 8 inch minimum gravel backfill or drain rock bed.

    b. Longitudinal pipes in an 8 inch minimum gravel backfill or drain rock bed, with a collection pipe at the outfall.

    c. Small sand filters may use a single underdrain pipe in an 8 inch minimum gravel backfill or drain rock bed.

2) All underdrain pipes and connectors should be 6 inches or greater so they can be cleaned without damage to the pipe. Clean-out risers with diameters equal to the underdrain pipe should be placed at the terminal ends of all pipes and extend to the surface of the filter. A valve box should be provided for access to the cleanouts and the cleanout assembly should be water tight to prevent short circuiting of the sand filter.

3) The underdrain pipe should be sized and perforated as to ensure free draining of the sand filter bed. Round perforations should be at least 1/2-inch in diameter and the pipe should be laid with holes downward.

4) The maximum perpendicular distance between any two lateral collection pipes or from the edge of the filter and the collection pipes should be 9 feet.

5) All pipes should be placed with a minimum slope of 0.5%.

6) The invert of the underdrain outlet should be above the seasonal high groundwater level.

7) At least 8 inches of gravel backfill should be maintained over all underdrain piping, and at least 6 inches should be maintained on both side and beneath the pipe to prevent damage by heavy equipment during maintenance. Either drain rock or gravel backfill may be used between pipes.

8) The bottom gravel layer should have a diameter at least 2X the size of the openings into the drainage system. The grains should be hard, preferably rounded, with a specific gravity of at least 2.5, and free of clay, debris and organic impurities.

9) Either a geotextile fabric or a two-inch transition gradation layer (preferred) should be placed between the sand layer and the drain rock or gravel backfill layer. If a geotextile is used, one inch of drain rock or gravel backfill should be place above the fabric. This allows for a transitional zone between sand and gravel and may reduce pooling of water at the liner interface. The geotextile should meet the following minimum materials requirements.

Geotextile Property	Value	Test Method
Trapezoidal Tear (lbs)	40 (min)	ASTM D4533
Permeability (cm/sec)	0.2 (min)	ASTM D4491
AOS (sieve size)	#60 - #70 (min)	ASTM D4751
Ultraviolet resistance	70% or greater	ASTM D4355

Flow Spreader

1) A flow spreader should be installed at the inlet along one side of the filter to evenly distribute incoming runoff across the filter and to prevent erosion of the filter surface.

   a. If the sand filter is curved or an irregular shape, a flow spreader should be provided for a minimum of 20 percent of the filter perimeter.

   b. If the length-to-width ratio of the filter is 2:1 or greater, a flow spreader should be located on the longer side and for a minimum length of 20 percent of the facility perimeter.

   c. In other situations, use good engineering judgment in positioning the spreader.

2) Erosion protection should be provided along the first foot of the sand bed adjacent to the flow spreader. Geotextile weighted with sand bags at 15-foot intervals may be used. Quarry spalls may also be used.

Vegetation

1) The use of vegetation in sand filters is optional. However, no top soil should be added to the sand filter bed because the fine-grained materials (silt and clay) would reduce the hydraulic capacity of the filter.

2) Growing grass or other vegetation requires the selection of species that can tolerate the demanding environment of a sand filter bed. Plants not receiving sufficient dry weather flows should be able to withstand long periods of drought during summer periods, followed by periods of saturation during storm events. A horticultural specialist should be consulted for advice on species selection.

3) A sod grown in sand may be used on the sand surface as long as there is no clay in the sand substrate and the particle size gradation of the substrate meets the sand filter specifications. No other sod should be used due to the high clay content in most sod soils.

4) To prevent uses that could compact and damage the filter surface, permanent structures are not permitted on sand filters (e.g. playground equipment).

Emergency Overflow Structure

Sand filters may only be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged. The overflow structure must be able to safely convey flows from the stormwater quality design storm to the downstream conveyance system or other acceptable discharge point.

Side Slopes

1) Interior side slopes above the stormwater quality design depth and up to the emergency overflow water surface steeper than 4:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

2) Exterior side slopes steeper than 2:1 (H:V) should be stabilized to prevent erosion with a method approved by the local permitting authority.

3) For any slope (interior or exterior) greater than 2:1 (H:V), a geotechnical investigation and report must be submitted and approved by the local permitting authority.

4) Pond walls may be vertical retaining walls, provided: (a) they are constructed of reinforced concrete, (b) a fence, which prevents access, is provided along the top of the wall or further back, and (c) the design is stamped by a licensed civil engineer and approved by the County.

Embankments

1) Embankments (earthen slopes or berms) may be used for detaining or redirecting the flow of water.

2) The minimum top width of all berm embankments should be 20 feet, or as approved by the geotechnical engineer.

3) Basin berm embankments should be constructed on native consolidated soil (or adequately compacted and stable fill soils analyzed by a l icensed geotechnical engineer) free of loose surface soil materials, roots, and other organic debris.

4) Earthworks should be in accordance with Section 300-6 of the Standard Specifications for Public Works Construction, most recent edition.

5) Basin berm embankments greater than 4 feet in height should be constructed by excavating a key equal to 50% of the berm embankment cross-sectional height and width. This requirement may be waived if specifically recommended by a licensed geotechnical engineer.

6) The berm embankment should be constructed of compacted soil (95% minimum dry density, modified proctor method per ASTM D1557), placed in 6-inch lifts.

Maintenance Access

Maintenance access road(s) shall be provided to the control structure and other drainage structures associated with the basin (e.g., inlet, emergency overflow or bypass structures). Manhole and catch basin lids should be in or at the edge of the access road.

An access ramp is required for removal of sediment with a backhoe or loader and truck. The ramp should extend to the bottom of the sand filter.

Landscaping Outside of the Facility

A sand filter can add aesthetics to a site and should be incorporated into a project's landscape design. Interior side slopes may be stepped with flat areas to provide informal seating with a g ame or play area below. Perennial beds may be planted above the overflow water surface elevation. Large shrubs and trees are not recommended, however, as shading limits evaporation and falling leaves can clog the filter surface. If a sand filter area is intended for recreational uses, such as a volleyball area, the interior side slopes of the filter embankment should be no steeper than 3:1 and may be stepped.

1) No trees or shrubs may be planted within 10 feet of inlet or outlet pipes or manmade drainage structures such as spillways, flow spreaders, or earthen embankments. Species with roots that seek water, such as willow or poplar, should not be used within 50 feet of pipes or manmade structures.

2) Prohibited non-native plant species will not be permitted. For more information on invasive weeds, including biology and control of listed weeds, look at the

encycloweedia located at the California Department of Food and Agriculture website at or the California Invasive Plant Council website at www.cal-ipc.org.

Operations and Maintenance

Sand filters are subject to clogging by fine sediment, oil and grease, and other debris (e.g., trash and organic matter such as leaves). Filters and pretreatment facilities should be inspected every 6 months during the first year of operation. Inspection should also occur immediately following a storm event to assess the filtration capacity of the filter. Once the filter is performing as designed, the frequency of inspection may be reduced to once per year.

Most of the maintenance should be concentrated on the pretreatment practices, such as buffer strips and swales upstream of the trench to ensure that sediment does not reach the infiltration trench. Regular inspection should determine if the sediment removal structures require preventative maintenance.

Inspect basin a minimum of twice a year, before and after the rainy season, after large storm events, or more frequently if needed. Some important items to check for include: differential settlement, cracking; erosion, leakage, or tree growth on the embankment; the condition of the riprap in the inlet, outlet and pilot channels; sediment accumulation in the basin; and the vigor and density of the vegetation on the basin side slopes and floor. Correct observed problems as necessary.

- Remove litter and debris from banks and basin bottom as required.
- Repair erosion to banks and bottom as required.
- Check infiltration rate of sand bed twice annually, once after significant rainfall.
- Scarify top 3 to 5 inches of filters surface by raking once annually or as required to restore infiltration rate of the filter.
- Clean forebay every two years at a minimum, to avoid accumulation in main basin.
- Inspect outlet for clogging a minimum of twice a year, before and after the rainy season, after large storms, and more frequently if needed. Correct observed problems as necessary.

RB-AR34851

TCM-5: Cartridge Media Filter

Cartridge media filters are manufactured devices that typically consist of a series of cylindrical vertical filters contained in a c atch basin, manhole, or vault that provide treatment through filtration and sedimentation. The manhole or vault may be divided into multiple chambers where the first chamber acts as a pre-settling basin for removal of coarse sediment while another chamber acts as the filter bay and houses the filter cartridges.

Cartridge Media Filters

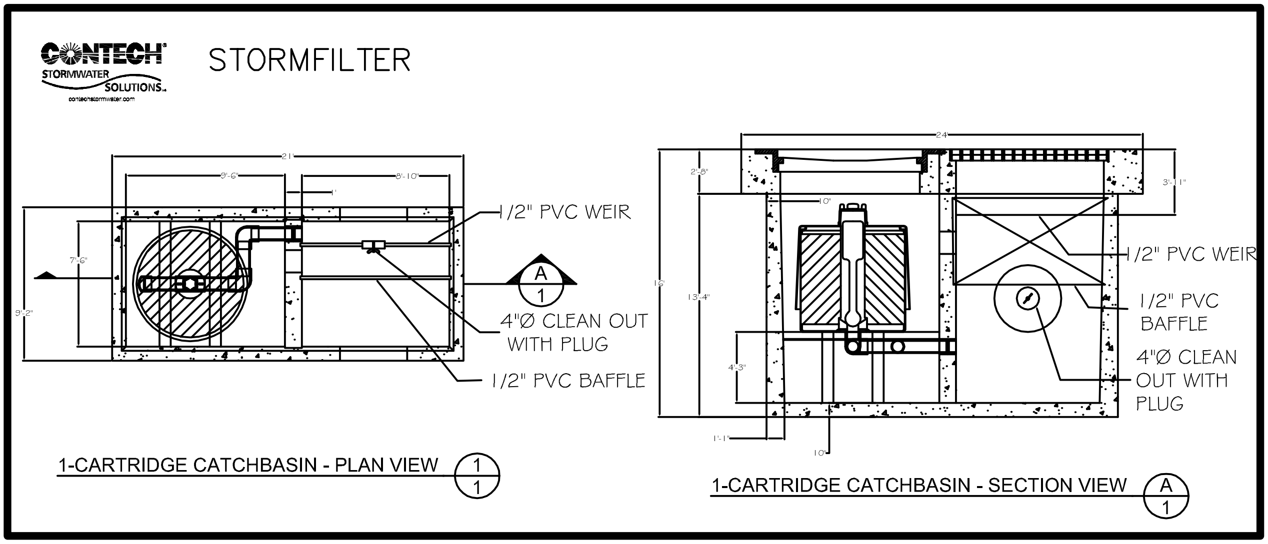
Photo Credits: Contech Stormwater Solutions, Inc.

Application

- Parking lots
- Roadways
- Playgrounds
- Outdoor eating areas

Preventative Maintenance

- Filter media replacement
- Solids removal from vault, manhole, or catch basin
- Inspect for inlet and outlet for clogging



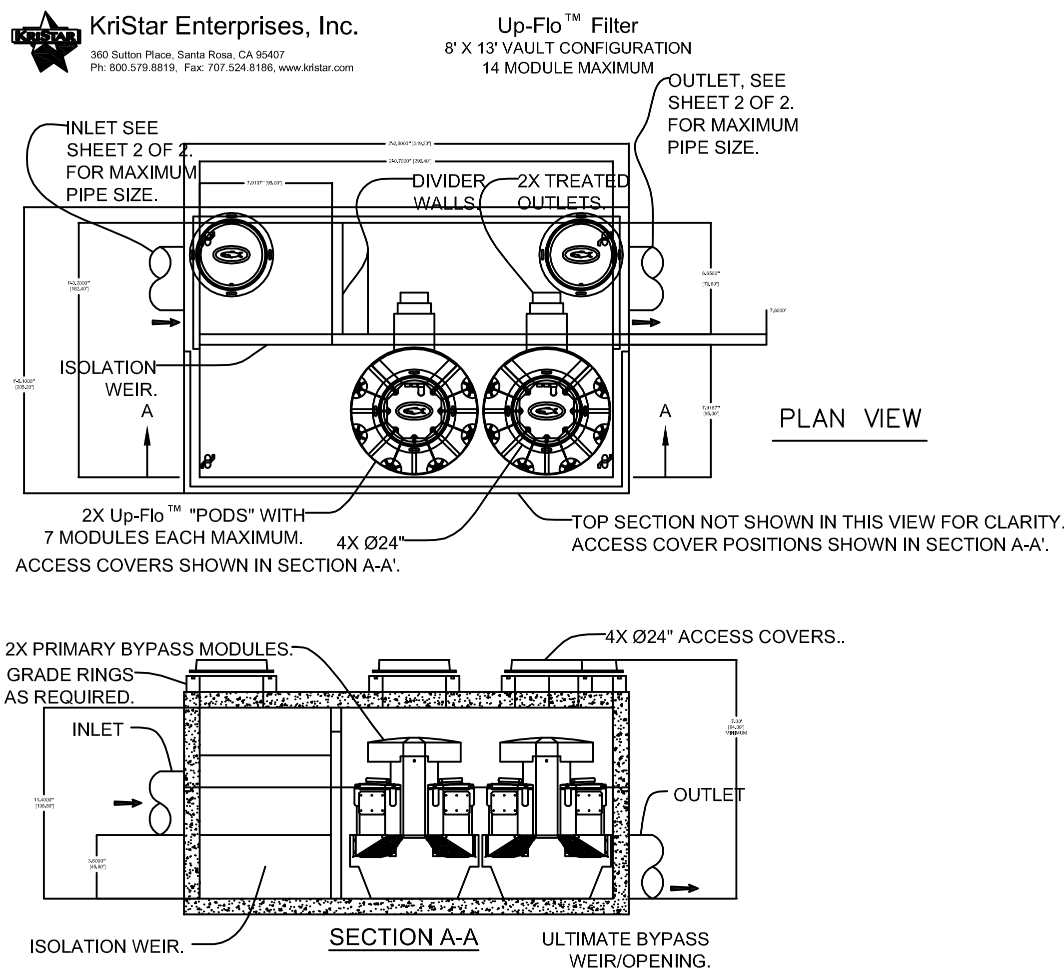


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Figure 6-24: Cartridge Media Filter

Table 6-27: Proprietary Cartridge Media Filter Manufacturer Websites

Device	Manufacturer	Website
BaySaver BayFilter	Baysaver Technologies Inc.	www.baysaver.com
ConTech StormFilter™	Contech® Construction Products Inc.	www.contech-cpi.com
CrystalStream	CrystalStream Technologies	www.crystalstream.com
KriStar Fossil Tee™ (media filter)	KriStar Enterprises Inc.	www.kristar.com
KriStar Up-Flo™ Filter and Perk™ Filter	KriStar Enterprises Inc.	www.kristar.com

Limitations

As with all filtration systems, use in catchments that have significant areas of non-stabilized soils can lead to premature clogging.

Design Criteria

1) Cartridge media filter BMP vendors are constantly updating and expanding their product lines, so refer to the latest design guidance from each of the vendors.

2) Selected filter media should target pollutants of concern. A combination of media is often recommended to maximize pollutant removal. Perlite is effective for removing TSS and oil and grease. Zeolite removes soluble metals, ammonium, and some organics. Vendors also offer proprietary medias (such as leaf compost or activated carbon) that are designed to remove soluble metals, organics, and other pollutants.

3) Manufacturers try to distinguish their products through innovative designs that aim at providing self cleaning and draining, uniformly loaded, and clog resistant cartridges that functional properly over a wide range of hydraulic loadings and pollutant concentrations.

4) All stormwater vaults containing cartridge filters that have standing water for longer than 72 hours can become a breeding area for mosquitoes. The selected BMP should have a system to completely drain the vault, such as weep holes in the bottom of the vault.

Sizing

1) Cartridge media filters should be sized to capture and treat the stormwater quality design flow rate.

2) Proprietary cartridge media filter devices, like most proprietary BMPs, and auxiliary components such as media, screens, baffles, and sumps are selected based onsite-specific conditions such as the loading that is expected and the desired frequency of maintenance. Sizing of proprietary devices is reduced to a simple process whereby a model can simply be selected from a table or a chart based on a few known quantities

(tributary area, location, design flow rate, etc). Most of the manufacturers either size the devices for potential clients or offer calculators on their websites that simplify the design process. For the latest sizing guidelines, refer to the manufacturer's website.

PT-1: Hydrodynamic Separation Device

Hydrodynamic separation devices (alternatively, swirl concentrators) are devices that remove trash, debris, and coarse sediment from incoming flows using screening, gravity settling, and centrifugal forces generated by forcing the influent into a circular motion. By having the water move in a circular fashion, rather than a straight line, it is possible to obtain significant removal of suspended sediments and attached pollutants with less space as compared to wet vaults and other settling devices. Hydrodynamic devices were originally developed for combined sewer overflows (CSOs), where they were used primarily to remove coarse inorganic solids. Hydrodynamic separation has been adapted for stormwater treatment by several manufacturers and is currently used to remove trash, debris, and other coarse solids down to sand-sized particles. Several types of hydrodynamic separation devices are also designed to remove floating oils and grease using sorbent media.

Hydrodynamic Separation

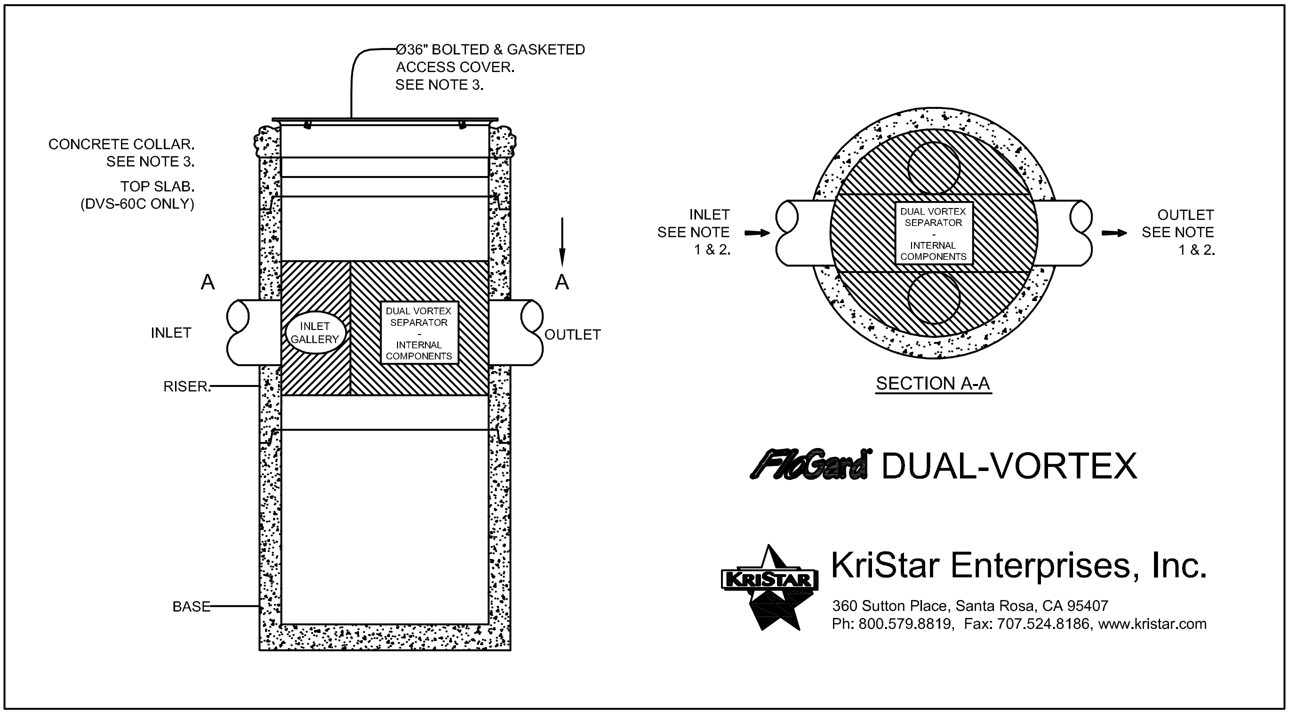
Photo Credits: 1. Contech Stormwater Solutions, Inc.; 2. Dave Weller, FedCo Construction

Application

- Parking lots
- Areas adjacent to parking lots
- Areas adjacent to buildings
- Road medians and shoulders

Preventative Maintenance

- Sediment, trash and debris removal
- Vector control



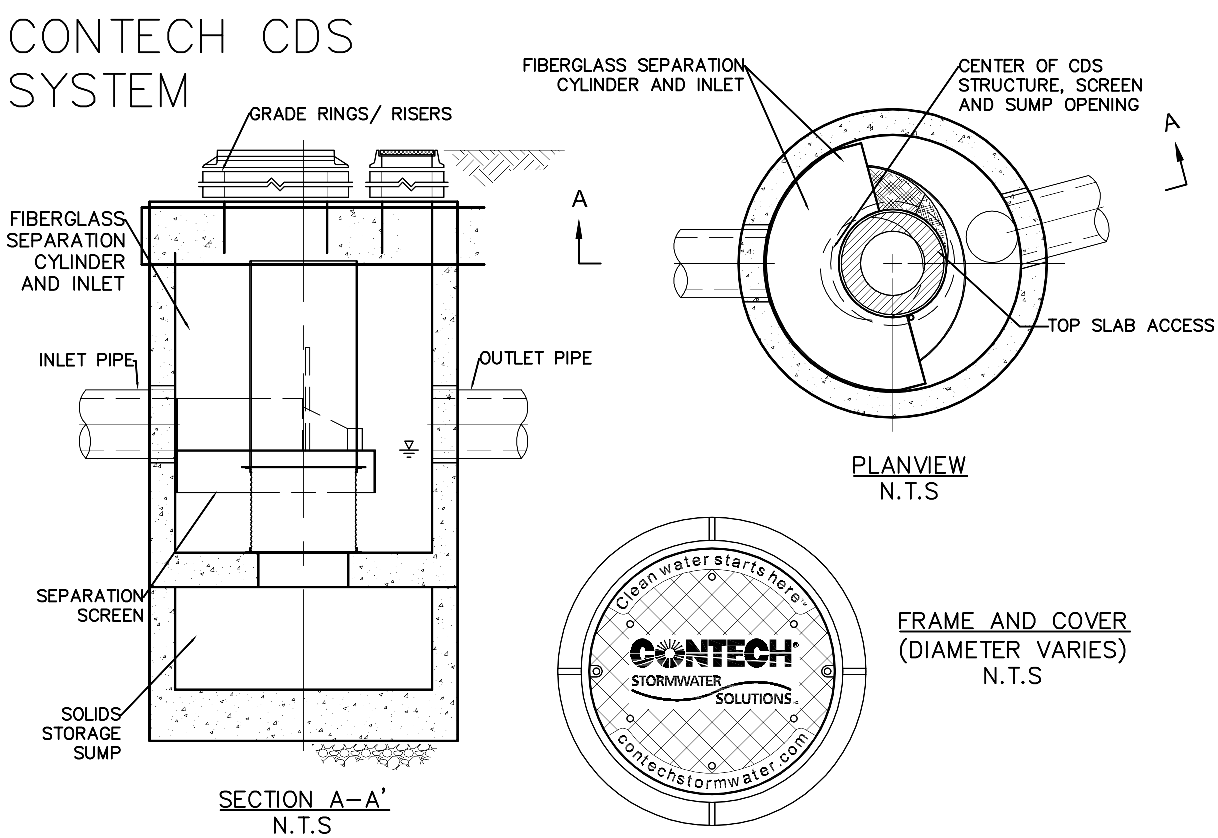


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Figure 6-25: Hydrodynamic Separation

Table 6-28: Proprietary Hydrodynamic Device Manufacturer Websites

Device	Manufacturer	Website
Rinker In-Line Stormceptor®	Rinker Materials™	www.rinkerstormceptor.com
FloGard® Dual-Vortex Hydrodynamic Separator	KriStar Enterprises Inc.	www.kristar.com
Contech® CDSª™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® Vortechs™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® VorSentry™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® VorSentry™ HS	Contech® Construction Products Inc.	www.contech-cpi.com
BaySaver BaySeparator	Baysaver Technologies Inc.	www.baysaver.com

Limitations

Hydrodynamic separation devices are effective for the removal of course sediment, trash, and debris, and are useful as pretreatment in combination with other BMP types that target smaller particle sizes.

Hydrodynamic devices represent a wide range of device types that have different unit processes and design elements (e.g., storage versus flow-through designs, inclusion of media filtration, etc.) that vary significantly within the category. These design features likely have significant effects on BMP performance; therefore, generalized performance data for hydrodynamic devices is not practical.

Design Criteria

Proprietary hydrodynamic device BMP vendors are constantly updating and expanding their product lines, so refer to the latest design guidance from each of the vendors. General guidelines on the performance, sizing, operations and maintenance of proprietary devices are provided by the vendors.

Sizing

Hydrodynamic devices shall be sized to capture and treat the stormwater quality design flow rate and to completely drain within 72 hours.

Sizing of proprietary devices is reduced to a simple process whereby a model can simply be selected from a table or a chart based on a few known quantities (tributary area, location, design flow rate, design volume, etc). A few of the manufacturers either size the devices for potential clients or offer calculators on their websites that simplify the design process even further and lessens the possibility of using obsolete design information. For the latest sizing guidelines, refer to the manufacturer's website.

The hydrodynamic separators listed in Table 6-28 are designed to have a permanent pool of water stored within the system. Various methods of vector control are available to prevent mosquito breeding including manhole cover screens and the use of mosquito dunks. In many designs, oil and grease is stored at the water surface and provides a deterrent to mosquito breeding.

Operations and Maintenance

Hydrodynamic devices should be inspected every 6 months during the first year of operation. Inspection should also occur immediately following a storm event to assess the function of the device. Once the device is performing as designed, the frequency of inspection may be reduced to once per year.

RB-AR34859

PT-2: Catch Basin Insert

Catch basin inserts are manufactured filters or fabric placed in a drop inlet to remove sediment and debris and may include sorbent media (oil absorbent pouches) to remove floating oils and grease. Catch basin inserts are selected specifically based upon the orientation of the inlet.

Catch Basin Inserts

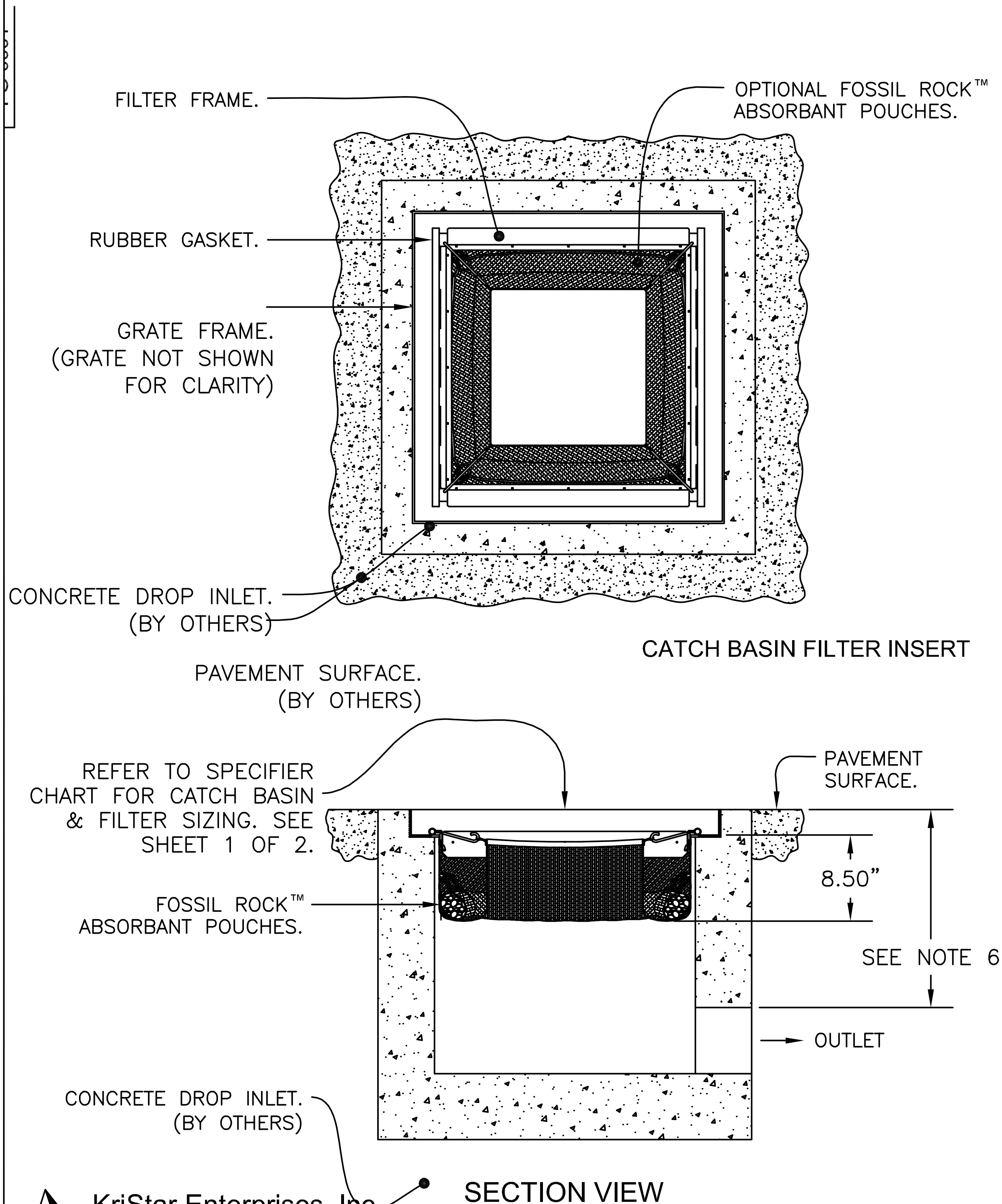
Photo Credits: 1. KriStar; 2. Aquashield

Application

- Parking lots
- Roads
- Athletic courts
- Outdoor food areas

Preventative Maintenance

- After storm inspection
- Sediment removal
- Trash removal
- Filter/sorbent media replacement



KriStar Enterprises, Inc.
360 Sutton Place, Santa Rosa, CA 95407
Ph: 800.579.8819, Fax: 707.524.8186, www.kristar.com

FloGard®

Geosyntec consultants

Figure 6-26: Catch Basin

Table 6-29: Proprietary Catch Basin Insert Manufacturer Websites

Device	Manufacturer	Website
AbTech Industries Ultra-Urban Filter™	AbTech Industries	www.abtechindustries.com
Aquashield Aqua-Guardian™ Catch Basin Insert	Aquashield™ Inc.	www.aquashieldinc.com
Bowhead StreamGuard™	Aquashield™ Inc.	www.aquashieldinc.com
Contech® Triton Catch Basin Filter™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® Triton Curb Inlet Filter™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® Triton Basin StormFilter™	Contech® Construction Products Inc.	www.contech-cpi.com
Contech® Curb Inlet StormFilter™	Contech® Construction Products Inc.	www.contech-cpi.com
Curb Inlet Basket	SunTree Technologies Inc.	www.suntreetech.com
Curb Inlet Grates	EcoSense International™	www.ecosenseinternational.org
Grate Inlet Skimmer Box	SunTree Technologies Inc.	www.suntreetech.com
Hydro-Kleen™ Filtration System	Hydro Compliance Management Inc.	Not available
KriStar FloGard+PLUS®	KriStar Enterprises Inc.	www.kristar.com
KriStar FloGard®	KriStar Enterprises Inc.	www.kristar.com
KriStar FloGard LoPro Matrix Filter®	KriStar Enterprises Inc.	www.kristar.com
Nyloplast Storm-PURE Catch Basin Insert	Nyloplast Engineered Surface Drainage Products	www.nyloplast-us.com
StormBasin®	FabCo® Industries Inc.	www.fabco-industries.com
Stormdrain Solutions Interceptor	FabCo® Industries Inc.	www.fabco-industries.com
Stormdrain Solutions Inceptor®	Stormdrain Solutions	www.stormdrains.com
StormPod®	FabCo® Industries Inc.	www.fabco-industries.com
Stormwater Filtration Systems	EcoSense International™	www.ecosenseinternational.org
Ultra-CurbGuard®	UltraTech International Inc.	www.spillcontainment.com
Ultra-DrainGuard®	UltraTech International Inc.	www.spillcontainment.com
Ultra-GrateGuard®	UltraTech International Inc.	www.spillcontainment.com
Ultra-GutterGuard®	UltraTech International Inc.	www.spillcontainment.com
Ultra-InletGuard®	UltraTech International Inc.	www.spillcontainment.com

Limitations

Catch basin inserts come in such a wide range of configurations that it is practically impossible to generalize the expected performance. Inserts should mainly be used for catching coarse sediments and floatable trash, and are effective as pretreatment in combination with other types of structures that are recognized as water quality treatment BMPs. Trash and large objects can greatly reduce the effectiveness of catch basin inserts with respect to sediment and hydrocarbon capture. Frequent maintenance and the use of screens and grates to keep trash out may decrease the likelihood of clogging and prevent obstruction and bypass of incoming flows.

Design Criteria

Catch basin inserts shall be sized to capture and treat the stormwater quality design flow rate.

Operations and Maintenance

1) Trash, debris, and sediment around insert grate and inside chamber requiring trash to be cleared.

2) Repair filter media if damaged or severely clogged.

3) Inspection of catch basin insert after each storm greater than 0.2 inches is recommended.

7 MAINTENANCE PLAN

This chapter identifies the basic information that should be included in a maintenance plan. Refer to Fact Sheets for individual control measures in Chapter 6 regarding device-specific maintenance requirements.

7.1 Site Map

1) Provide a site map showing boundaries of the site, acreage and drainage patterns/contour lines. Show each discharge location from the site and any drainage flowing onto the site. Distinguish between soft and hard surfaces on the map.

2) Identify locations of existing and proposed storm drain facilities, private sanitary sewer systems and grade-breaks for purposes of pollution prevention.

3) With legend, show locations of expected sources of pollution generation (outdoor work and storage areas, heavy traffic areas, delivery areas, trash enclosures, fueling areas, industrial clarifiers, wash-racks, etc). Identify any areas having contaminated soil or where toxins are stored or have been stored/disposed of in the past.

4) With legend, indicate types and locations of stormwater management control measures which will be built to permanently control stormwater pollution. Distinguish between pollution prevention, treatment, sewer diversion, and containment devices.

7.2 Baseline Descriptions

1) List the property owners and persons responsible for operation and maintenance of the stormwater management control measures onsite. Include phone numbers and addresses.

2) Identify the intended method of providing financing for operation, inspection, routine maintenance and upkeep of stormwater control measures.

3) List all permanent stormwater control measures. Provide a brief description of stormwater management control measures selected and if appropriate, facts sheets or additional information.

4) As appropriate for each stormwater control measure provide:

    a. A written description and check list of all maintenance and waste disposal activities that will be performed. Distinguish between the maintenance appropriate for a 2-year establishment period and expected long-term maintenance. For example, maintenance requirements for vegetation in a constructed wetland may be more intensive during the first few years until the vegetation is established. The post-establishment maintenance plan should address maintenance needs (e.g., pruning, irrigation, weeding) for a larger, more stable system. I nclude maintenance performance procedures for facility components that require relatively unique maintenance knowledge, such as specific plant removal / replacement, landscape features, or constructed wetland maintenance. These procedures should provide enough detail for a person unfamiliar with maintenance to perform the activity, or identify the specific skills or knowledge necessary to perform and document the maintenance.

b. A description of site inspection procedures and documentation system, including record-keeping and retention requirements.

c. An inspection and maintenance schedule, preferably in the form of a table or matrix, for each activity for all facility components. The schedule should demonstrate how it will satisfy the specified level of performance, and how the maintenance / inspection activities relate to storm events and seasonal issues.

d. Identification of the equipment and materials required to perform the maintenance.

5) As appropriate, list all housekeeping procedures for prohibiting illicit discharges or potential illicit discharges to the storm drain. I dentify housekeeping BMPs that reduce maintenance of Treatment Control Measures. These procedures are listed based on facility operations and can be found in the Ventura County Industrial/Commercial Clean Business Program document.

7.3 Spill Plan

1) Provide emergency notification procedures (phone and agency/persons to contact)

2) As appropriate for site, provide emergency containment and cleaning procedures.

3) Note downstream receiving water bodies or wetlands which may be affected by spills or chronic untreated discharges.

4) As appropriate, create an emergency sampling procedure for spills. (Emergency sampling can protect the property owner from erroneous liability for down-stream receiving area clean-ups).

7.4 Facility Changes

Operational or facility changes which significantly affect the character or quantity of pollutants discharging into the stormwater management control measures will require modifications to the Maintenance Plan and/or additional stormwater control measures.

7.5 Training

1) Identify appropriate persons to be trained and assure proper training.

2) Training to include:

   a. Good housekeeping procedures defined in the plan.

   b. Proper maintenance of all pollution mitigation devices.

   c. Identification and cleanup procedures for spills and overflows.

   d. Large-scale spill or hazardous material response.

   e. Safety concerns when maintaining devices and cleaning spills.

7.6 Basic Inspection and Maintenance Activities

1) Create and maintain onsite, a log for inspector names, dates and stormwater control measure devices to be inspected and maintained. Provide a checklist for each inspection and maintenance category.

2) Once annually, perform testing of any mechanical or electrical devices prior to wet weather.

3) Report any significant changes in stormwater management control measures to the site management. As a ppropriate, assure mechanical devices are working properly and/or landscaped BMP plantings are irrigated and nurtured to promote thick growth.

4) Note any significant maintenance requirements due to spills or unexpected discharges.

5) As appropriate, perform maintenance and replacement as scheduled and as needed in a timely manner to assure stormwater management control measures are performing as designed and approved.

6) Assure unauthorized low-flow discharges from the property do not by-pass stormwater control measures.

7) Perform an annual assessment of each pollution generation operation and its associated stormwater management control measures to determine if any part of the pollution reduction train can be improved.

7.7 Revisions of Pollution Mitigation Measures

If future correction or modification of past stormwater management control measures or procedures is required, the owner shall obtain approval from the governing stormwater agency prior to commencing any work. Corrective measures or modifications shall not cause discharges to bypass or otherwise impede existing stormwater control measures.

7.8 Monitoring & Reporting Program

1) The governing stormwater agency may require a Monitoring & Reporting Program to assure the stormwater management control measures approved for the site are performing according to design.

2) If required by local permitting agency, the Maintenance Plan shall include performance testing and reporting protocols.

APPENDIX A : ACRONYMS AND GLOSSARY OF TERMS

RB-AR34868

A.1 Acronyms and Abbreviations

303(d)	303(d) List of Impaired Water Bodies
API	American Petroleum Institute (oil/water separator type)
BMP	Best Management Practice
CEQA	California Environmental Quality Act
CP	Coalescing Plate (oil/water separator type)
CTR	California Toxics Rule
CWA	Clean Water Act
CDFG	California Department of Fish and Game
EIA	Effective Impervious Area
EMC	Event Mean Concentration
ESA	Environmentally Sensitive Area
LID	Low Impact Development
MEP	Maximum Extent Practicable
MS4	Municipal Separate Storm Sewer System
RPAMP	Redevelopment Project Area Master Plan
SQDV	Stormwater Quality Design Volume
SQDF	Stormwater Quality Design Flow
TSS	Total Suspended Solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
WERF	Water Environment Research Foundation

A.2 Glossary

Automotive Repair Shop: A facility that is categorized in any one of the following Standard Industrial Classification (SIC) codes: 5013, 5014, 5541, 7532-7534, or 7536-7539.

Backfill: Earth or engineered material used to refill a trench or an excavation.

Berm: An earthen mound used to direct the flow of runoff around or through a structure.

Best Management Practice (BMP): Any program, technology, process, siting criteria, operational methods or measures, or engineered systems, which when implemented prevent, control, remove, or reduce pollution.

Best Management Practices (BMPs): Includes schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the United States. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Biofiltration: The simultaneous process of filtration, infiltration, adsorption, and biological uptake of pollutants in stormwater that takes place when runoff flows over and through vegetated areas.

Bioretention Facility: A facility that utilizes soil infiltration and both woody and herbaceous plants to remove pollutants from stormwater runoff. Runoff is typically captured and infiltrated or released over a period of 24 to 48 hours.

Blue Roof: A roof that is designed to store rainwater, typically in a cistern-type device.

Brown Roof: A type of green roof which focuses on biodiversity and locally-sourced material.

Buffer Strip or Zone: Strip of erosion-resistant vegetation over which stormwater runoff is directed.

Capacity: The capacity of a stormwater drainage facility is the flow volume or rate that the facility (e.g., pipe, basin, vault, swale, ditch, drywell, etc.) is designed to safely contain, receive, convey, reduce pollutants from, or infiltrate stormwater to meet a specific performance standard. There are different performance standards for pollution reduction, flow control, conveyance, and destination/ disposal, depending on location.

Catch Basin: Box-like underground concrete structure with openings in curbs and gutters designed to collect runoff from streets and pavements.

Check Dam: Small temporary barrier, grade control structure, or dam constructed across a swale, drainage ditch, or area of concentrated flow with the intent to slow or stop runoff.

Clean Water Act (CWA): (33 U.S.C. 1251 et seq.) requirement of the National Pollutant Discharge Elimination System (NPDES) program are defined under Sections 307, 402, 318 and 405 of the CWA.

Commercial Development: Any development on private land that is not heavy industrial or residential. The category includes, but is not limited to: hospitals, laboratories and other medical facilities, educational institutions, recreational facilities, plant nurseries, multi-apartment buildings, car wash facilities, mini-malls and other business complexes, shopping malls, hotels, office buildings, public warehouses and other light industrial complexes.

Conduit: Any channel or pipe for directing the flow of water.

Construction General Permit: A NPDES permit issued by the State Water Resources Control Board (SWRCB) for the discharge of stormwater associated with construction activity from soil disturbance of five (5) acres or more.

Control Device: A d evice used to hold back or direct a calculated amount of stormwater to or from a stormwater management facility. Typical control structures include vaults or manholes fitted with baffles, weirs, or orifices.

Conveyance System: Any channel or pipe for collecting and directing the Stormwater.

Culvert: A covered channel or a large diameter pipe that crosses under a road, sidewalk, etc.

Dead-end Sump: A below surface collection chamber for small drainage areas that is not connected to the public storm drainage system. Accumulated water in the chamber must be pumped and disposed in accordance with all applicable laws.

Designated Public Access Points: Any pedestrian, bicycle, equestrian, or vehicular point of access to jurisdictional channels in the area of Ventura County subject to permit requirements.

Detention: The temporary storage of stormwater runoff to allow treatment by sedimentation and metered discharge of runoff at reduced peak flow rates.

Detention Facility: A facility designed to receive and hold stormwater and release it at a slower rate, usually over a number of hours. The full volume of stormwater that enters the facility is eventually released.

Detention Tank, Vault, or Oversized Pipe: A structural subsurface facility used to provide flow control for a particular drainage basin.

Development: any construction, rehabilitation, redevelopment or reconstruction of any public or private residential project (whether single-family, multi-unit or planned unit development); industrial, commercial, retail and any other non-residential projects, including public agency projects; or mass grading for future construction.

Directly Adjacent: Situated within 200 feet of the contiguous zone required for the continued maintenance, function, and structural stability of the environmentally sensitive area.

Directly Connected Impervious Area (DCIA): The area covered by a building, impermeable pavement, and/ or other impervious surfaces, which drains directly into the storm drain without first flowing across permeable land area (e.g. turf buffers).

Directly Discharging: Outflow from a drainage conveyance system that is composed entirely or predominantly of flows from the subject, property, development, subdivision, or industrial facility, and not commingled with the flows from adjacent lands.

Discharge: A release or flow of Stormwater or other substance from a conveyance system or storage container.

Disturbed Area: Any area that is altered as a result of land disturbance, such as: clearing, grading, grubbing, stockpiling and excavation.

Drainage Basin: A specific area that contributes stormwater runoff to a particular point of interest, such as a stormwater management facility, drainageway, wetland, river, or pipe.

Effective Impervious Area (EIA): That portion of the surface area that is hydrologically connected via sheet flow over a hardened conveyance or impervious surface without any intervening medium to mitigate flow volume.

Environmentally Sensitive Area (ESA): An area "in which plant or animal life or their habitats are either rare or especially valuable because of their special nature or role in an ecosystem and which would be easily disturbed or degraded by human activities and developments" (California Public Resources Code § 30107.5). Areas subject to stormwater mitigation requirements are: 303(d) listed water bodies in all reaches that are unimproved, all California Coastal Commission's *Environmentally Sensitive Habitat Areas* as delineated on maps in Local Coastal Plans, and Regional Water Quality Control Board's Basin Plan Rare, Threatened or Endangered Species (RARE) and Preservation of Biological Habitats (BIOL) designated waterbodies. The California Department of Fish and Game's (CDFG) *Significant Natural Areas* map will be considered for inclusion as the department field-verifies the designated locations. Watershed restoration projects will be considered for inclusion as the department field verifies the designated locations.

Erosion: The wearing a way of land surface by wind or water. Erosion occurs naturally from weather or runoff, but can be intensified by land-clearing practices relating to farming; residential, commercial, or industrial development; road building; or timber cutting.

Excavation: The process of removing earth, stone, or other materials, usually by digging.

Existing Urban Area: Existing urban areas and corresponding maps in Appendix B are based on the cities' City Urban Restriction Boundaries (CURB) lines and the Existing Community designation in the unincorporated County. These boundaries are a growth management tool intended to channel growth and protect agricultural and open-space land. The 2011 TGM utilizes existing urban areas (as defined in Appendix B) to provide parameters around eligibility for alternative compliance in two areas: 1) Smart Growth and 2) low income housing projects.

Extended Detention Basin: A su rface vegetated basin used to provide flow control for a particular drainage basin. Stormwater temporarily fills the extended detention basin during large storm events and is slowly released over a number of hours, reducing peak flow rates.

Facility: Is a collection of industrial process discharging stormwater associated with industrial activity within the property boundary or operational unit.

Filter Fabric: Geotextile of relatively small mesh or pore size that is used to: (a) allow water to pass through while keeping sediment out (permeable); or (b) prevent both runoff and sediment from passing through (impermeable).

Filter Strip: A gently sloping, densely grassed area used to filter, slow, and infiltrate stormwater.

Flow Control Facility: Any structure or drainage device that is designed, constructed, and maintained to collect, retain, infiltrate, or detain surface water runoff during and after a storm event for the purpose of controlling post-development quantity leaving the site.

Flow Control: The practice of limiting the release of peak flow rates, flow durations, and volumes from a site. Flow control is intended to protect downstream properties, infrastructure, and natural resources from the increased stormwater runoff flow rates and volumes resulting from development.

Grading: The cutting and/or filling of the land surface to a desired shape or elevation.

Green Roof: A roofing system that layers a soil/vegetative cover over a waterproofing membrane. Green roofs rely on highly porous media and moisture retention layers to store intercepted precipitation and to support vegetation that can reduce the volume of stormwater runoff via evapotranspiration

Hazardous Substance: (1) Any material that poses a threat to human health and/or the environment. T ypical hazardous substances are toxic, corrosive, ignitable, explosive, or chemically reactive; (2) Any substance named by EPA to be reported if a designated quantity of the substance is spilled in the waters of the United States or if otherwise emitted into the environment.

Hazardous Waste: By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (flammable, corrosivity, reactivity, or toxicity), or appears on special EPA lists.

Hillside: Property located in an area with known erosive soil conditions, where the development contemplates grading on any natural slope that is 25 percent or greater.

Hydrodynamic Separation: Flow-through structures with a settling or separation unit to remove sediments and other pollutants in which no outside power source is required, because the energy of the flowing water allows the sediments to efficiently separate. Depending on the type of unit, this separation may be by means of swirl action or indirect filtration.

Illegal Discharges: Any discharge to a municipal separate storm sewer that is not composed entirely of stormwater except discharges authorized by an NPDES permit (other than the NPDES permit for discharges from the municipal separate storm sewer) and discharges resulting from fire fighting activities.

Impervious Surface / Area: A hard surface area which either prevents or retards the entry of water into the predevelopment soil mantle. A hard surface area which causes water to run off the surface in greater quantities or at an increased rate of flow from the flow present under predevelopment conditions. Common impervious surfaces include, but are not limited to, roof tops, walkways, patios, driveways, parking lots or storage areas, (impermeable) concrete or asphalt paving, gravel roads, packed earthen materials, and oiled macadam or other surfaces which similarly impede the natural infiltration of storm water.

Industrial General Permit: A NPDES permit issued by the State Water Resources Control Board for the discharge of Stormwater associated with industrial activity.

Infiltration: The downward entry of water into the surface of the soil.

Infiltration Trench: A linear excavation, backfilled with gravel, used to filter pollutants and infiltrate storm water.

Integrated Pest Management Plan (IPMP): A balanced approach to pest management which incorporates the many aspects of plant health care in ways that mitigate harmful environmental impacts and protect human health.

Inlet: An entrance into a ditch, storm sewer, or other waterway.

Legacy Pollutants: Pollutants that are no longer in production but remain in site soils and groundwater and still have the potential to cause ecological and water quality impacts.

Material Storage Areas: On site locations where raw materials, products, final products, by-products, or waste materials are stored.

Maximum Extent Practicable (MEP): The technology-based permit requirement established by Congress in CWA section 402(p)(3)(B)(iii) that municipal dischargers of stormwater must meet. T echnology-based requirements, including MEP, establish a level of pollutant control that is derived from available technology or other controls. MEP requires municipal dischargers to perform at maximum level that is practicable. C ompliance with MEP may be achieved by emphasizing pollution prevention and source control BMPs in combination with structural and treatment methods where appropriate. The MEP approach is an ever evolving and advancing concept, which considers technical and economic feasibility.

Municipal Separate Storm Sewer System (MS4) Permit: : A NPDES permit issued by the Regional Water Quality Control Board for the discharge of Stormwater from Municipal Separate Storm Sewer Systems.

New Development: Land disturbing activities; structural development, including construction or installation of a building or structure, creation and replacement of impervious surfaces; and land subdivision.

Non-Stormwater Discharge: Any discharge to municipal separate storm drain that is not composed entirely of stormwater. D ischarges containing process wastewater, non-contact cooling water, or sanitary wastewater are non-stormwater discharges.

Non-Structural Source Control Measure: Low technology, low cost activities, procedures or management practices designed to prevent pollutants associated with site functions and activities from being discharged with Stormwater runoff. Examples include good housekeeping practices, employee training, standard operating practices, inventory control measures, etc.

Notice of Intent (NOI): A formal notice to State Water Resources Control Board submitted by the owner/developer that a construction project is about to begin. The NOI provides information on the owner, location, type of project, and certifies that the permittee will comply with the conditions of the construction general permit.

NPDES Permit: An authorization, license, or equivalent control document issued by EPA or an approved State agency to implement the requirements of the NPDES program.

Operations and Maintenance (O&M): The continuing activities required to keep storm water management facilities and their components functioning in accordance with design objectives.

Outfall: The point where stormwater discharges from a pipe, channel, ditch, or other conveyance to a waterway.

Parking Lot: Land area or facility for the temporary parking or storage of motor vehicles used personally, for business or for commerce with an impervious surface area of 5,000 square feet or more, or with 25 or more parking spaces.

Permeability: A property of soil that enables water or air to move through it. Usually expressed in inches/hour or inches/day.

Pervious Surface/Area: A su rface or area with a surface (i.e., soil, loose rock, permeable pavement, etc.) that allows water to infiltrate (soak) into the ground.

Planter Box: A structural facility filled with topsoil and gravel and planted with vegetation. The planter is completely sealed, and a perforated collection pipe is placed under the soil and gravel, along with an overflow provision, and directed to an acceptable destination point. The storm water planter receives runoff from impervious surfaces, which is filtered and retained for a period of time.

Pollutant: An elemental or physical material that can be mobilized or dissolved by water or air and creates a negative impact to human health and/ or the environment. Pollutants include suspended solids (sediment), heavy metals (such as lead, copper, zinc, and cadmium), nutrients (such as nitrogen and phosphorus), bacteria and viruses, organics (such as oil, grease, hydrocarbons, pesticides, and fertilizers), floatable debris, and increased temperature.

Pollutants of Concern: constituents that have exceeded Basin Plan Objectives, and California Toxics Rule chronic or acute objectives during monitoring at mass emission, receiving water, and land use stations.

Pollution Reduction: The practice of filtering, retaining, or detaining surface water runoff during and after a s torm event for the purpose of maintaining or improving surface and/or groundwater quality.

Precipitation: Any form of rain or snow.

Predevelopment: The existing land use condition prior to the proposed development activity.

Practicable: Available and capable of being done, after taking into consideration existing technology, legal issues, and logistics in light of overall project purpose.

Pre-developed Condition: the native vegetation and soils that existed at a site prior to first development. The pre-developed condition may be assumed to be the typical vegetation, soil, and stormwater runoff characteristics of open space areas in coastal Southern California unless reasonable historic information is provided that the area was atypical.

Pre-project Condition: the condition of the site at the time of the proposed project.

Pretreatment: Treatment of wastewater before it is discharged to a wastewater collection system.

Process Wastewater: Wastewater that has been used in one or more industrial processes.

Project: development, redevelopment, and land disturbing activities. The term is not limited to "project" as defined under CEQA (Reference: California Public Resources Code § 21065).

Public Facility: A str eet, right-of-way, park, sewer, drainage, storm water management, or other facility that is either currently owned by the City/County or will be conveyed to the City/County for maintenance responsibility after construction.

Rainwater Harvesting: Rainwater harvesting is a BMP that stores and uses rainwater or stormwater runoff. This is consistent with the use of the term "reuse" contained in Order R4-2010-0108.

Receiving Stream: (for purposes of this Manual only) any natural or man-made surface water body that receives and conveys stormwater runoff.

Redevelopment: Land-disturbing activity that results in the creation, addition, or replacement of 5,000 square feet or more of impervious surface area on an already developed site. Redevelopment includes, but is not limited to: the expansion of a building footprint; addition or replacement of a structure; replacement of impervious surface area that is not part of a routine maintenance activity; and land disturbing activities related to structural or impervious surfaces. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility, nor does it include emergency construction activities required to immediately protect public health and safety. Note: redevelopment as defined here is not the same as a "Redevelopment Project" as defined by California redevelopment law.

Redevelopment Project Area Master Plan (RPAMP): A plan submitted to the Regional Water Board for approval by a Permittee or a coalition of Permittees to establish standards for redevelopment projects within Redevelopment Project Areas, in consideration of exceptional site constraints that inhibit site-by-site or project-by-project implementation of post-construction requirements. See Section 4.E.IV.3 of Order R4-2010-0108.

Restaurant: A stand-alone facility that sells prepared foods and/or drinks for consumption, including stationary lunch counters and refreshment stands selling prepared foods and/or drinks for immediate consumption (SIC code 5812).

Retail Gasoline Outlet: Any facility engaged in selling gasoline and lubricating oils.

Retention Facility: A facility designed to receive and hold stormwater runoff. Rather than storing and releasing the entire runoff volume, retention facilities permanently retain a portion of the water on-site, where it infiltrates, evaporates, or is absorbed by surrounding vegetation. In this way, the full volume of storm water that enters the facility is not released off-site.

Retrofit: Retrofit projects implement structural treatment BMPs as a stand-alone project, without other site improvements. T he BMP sizing requirements of this Technical Guidance Manual do not apply to retrofit projects.

Runoff: Water originating from rainfall and other precipitations (e.g., sprinkler irrigation) that is found in drainage facilities, rivers, streams, springs, seeps, ponds, lakes, wetlands, and shallow groundwater.

Runon: Stormwater surface flow or other surface flow which enters property other than that where it originated.

Secondary Containment: Structures, usually dikes or berms, surrounding tanks or other storage containers and designed to catch spilled material from the storage containers.

Sedimentation: The process of depositing soil particles, clays, sands, or other sediments that were picked up by runoff.

Sediments: Soil, sand, and minerals washed from land into water usually after rain, that accumulate in reservoirs, rivers, and harbors, destroying aquatic animal habitat and clouding the water so that adequate sunlight might not reach aquatic plants.

Site: land or water area where any "facility" or "activity" is physically located or conducted including adjacent land used in connection with the facility or activity.

Source Control BMP or Measure: Any schedules of activities, structural devices, prohibitions of practices, maintenance procedures, managerial practices or operational practices that aim to prevent Stormwater pollution by reducing the potential for contamination at the source of pollution.

Source Control BMPs: Operational practices or design features that prevent pollution by reducing potential pollutants at the source.

Spill Guard: A device used to prevent spills of liquid materials from storage containers.

Spill Prevention Control and Countermeasures Plan (SPCC): Plan consisting of structures, such as curbing, and action plans to prevent and respond to spills of hazardous substances as defined in the Clean Water Act.

Storm Drains: Above and below ground structures for transporting stormwater to streams or outfalls for flood control purposes.

Storm Drain System: Network of above and below-ground structures for transporting stormwater to streams or outfalls.

Storm Event: A rainfall event that produces more than 0.1 inch of precipitation and is separated from the previous storm event by at least 72 hours of dry weather.

Stormwater Discharge Associated with Industrial Activity: Discharge from any conveyance which is used for collecting and conveying stormwater which is related to manufacturing processing or raw materials storage areas at an industrial plant [see 40 CFR 122.26(b)(14)].

Stormwater: Stormwater runoff, snow-melt runoff, surface runoff, and drainage, excluding infiltration and irrigation tailwater.

Structural BMP or Control Measure: Any structural facility designed and constructed to mitigate the adverse impacts of stormwater and urban runoff pollution (e.g. canopy, structural enclosure). The category may include both Treatment Control BMPs and Source Control BMPs.

Total Project Area: Total project area (or "gross project area") for new development and redevelopment projects is the disturbed, developed, and undisturbed portions within the project's property (or properties) boundary, at the project scale submitted for first approval. Areas proposed to be permanently dedicated for open space purposes as part of the project are explicitly included in the "total project area." Areas of land precluded from development through a restrictive covenant, conservation easement, or other recorded document for the permanent preservation of open space prior to project submittal shall not be included in the "total project area."

Total Suspended Solids (TSS): Matter suspended in stormwater excluding litter, debris, and other gross solids exceeding 1 millimeter in diameter.

Treatment Control BMP or Measure: Any engineered system designed to remove pollutants by simple gravity settling of particulate pollutants, filtration, biological uptake, media adsorption or any other physical, biological, or chemical process.

Treatment: The application of engineered systems that use physical, chemical, or biological processes to remove pollutants. Such processes include, but are not limited to, filtration, gravity settling, media adsorption, biodegradation, biological uptake, chemical oxidation and UV radiation.

Tributary Area: The area from which all runoff produced flows to the same specific discharge point.

Vegetated Facilities: Stormwater management facilities that rely on plantings to enhance their performance. Plantings can provide wildlife habitat and enhance many facility functions, including infiltration, pollutant removal, water cooling, flow calming, and prevention of erosion.

Vegetated Swale: A long and narrow, trapezoidal or semicircular channel, planted with a variety of trees, shrubs, and grasses or with a dense mix of grasses. Stormwater runoff from impervious surfaces is directed through the swale, where it is slowed and in some cases infiltrated, allowing pollutants to settle out. Check dams are often used to create small ponded areas to facilitate infiltration.

APPENDIX B : MAPS

NOTES:

1. Contact the local permitting authority for more detailed maps.
2. Existing Urban Area maps are current as of 11/2/10.

Legend

River	Santa Paula
Lake	Simi Valley
National Forest	Thousand Oaks
10-Digit Hydrologic Unit Boundary	Port Hueneme
Existing Urban Area	Ventura
Camarillo	Ojai
Fillmore	Urban County
Moorpark	Non-Urban County
Oxnard	Adjacent County

10 5 0 10 Miles

Hydrologic Areas

Ventura County, CA

Geosyntec consultants

Oakland Office | April 2010

Figure **B-1**

P:\GIS\Ventura_County_Manual\Projects\B-1_Ventura_County_Watersheds_MS4_Urban_Areas_042910.mxd, WHL, September 1, 2010

Legend

- BIOL Designated Waterbody
- 303(d) Listed Waterbody
- Environmentally Sensitive Habitat Areas
- Lake
- National Forest

Existing Urban Area

- Camarillo
- Fillmore
- Moorpark
- Oxnard
- Santa Paula
- Simi Valley
- Thousand Oaks
- Port Hueneme
- Ventura
- Ojai
- Urban County
- Non-Urban County
- Adjacent County

10 5 0 10 Miles

Environmentally Sensitive Areas

Ventura County, CA

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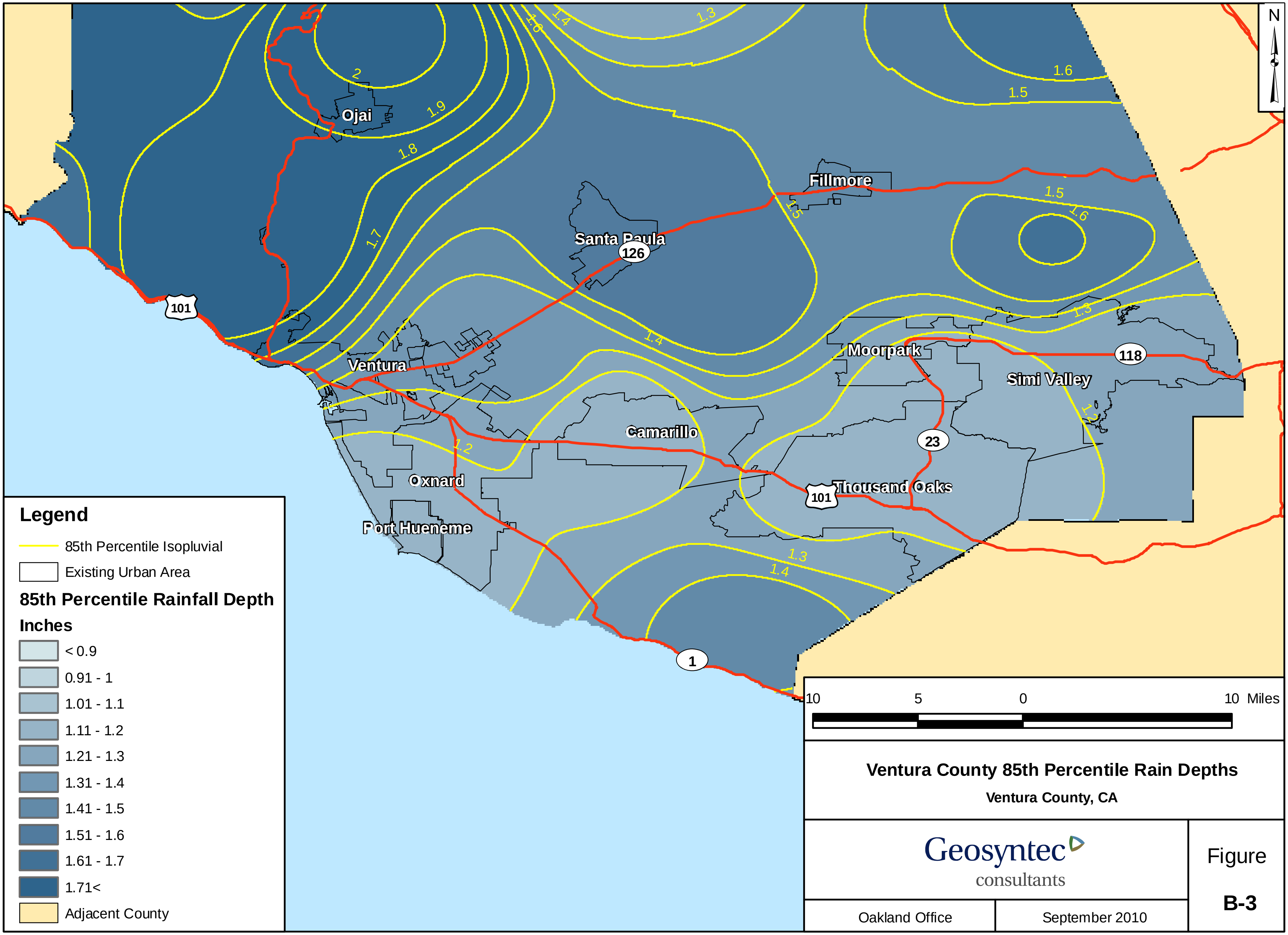
Figure

B-2

B-2_Ventura_County_ESA_042910.mxd, WHL, September 1, 2010



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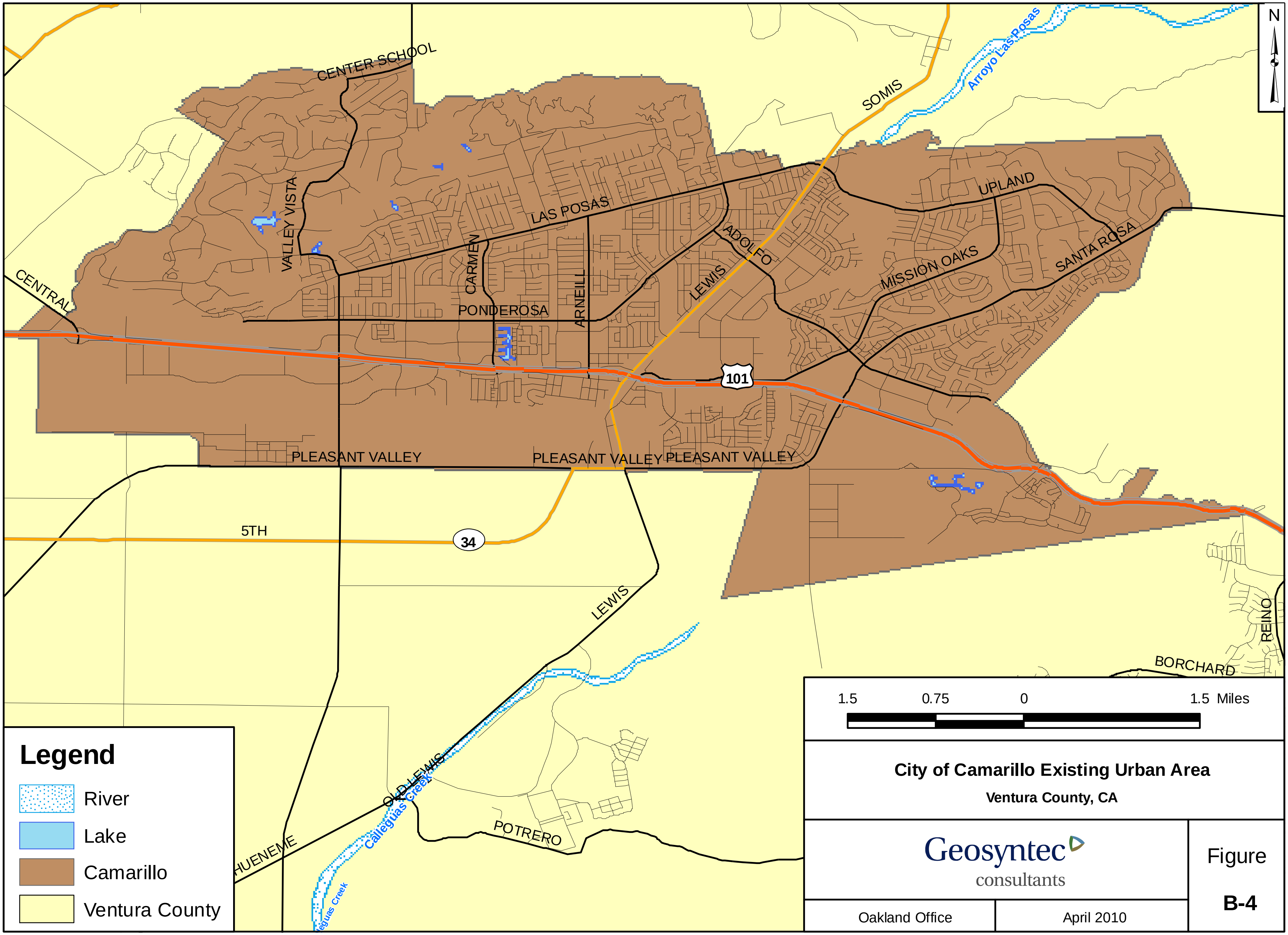
RB-AR34884



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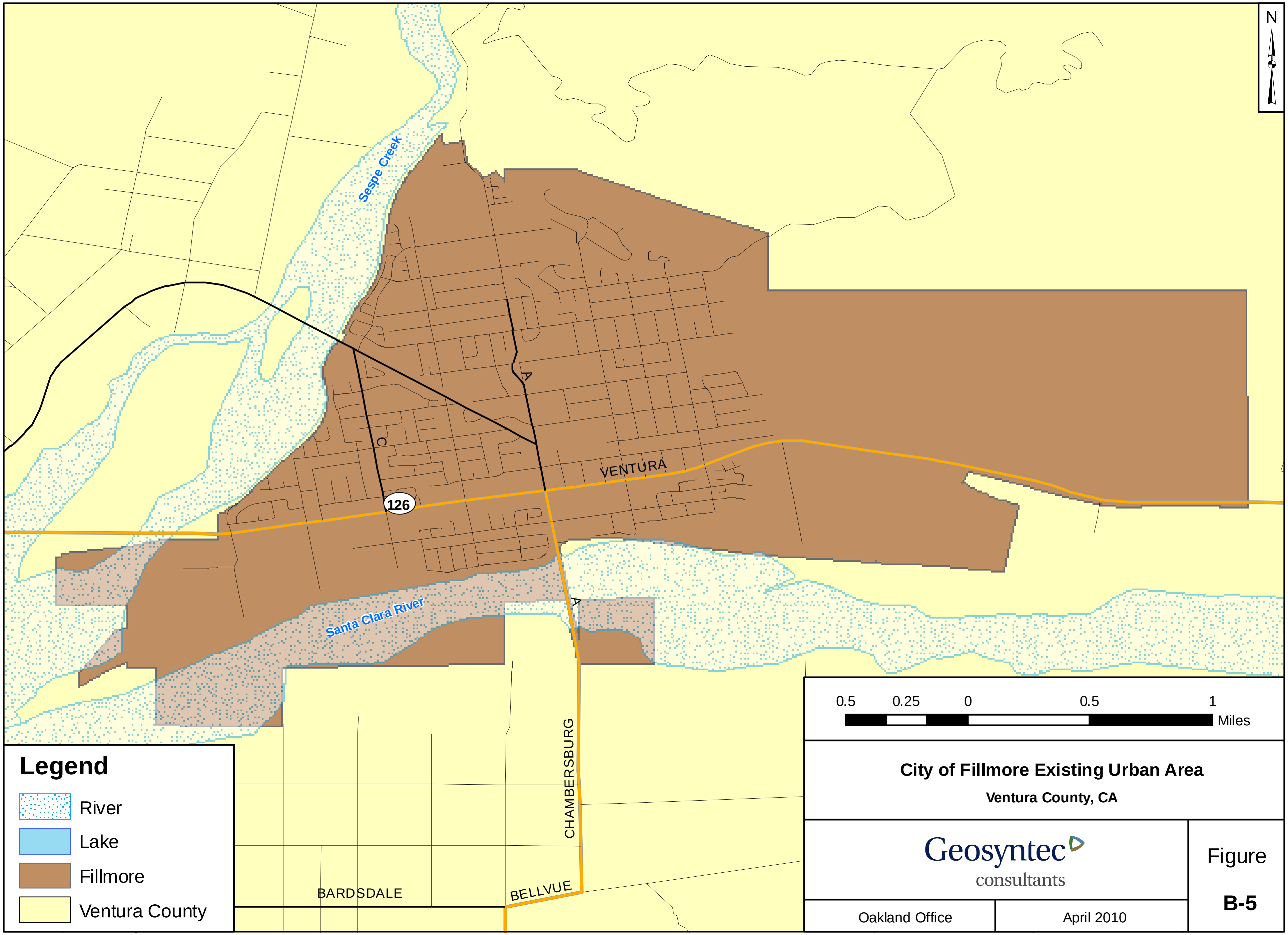
RB-AR34885



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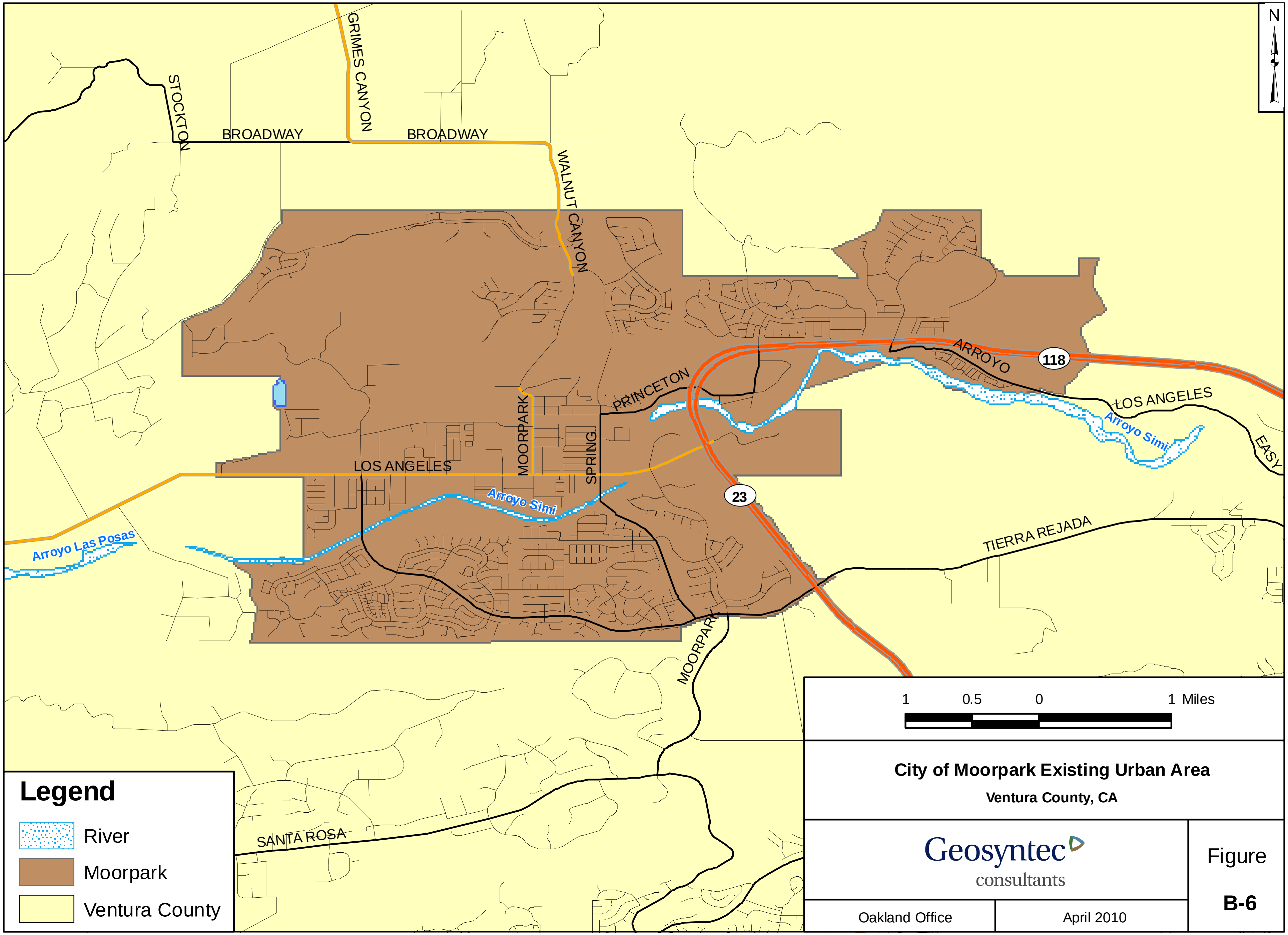
101

RB-AR34886



City of Moorpark Existing Urban Area

Ventura County, CA

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Figure

B-6

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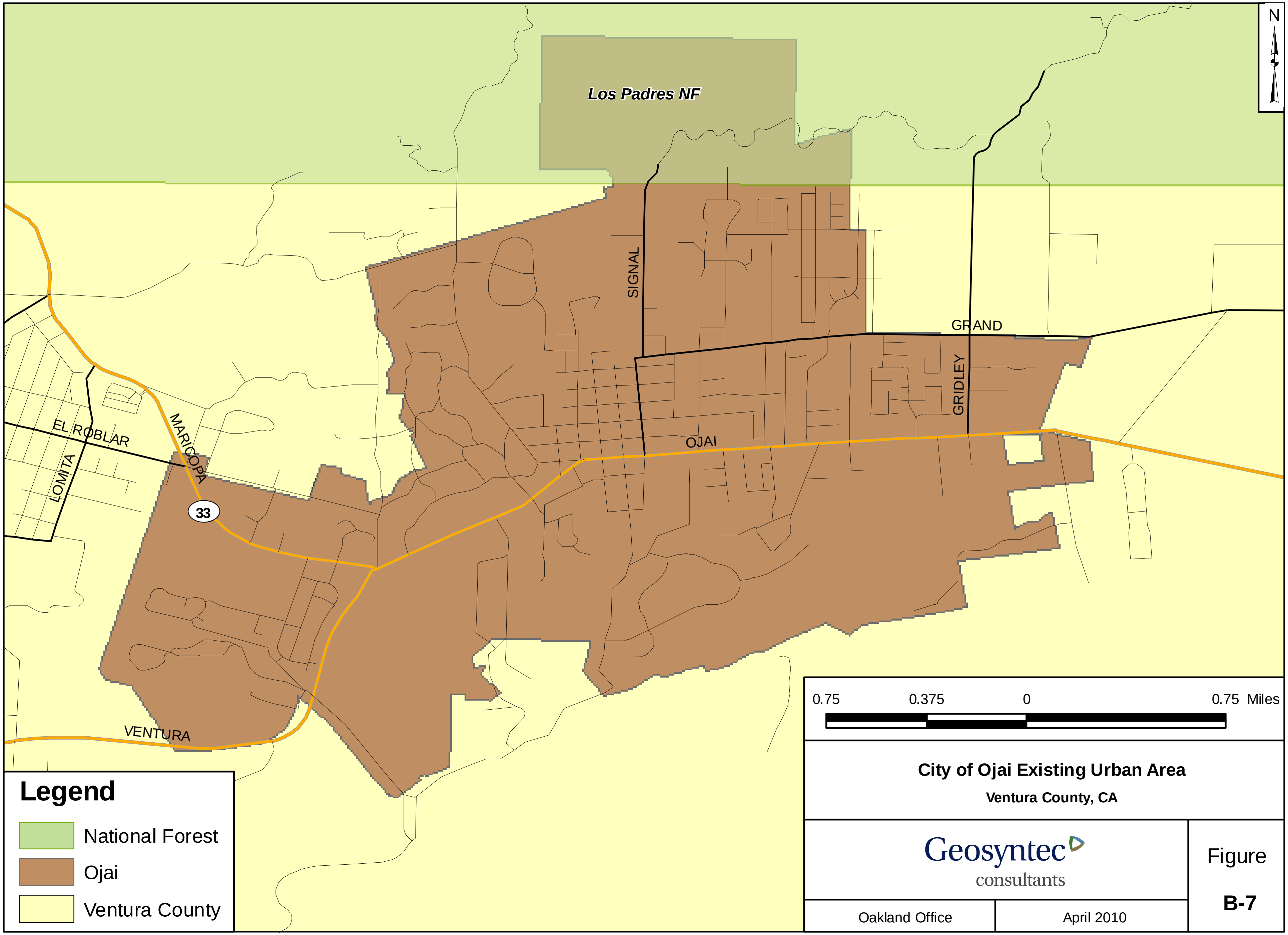
P:\GIS\Ventura_County_Manual\Projects\B-6_Moorpark_MS4_Pop_Areas_092310.mxd, WHL, September 23, 2010



City of Ojai Existing Urban Area

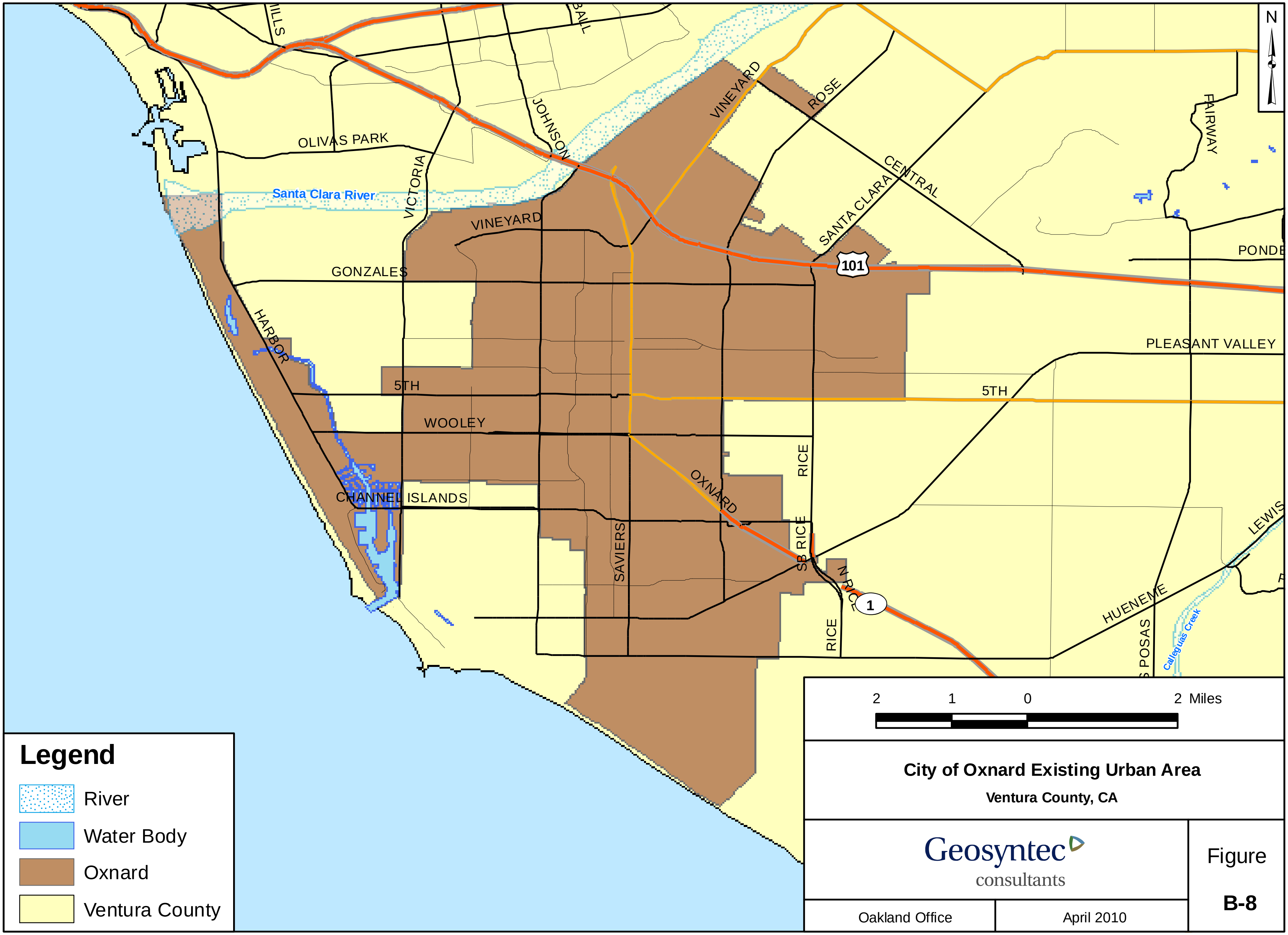
Ventura County, CA

Geosyntec consultants

Figure **B-7**

Oakland Office	April 2010

P:\GIS\Ventura_County_Manual\Projects\B-7_Ojai_MS4_Pop_Areas_092310.mxd, WHL, September 23, 2010



City of Oxnard Existing Urban Area

Ventura County, CA

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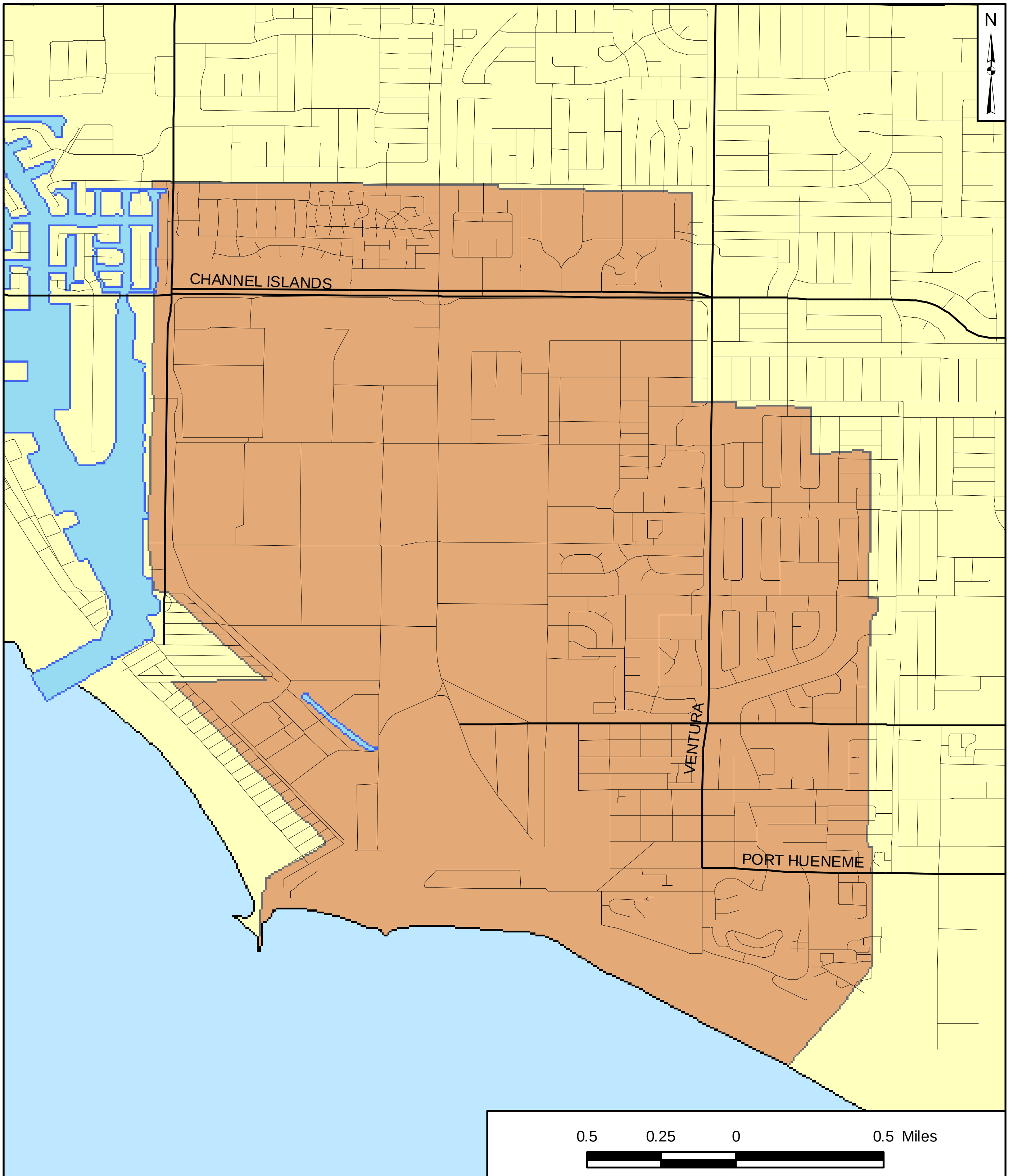
Oakland Office | April 2010

Figure

B-8

RB-AR34889



Legend

- River
- Water Boday
- Port Hueneme
- Ventura County

City of Port Hueneme Existing Urban Area

Ventura County, CA

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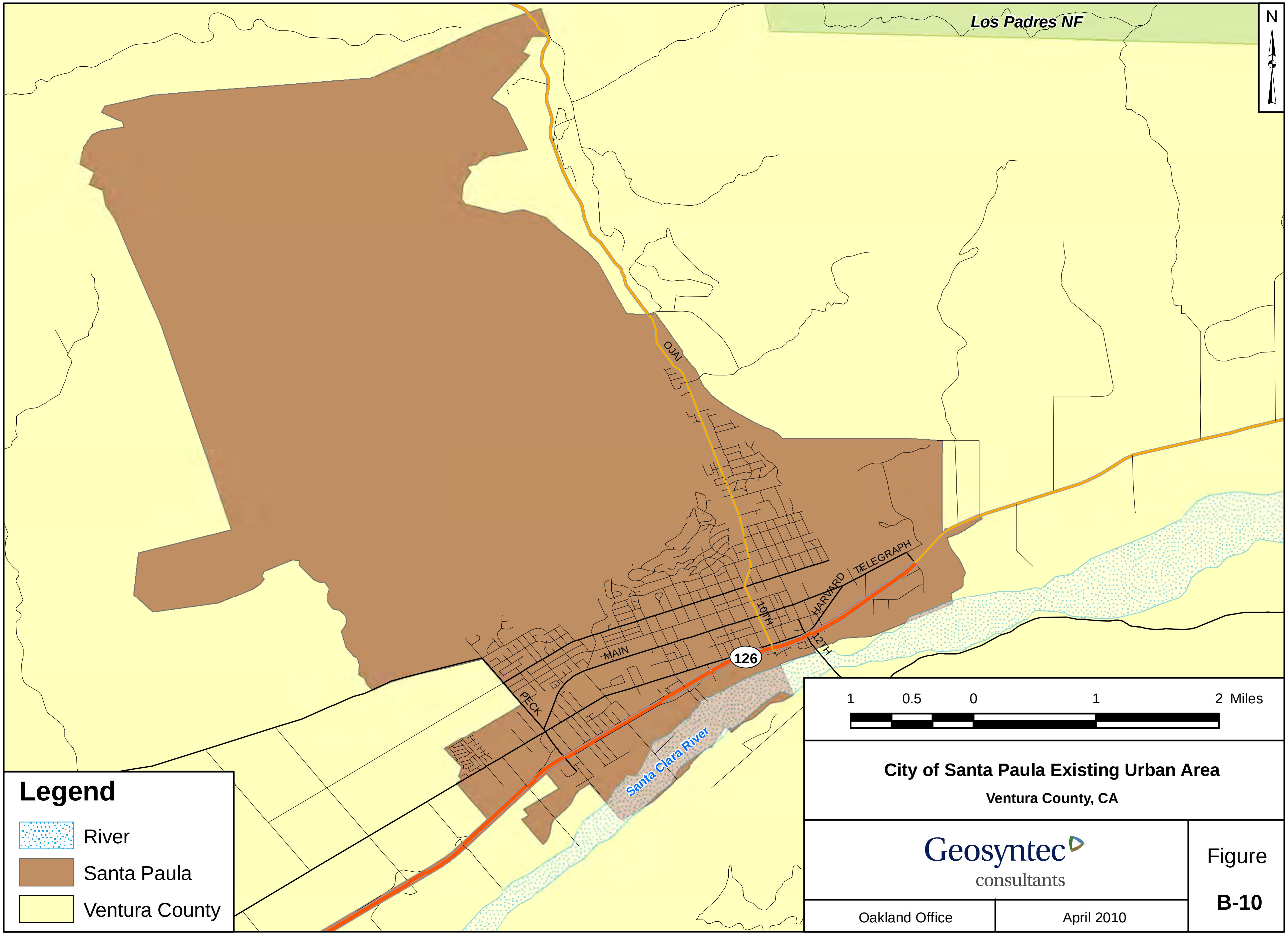
Figure **B-9**

P:\GIS\Ventura_County_Manual\Projects\B-9_Port_Hueneme_MS4_Urban_Areas_092310.mxd, WHL, September 23, 2010

RB-AR34890



City of Santa Paula Existing Urban Area

Ventura County, CA

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Figure **B-10**

Oakland Office | April 2010

P:\GIS\Ventura_County_Manual\Projects\B-10_Santa_Paula_MS4_Pop_Areas_092310.mxd, WHL, September 23, 2010

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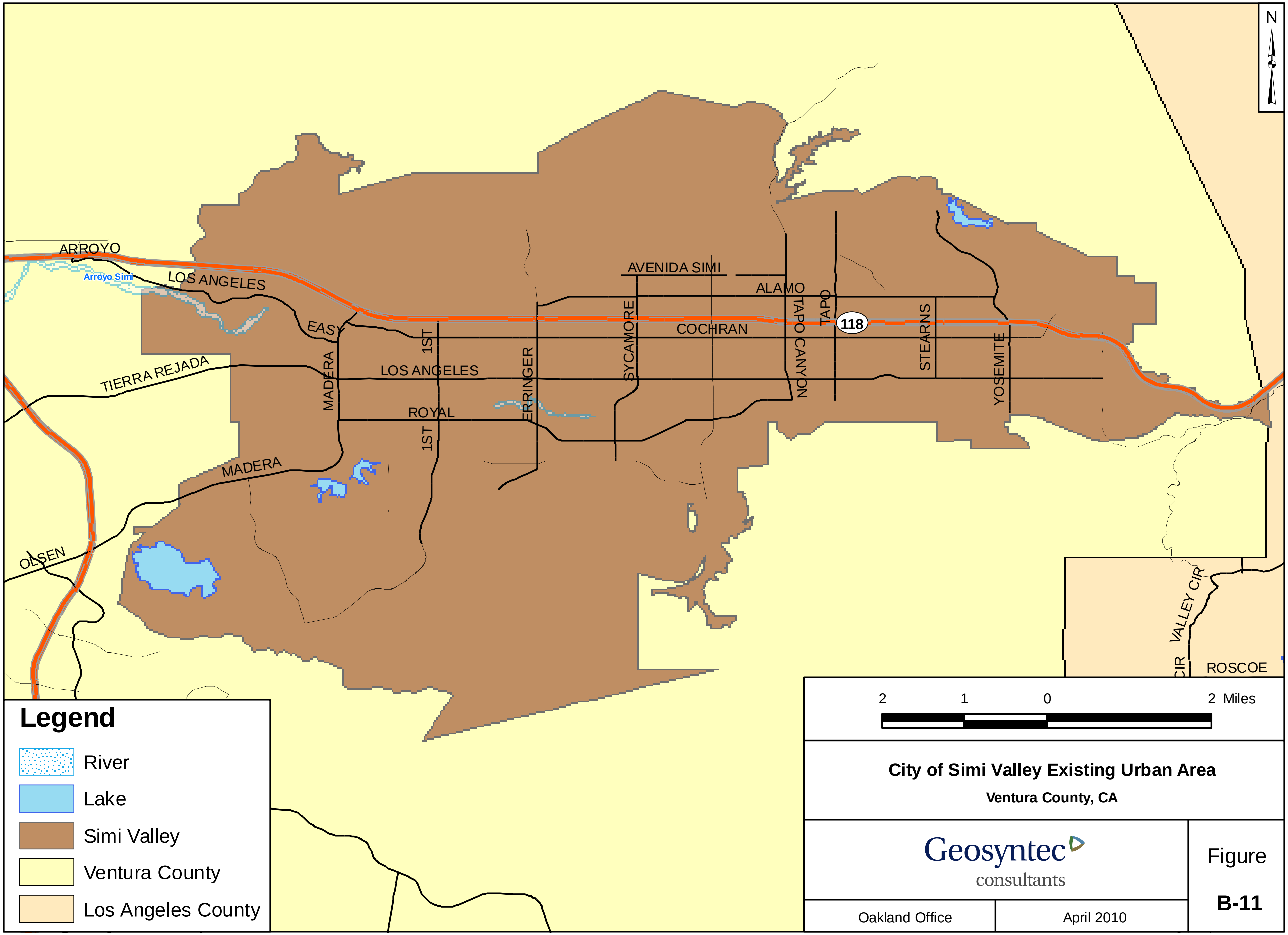

City of Simi Valley Existing Urban Area

Ventura County, CA

Geosyntec consultants

Figure

B-11

Oakland Office | April 2010

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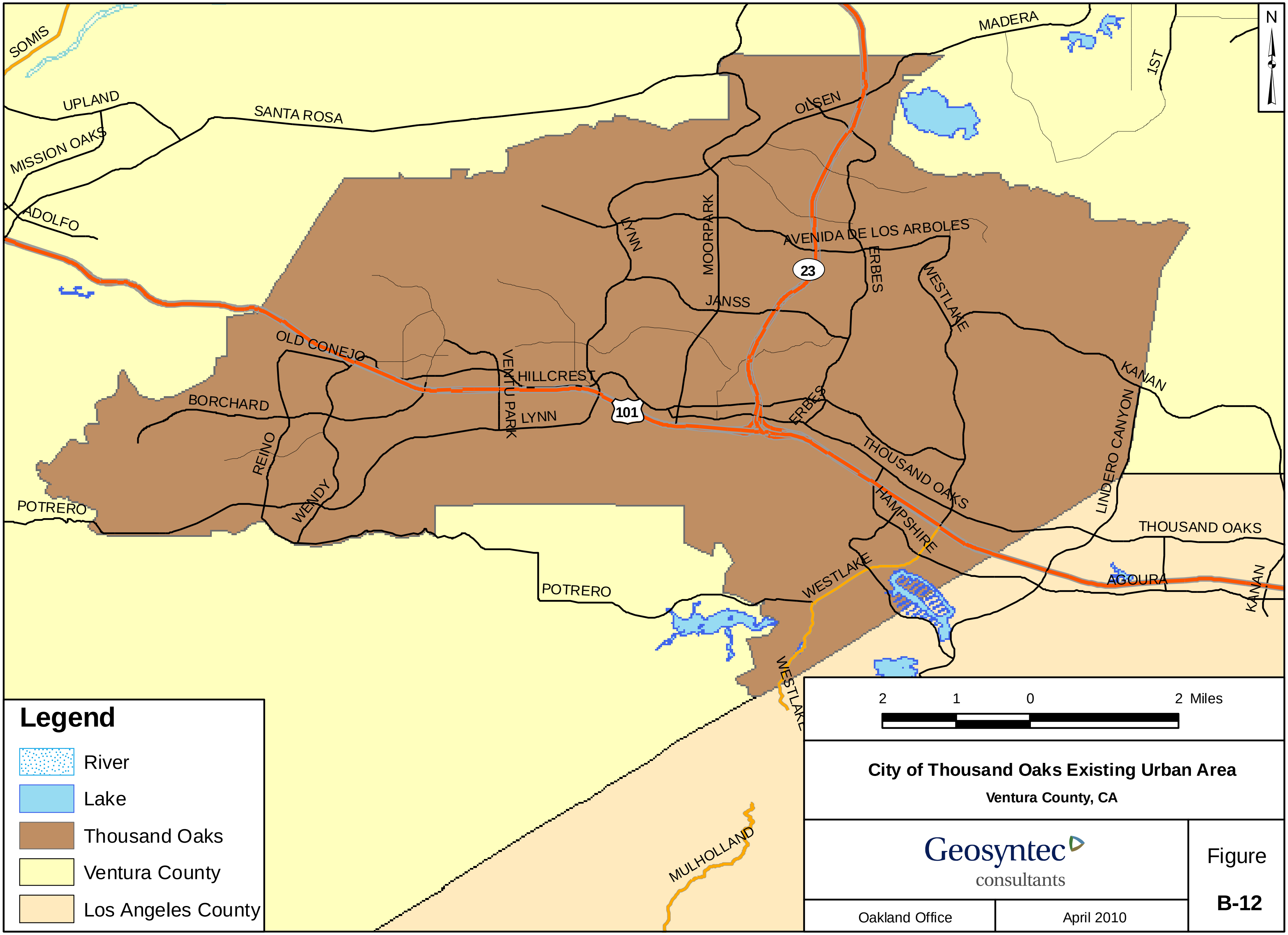
RB-AR34892



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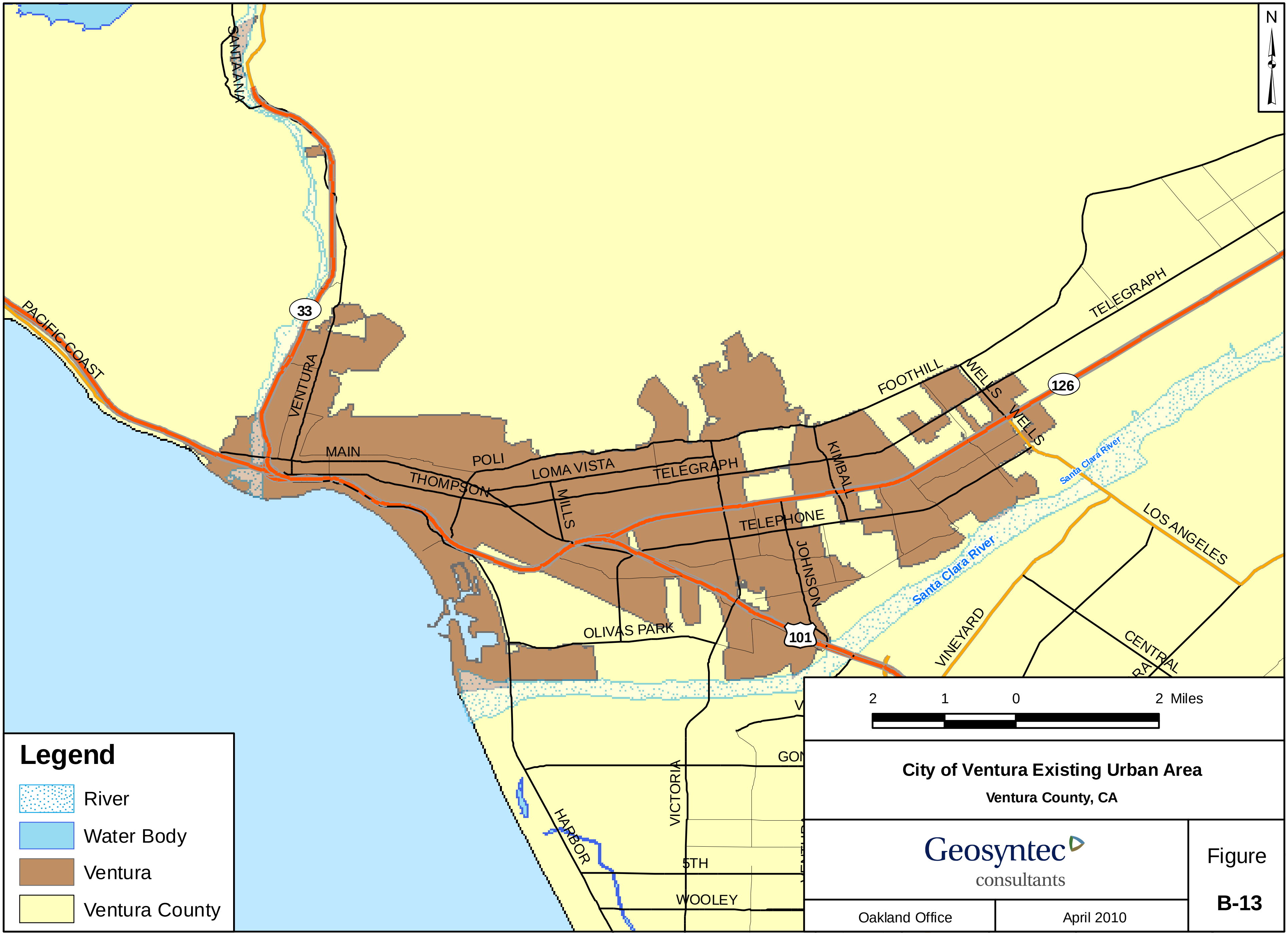
RB-AR34893



City of Ventura Existing Urban Area

Ventura County, CA

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Figure B-13

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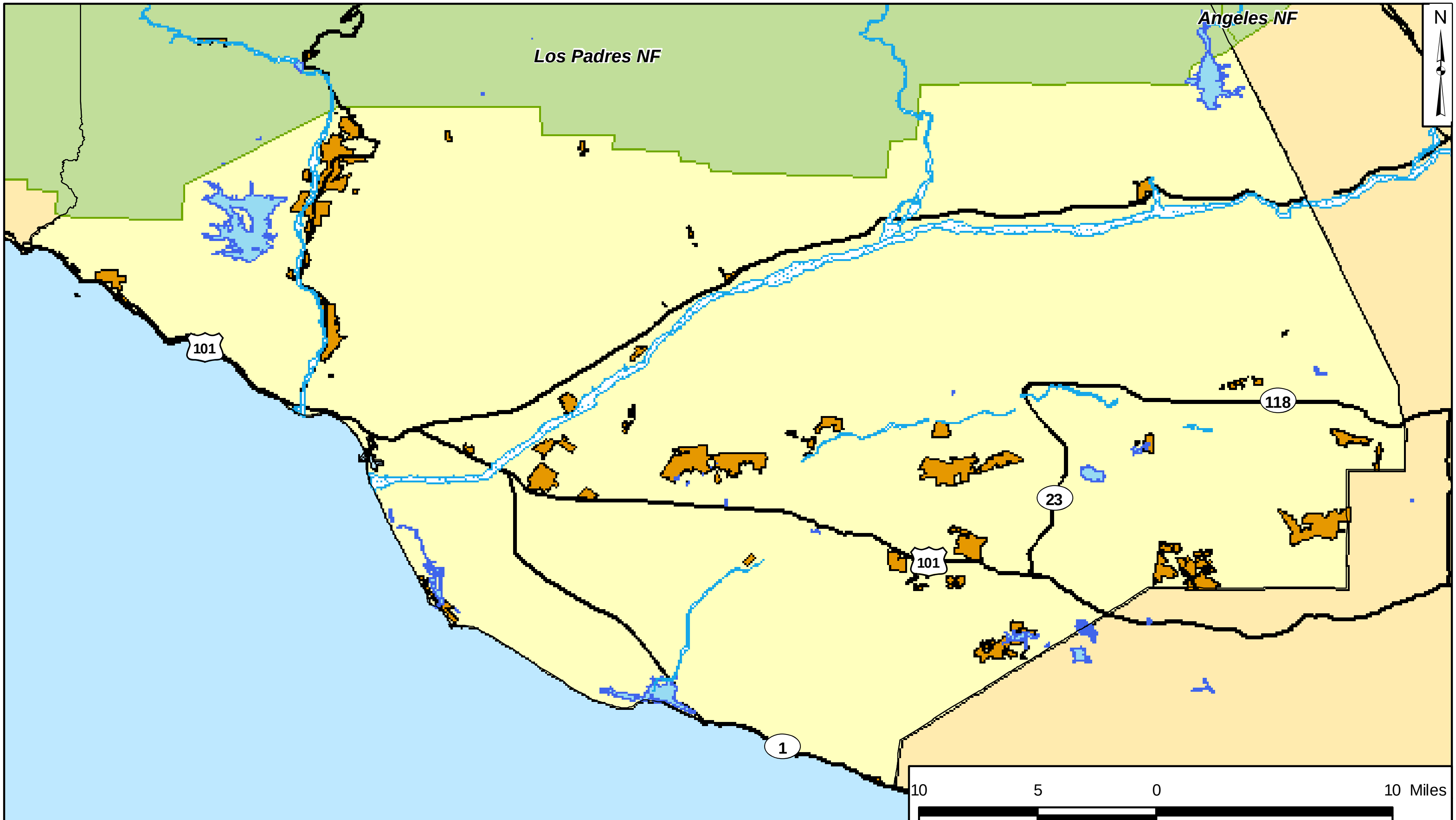

Legend

- River
- Lake
- Unincorporated Urban County
- National Forest
- Non-Urban County
- Adjacent County

Note: An Unincorporated Urban Center is an existing or planned community which is located in an Area of Interest where no city exists. The unincorporated urban center represents the focal center for community and planning activities within an Area of Interest. For example, the Community of Piru represents the focal center in the Piru Area of Interest. This map represents the existing Unincorporated Urban Centers as defined by the Ventura County General Plan.

Ventura County Unincorporated Urban Areas

Ventura County, CA

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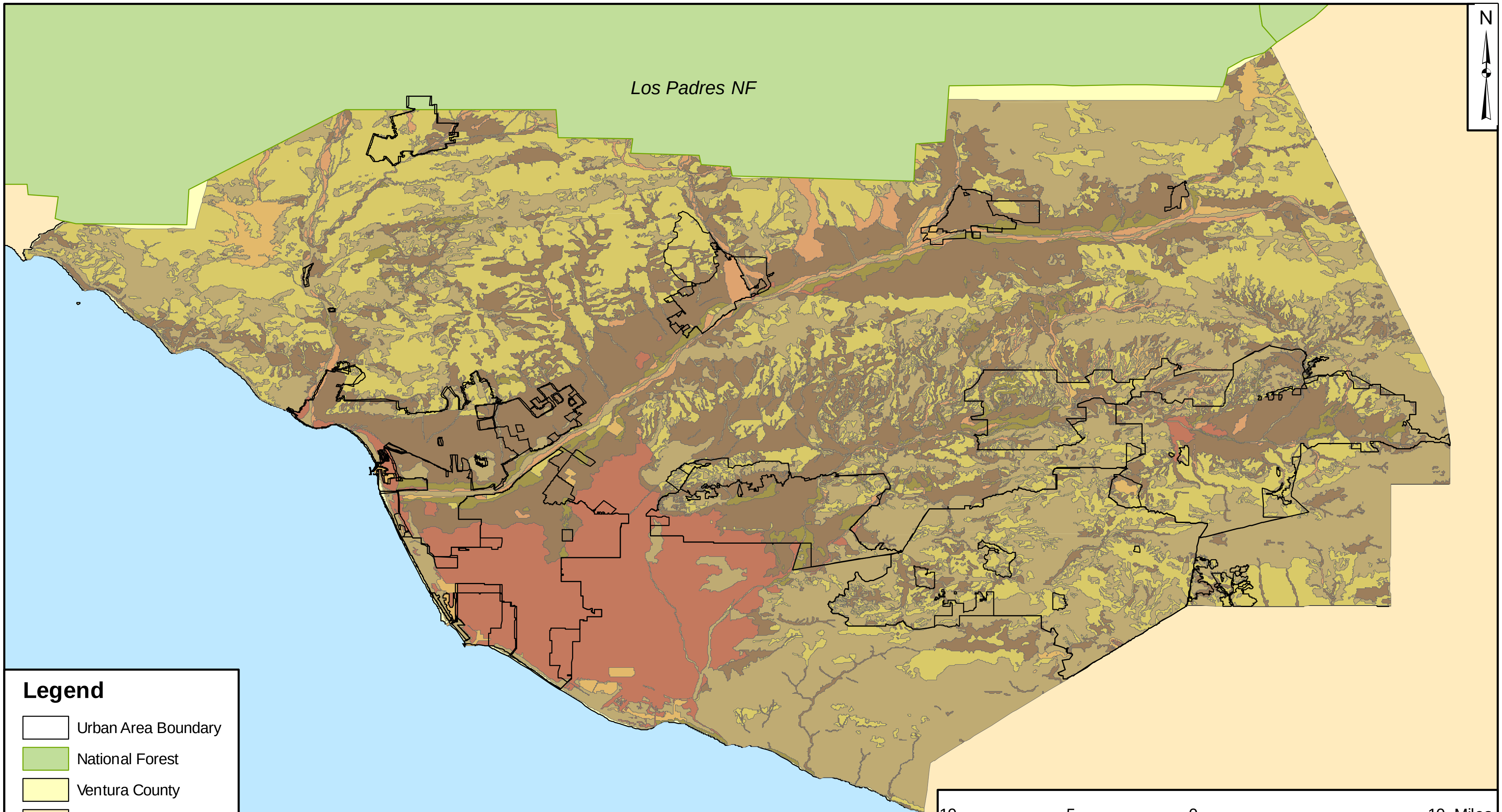
Figure

B-14

P:\GIS\Ventura_County_Manual\Projects\B-14_Ventura_County_Urban_092310.mxd, WHL, September 23, 2010



Legend

Urban Area Boundary
National Forest
Ventura County
Adjacent County

Ventura County Soil Number

1
2
3
4
5
6
7

Southern Ventura County Soil Classification

Ventura County, CA

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Figure **B-15**

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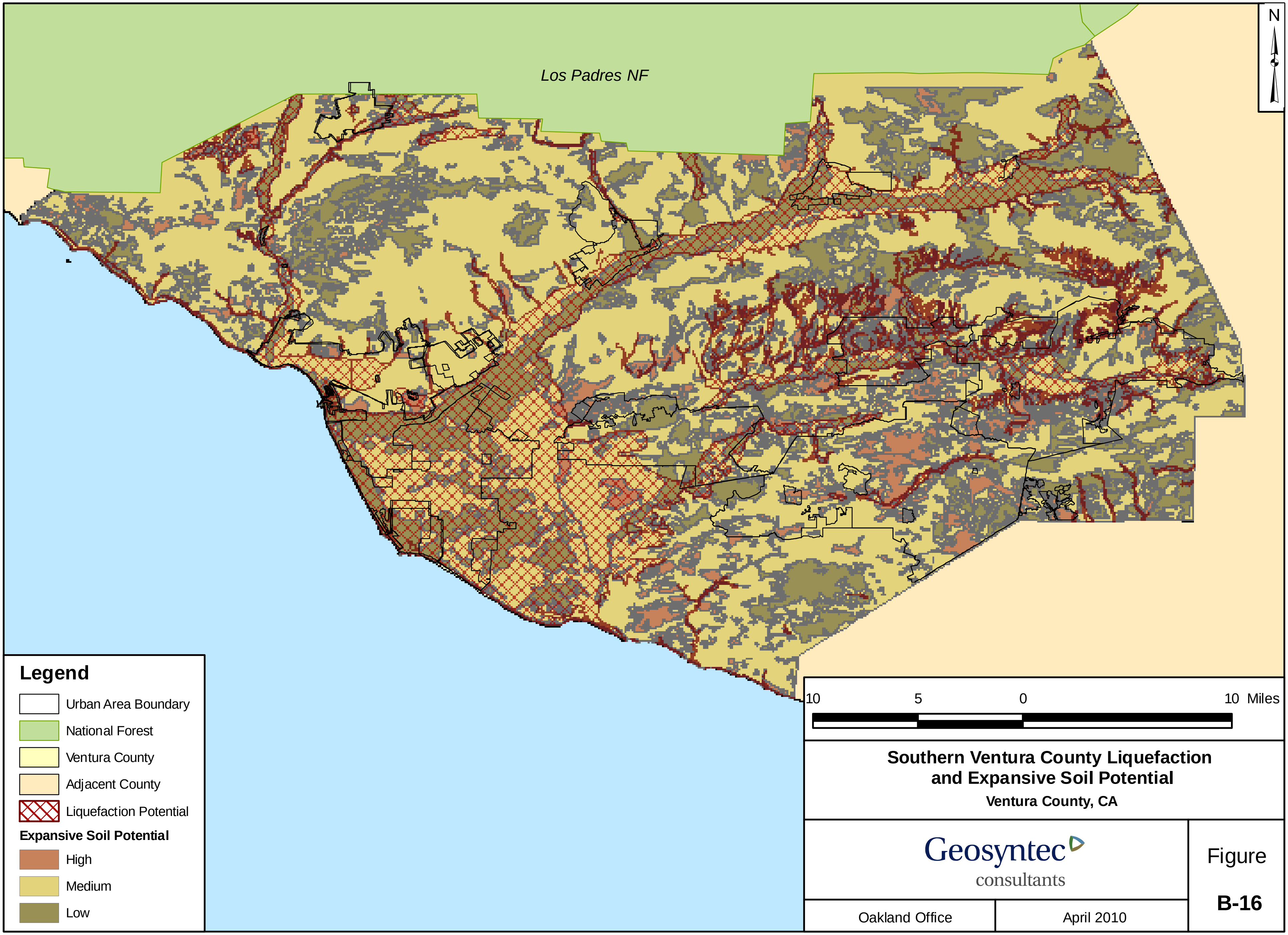
RB-AR34896



Southern Ventura County Liquefaction and Expansive Soil Potential

Ventura County, CA

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Figure **B-16**

Oakland Office | April 2010

P:\GIS\Ventura_County_Manual\Projects\B-16_Liq_Expan_Soils_092310.mxd, WHL, September 23, 2010

APPENDIX C : SITE SOIL TYPE AND INFILTRATION TESTING

C.1 Introduction

The purpose of site soil and infiltration testing is to more accurately determine where LID and structural treatment BMPs should be located and if infiltration is feasible on the site. The preliminary site assessment, discussed in Section 3, will likely reduce the number of test pit investigations needed by identifying candidate test sites that are most amenable to infiltration. This section summarizes the methods for conducting (1) soil test pit investigations and (2) infiltration testing at key locations identified in the preliminary site assessment that require further investigation.

A qualified soil scientist or geotechnical professional should conduct the test pit investigation and infiltration tests. The professional should be experienced with the testing procedures as well as the hydraulic functioning of the potential BMPs to ensure that additional information regarding BMP siting is acquired during the test pit investigation and infiltration tests.

This appendix is not intended to be applied as a protocol for conducting soil and infiltration testing. Instead, this section is provided to assist in specifying and standardizing soil and infiltration testing techniques across sites within Ventura County where development is occurring.

C.2 Test Pit Investigations

A test pit investigation is an integral part of assessing site soil conditions. Soil maps and hydrologic soil groups are based on regional data and provide only a general understanding of what to expect; however, there are undoubtedly unknowns that will be discovered during these initial field observations. A test pit investigation involves digging or excavating a test pit (deep hole). By excavating a test pit, overall soil conditions (both vertically and horizontally) can be observed in addition to the soil horizons. To maximize the knowledge gained during the test pit investigation, many tests and observations should be conducted during this process.

Test pits should be excavated to a depth at least three feet deeper than the proposed bottom of non-infiltration BMPs and at least eleven feet deeper than the proposed bottom of infiltration BMPs. A project that imports fill must characterize the proposed soil profile at the specified depths. For example, if the proposed depth of fill is 5 feet below grade and an infiltration BMP is to be used in the location of the fill, both the fill and the native subsoil require soil characterization. Figure C-1 illustrates the proposed soil profile that would result with 3 feet of fill. Since the test pit must be excavated to a depth that is 11 feet deeper than the bottom of the proposed infiltration BMP, a test pit investigation of the top 8 feet of native subsoil is required, in addition to the laboratory sample of the fill material. Characterization of the fill material should be conducted in a laboratory. It is recommended that soil compaction is limited in the location of a proposed infiltration BMP.

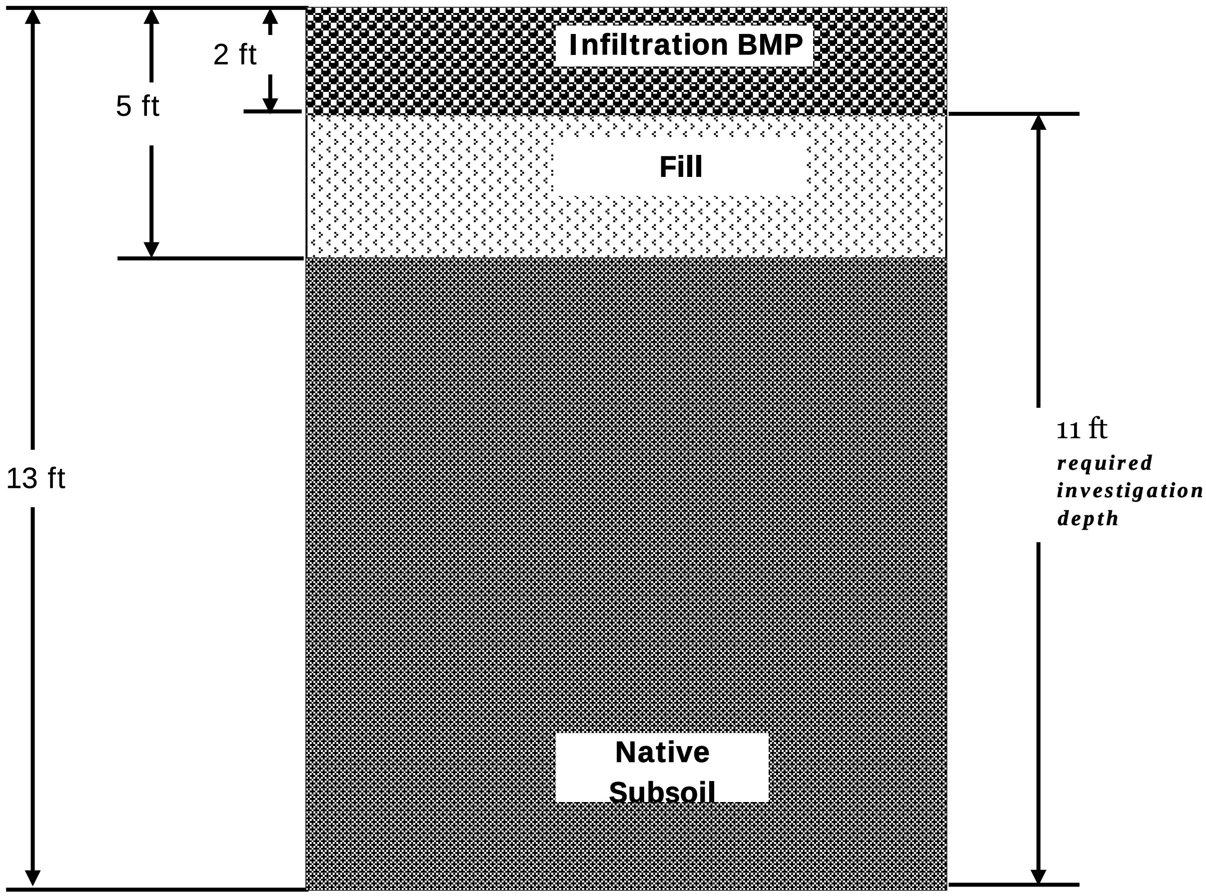

Figure C-1: Post-fill Soil Profile

As the test pit is excavated, the following measurements should be made:

Standard penetration testing to determined the relative density as it changes with depth (minimum intervals of 2 - 3 feet), and

Infiltration testing with at least one test occurring at the proposed bottom of the BMP and one test occurring of the bottom of the test pit (11 feet below the bottom of the infiltration BMP).

In addition, many observations should be made during and after the excavation of the soil pit, including:

- Elevation of groundwater table or indications of seasonally high groundwater table should be noted using the NRCS hydric soil field indicators guide (NRCS, 2003).
- Soil horizon observations, including: depths indicating upper and lower boundaries of the soil horizons, depths to limiting layers (i.e., bedrock and clay), soil textures, colors and their patterns, and estimates of the type and percent of coarse fragments.

- Locations and descriptions of macropores (i.e., pores and roots).
- Other pertinent information/observations.

The number of test pits required depends largely on the specific site and the proposed development plan. Additional tests should be conducted if local conditions indicate significant variability in soil types, geology, water table elevations, bedrock, topography, etc. Similarly, uniform site conditions may indicate that fewer test pits are required. Excessive testing and disturbance of the soil prior to construction is not recommended. When test pit investigations are complete, including infiltration testing, the pits should be refilled with the original soil and the surface replaced with the original topsoil.

C.3 Infiltration Testing

There are a variety of infiltration field test methodologies available to determine the infiltration rate of a soil. Infiltration tests should be conducted in the field in order to ensure that the measurements are representative of actual site conditions (including inherent heterogeneity). As mentioned above, usually infiltration rates should be determined at a minimum of two locations in each test pit and one must be conducted at the proposed bottom depth of the BMP. The actual number of infiltration tests required depends on the soil conditions; if the soils are highly variable, more tests may be required. To ensure groundwater is protected and that the infiltration BMP is not rendered ineffective by overload, it is important to periodically verify infiltration rates of the constructed BMP(s).

For BMPs that infiltrate water through the surface soil layer (e.g., bioretention areas, permeable pavement), choosing a method that measures infiltration in surface soils is important. For infiltration trenches and drywells, infiltration will occur at a greater depth in the soil matrix; therefore, borehole methods may be more appropriate.

Depending on the type of infiltration BMP and depth at which the infiltration test should be conducted, there are several types of infiltration tests that can be used including: disc permeameters, single and double ring infiltrometers, and borehole permeameters. Disc permeameters are typically used to provide estimates of soil near saturation but can prove to be difficult due to measures of three dimensional flow. This device is also commonly used for assessing infiltration rates of already constructed permeable pavements and is generally not used for assessing infiltration rates prior to site disturbance; therefore, the disc permeameter method will not be discussed further in this Appendix. Single and double ring infiltrometers directly measure vertical flow into the surface of the soil. Double ring infiltrometers account for lateral flow boundary affects with the addition of an outer water reservoir and are generally the preferred method for surface infiltration. Borehole permeameters are best suited to collect infiltration measurements below the soil surface. Two subsurface infiltration methods are discussed below including the Guelph and falling-head permeameters.

C.4 Double Ring Infiltrometer

The double ring infiltrometer method consists of driving two cylinders, one inside the other, into the ground and partially filling them with water and maintaining the liquid at a constant level (ASTM D3385-94). The volume of water added to the inner ring from a separate water reservoir, to maintain the constant head level is comparable to the volume of water infiltrating into the soil. The volume of water added to the inner ring divided by the time period for which the water was added is equal to the infiltration rate. A photograph of a common double ring infiltrometer is provided in Figure C-2.

Figure C-2: Double Ring Infiltrometer

Photo Credit: Geosyntec Consultants (Braga and Fitsik, 2008)

C.5 Borehole Guelph Infiltration Test

For shallow boreholes, the Guelph Permeameter has been developed as a field portable kit. This permeameter consists of a tube that is placed in a hand-drilled shallow borehole and water is provided to the tube through a separate reservoir. Water loss in the reservoir is used to estimate the hydraulic conductivity of the soil, which may be used to calculate infiltration based on various standard models (Soil Moisture Equipment, 2005). A photograph of a Guelph Permeameter is provided in Figure C-3. It is important to remember that this method will include vertical and lateral water flow from the borehole.

Figure C-3: Guelph Permeameter for Shallow Borehole Permeability

Photo Credit: USDA, 2005

C.6 Falling-Head Borehole Infiltration Test

The falling-head borehole infiltration test is commonly applied to assess infiltration at greater depths (e.g. 5 - 25 ft). The method is generally performed according to United States Bureau of Reclamation procedure 7300-89 (USBR, 1990). Caltrans has used the method to site stormwater infiltration structures (Caltrans, 2003). Essentially the method consists of boreholes, installing well casing with slots cut to release water at the target depths, backfilling the borehole, adding pre-soak water, and then filling again with water and recording the stage loss. An example diagram is shown in Figure C-4.

The testing procedures are summarized as follows:

1) Remove any smeared soil surfaces to provide a natural soil interface for testing the percolation of water. Remove all loose material. The U.S. EPA recommends scratching the sides with a sharp pointed instrument. (Note: upon tester's discretion, a 2-inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring and sediment.) Fill casing with clean water and allow to pre-soak for 24 hours or until the water has completely infiltrated.

2) Refill casing and monitor water level (distance from top of casing to top of water) for 1 hour. Repeat this procedure a total of four times. (Note: upon tester's discretion, the final field rate may either be the average of the four observations

or the value of the last observation. The final rate shall be reported in inches per hour.)

3) Testing may be done through a boring or open excavation.

4) The location of the test must be near the proposed facility.

5) Upon completion of the testing, the casings shall be immediately pulled and the test pit shall be back-filled.

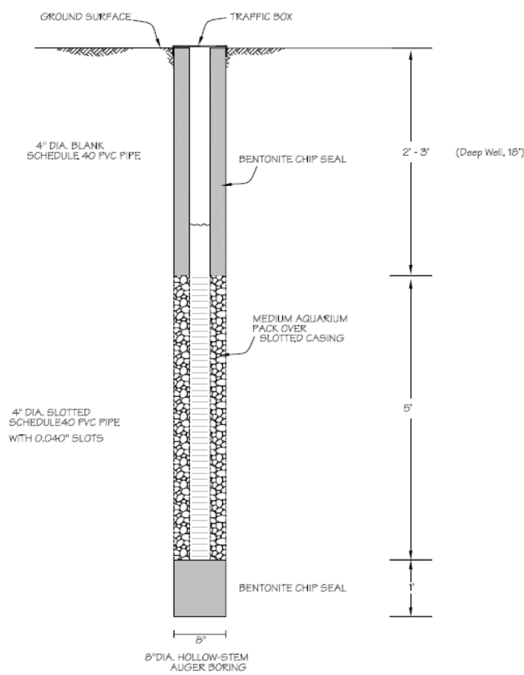

Figure C-4: Falling-Head Permeameter for Deep Borehole Permeability

Diagram Credit: Group Delta Consultants, 2008

C.7 Laboratory Soil Tests

If fill materials imported from off-site are part of an infiltration BMP design, a laboratory test is required to determine the infiltration rate of the fill soil. A sample of the fill soil from each area where a BMP will be located must be tested. The soil sample must be compacted to the same degree that will be present after final grading. Once prepared, the sample should be sent to a specialty laboratory to conduct a test of the infiltration rate. These results may then be used to assess the applicability of a specific BMP.

C.8 Assessment of Test Results

The results from field infiltration methods should be examined to consider data variability and sample distribution to determine if there has been adequate sampling. If the spatial variability (heterogeneity) is large, then additional field measurements may be necessary. The infiltration results should be compared to the information gathered on site soils and geology to see if they are consistent. The results of the site soils and infiltration testing may then be used in the siting, selection, sizing, and design of LID site design techniques and structural treatment BMPs.

C.9 References

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APPENDIX D : BMP PERFORMANCE GUIDANCE

D.1 Permit Requirement

Part 3, Section A.3 of Order R4-2010-0108 states the following:

3. *Each Permittee shall require that treatment control BMPs being implemented under the provisions of this Order shall be designed, at a minimum, to achieve the BMP performance criteria for storm water pollutants likely to be discharged as identified in Attachment "C", for an 85th percentile 24-hour runoff event determined as the maximized capture storm water volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998). Expected BMP pollutant removal performance for effluent quality was developed from the WERF-ASCE/ U.S. EPA International BMP Database. P ermittees shall select Treatment BMPs based on the primary class of pollutants likely to be discharged from the site/facility (e.g. metals from an auto repair shop). Permittees may develop guidance for appropriate Treatment BMPs for project type based on Attachment "C". For the treatment of pollutants causing impairments within the drainage of the impaired waterbody, permittees shall select BMPs from the top three performing BMP categories or alternative BMPs that are designed to meet or exceed the performance of the highest performing BMP for the pollutant causing impairment.*

Attachment C contains the following table:

Effluent Concentrations as Median Values

BMP Category	Total Suspended Solids (mg/L)	Total Nitrate-Nitrogen (mg/L)	Total Copper (µg/L)	Total Lead (µg/L)	Total Zinc (µg/L)
Detention Pond	27	0.48	15.9	14.6	58.7
Wet Pond	10	0.2	5.8	3.4	21.6
Wetland Basin	13	0.13	3.3	2.5	29.2
Biofilter	18	0.36	9.6	5.4	27.9
Media Filter	11	0.66	7.6	2.6	32.2
Hydrodynamic Device	23	0.29	11.8	5	75.1

Expected BMP pollutant performance for effluent quality was developed from the WERF-ASCE/U.S. EPA International BMP Database, 2007

D.2 Using Performance Statistics for BMP Selection

The observed performance of stormwater BMPs provides valuable quantitative information that can be used to infer the potential water quality benefits of stormwater BMP implementation. However, water quality data sets and the statistical methods used to summarize them inherently contain a high level of uncertainty. Consideration of this uncertainty is fundamental to the proper and responsible use of statistics. Some of the key issues that should be considered when drawing conclusions from data contained in the ASCE International BMP Database for the purposes of developing BMP selection guidance are discussed below.

Number of Representative BMPs

Some BMP types are not well represented in the ASCE International BMP Database due to small data sets. For example, the "Wetland Basin" category only included nine studies nationwide as compared to over 50 for biofilters at the time the data analysis was conducted for the MS4 permit (2007). For some pollutants, such as total copper, data are only available for four Wetland Basin studies. While the BMP Database continues to grow, there are currently less than 300 BMP studies included, with only approximately 50 in California. The size of the data set provides an indicator of the reliability of that data in representing the "typical" effluent concentration for that BMP type.

BMP Categorization

The BMP studies within the BMP database represent a wide spectrum of BMP types with a variety of designs and sizing criteria. While some guidance is provided on how to categorize BMPs, data providers are responsible for categorizing their own BMPs. Some of these BMPs could be poorly categorized due to a variety of reasons, such as differences in terminology, missing or inadequately sized treatment components (e.g., forebays, vegetation, or permanent pools) or variable treatment function (e.g., a seasonal wet pond). Ideally, the BMPs should be grouped according to common design components and/or sizing criteria, but there currently aren't enough data with design information to support such analyses. However, the BMP Database is currently undergoing a restructuring that is redefining or sub-categorizing the current BMP categories within the database.

Statistical Significant Difference between BMP Influent/Effluent

Some of the median effluent values reported in the BMP Database are not statistically different than the median influent values (i.e., no concentration reductions on average). No significant difference may indicate either low influent concentrations or poor performing BMPs for that pollutant. In either case, the effluent value alone would not be a r eliable indicator of BMP performance. For example, as summarized in Geosyntec and Wright Water (2008), the data for Wetland Basins, a "top performing" BMP according to Attachment C of the MS4 permit, did not conclusively show statistically significant removals of TSS, nitrate-nitrogen, or total lead. Data for hydrodynamic separators and media filters indicate they are also ineffective at reducing nitrate-nitrogen concentrations.

Statistical Significant Differences in Effluent between BMP Types

The median effluent concentrations of the various BMP types are not necessarily statistically significantly different from each other. Statistical significance can be determined by analyzing whether the 95^{th} percent confidence intervals overlap. The number of data points and the variability of those data points determine the confidence interval of each median value. If the effluent medians are not statistically significantly different from each other, it may not be possible to determine the "top three" performing BMPs as specified in the MS4 Permit. Confidence intervals about the median effluent concentrations for each BMP type are provided in Geosyntec and Wright Water (2008) (see attached).

D.3 Comparison of the Performance of Biofiltration BMPs and Retention BMPs

Background

Projects that demonstrate technical infeasibility for reducing EIA to ≤5% using Retention BMPs are eligible to use Biofiltration BMPs to achieve the EIA performance standard. Section 4.E.III.1.(b) of Order R4-2010-0108 states:

> *If on-site retention is determined to be technically infeasible pursuant to 4.E.III.2(b), an on-site biofiltration system that achieves equivalent stormwater volume and pollutant load reduction as would have been achieved by on-site retention shall satisfy the EIA limitation.*

Volume-based biofiltration BMPs shall be sized to treat 1.5 times the volume not retained using Retention BMPs. The remaining EIA requirement may also be satisfied with flow-based Biofiltration BMPs. Flow-based Biofiltration BMPs shall be sized for the remaining drainage area from which runoff must be retained (A_{Retain}) with a rainfall intensity that varies with time of concentration for the catchment tributary to the flow-based Biofiltration BMP, according to the following. Using this flow-based sizing method will achieve or exceed capture and treatment of 80% of the average annual runoff volume.

Time of Concentration, minutes	Design Intensity for 150% Sizing, in/hr
30	0.24
20	0.25
15	0.28
10	0.31
5	0.35

Methodology

A planning-level analysis was conducted to assess whether the range of Biofiltration BMPs included in the 2010 TGM, sized per these volume- or flow-based sizing criteria, would achieve equivalent pollutant load reduction to Retention BMPs. The following describes the step-wise method taken for the analysis.

Step 1: Estimate the Catchment Annual Load

Assumptions:

- Average Annual Rainfall- 14.5 inches (Oxnard Gauge) (precipitation, P)
- One acre Catchment (area, A)

Calculations:

1) Determine developed runoff coefficients for single-family, multi-family, commercial, and industrial land use types
   - Use average imperviousness values from Ventura Hydrology Manual (Exhibit 14B)
   - Assume soil group 2/3 (Group C soils) for pervious runoff coefficient (Cp, conservative value = 0.1)
   - Use developed runoff coefficient (C_d) equation from hydrology manual:

$$C_d = 0.95*(\text{imperviousness}) + (Cp)*(1\text{-imperviousness})$$

2) Calculate Average Annual Runoff Volume (cu-ft) using:

$$V_{avg\ annual} = C_d*(P/12)*A*43560$$

3) Multiply average annual runoff volume by respective event mean concentrations (EMCs) for pollutants of concern to get average annual loads.
   - Look at "EMC Arithmetic Means" to see EMCs by land use type.
   - EMCs calculated based on LA County Land Use specific data (LACDPW, 2000). Descriptive statistics estimated using the parametric bootstrap method suggested by Singh, Singh, and Engelhardt (1997).
   - Pollutants of concern: Total Suspended Solids (TSS), Total Copper, Total Zinc, and Total Nitrogen. TSS is representative of the sediment pollutant class as well as pollutants that are associated with particulates (e.g., total phosphorous, some metals, pesticides, some organics). Copper and zinc represent metals – lead has been removed from the environment using True Source Control (removal of lead from gasoline) and thus is not an important POC for Biofiltration BMP selection and design. Total nitrogen is representative in that it includes all of the species of nitrogen (organic nitrogen, ammonia, nitrate, and nitrite) and instead of focusing on one species (nitrate).

Step 2: Estimate Retention BMP Load Reduction

1) Determine Retention BMP Design volume:

- Design storm = 0.75”
- Use land use-based coefficients
- $V_{design} = C_d*(0.75/12)*A*43560$

2) Determine Retention BMP capture volume using CASQA 48-hour Drawdown Figure for Oxnard Gauge (CASQA, 2003)

   - Calculate Unit Basin Storage Volume using:
     - Unit Basin Storage Vol = V_{design}/ A
   - Using developed runoff coefficients, interpolate between runoff coefficient lines to determine the percentage of total runoff captured by Retention BMP.

3) Determine Annual Load Reduction

   - The percentage of the annual load that is reduced is the same as the percentage of runoff captured by the Retention BMP, assuming that all captured runoff is retained. The percent capture calculated in (2) can be multiplied by the catchment annual pollutant load to obtain the load reduction.

Step 3: Estimate Biofiltration BMP Load Reduction

1) Determine BMP Design volume as described in 2.a above, except:

   - Design storm = 1.5*0.75 = 1.125 inches

2) Determine BMP capture volume using CASQA 24-hour Drawdown Figure for Oxnard Gauge (CASQA, 2003) as described in 2.b. above

3) Determine annual load reduction. Load reduction in Biofiltration BMPs can occur via two pathways: incidental infiltration and treatment.

   - Incidental infiltration in Biofiltration BMPs was discussed in a publication by Strecker, Quigley, Urbonas, and Jones (Strecker et al, 2004). That study observed as much as 40% volume reduction through incidental infiltration. A recent summary of the studies in the ASCE BMP Database found the following average volume reductions: filter strips, 38%; vegetated swales, 48%; and bioretention with underdrain, 61% (Geosyntec, 2011; attached to this appendix).
   - Pollutant Load reduction via incidental infiltration can be calculated as follows (20% is the percent of the captured volume assumed to be reduced via incidental infiltration for this discussion):

Load reduced = Average annual Load * Percent Runoff Captured by BMP * 20%

- Load reduction through treatment calculated based on published literature on pollutant removals from biofiltration facilities.
- Load reduction through treatment is calculated as follows:

Load reduced = Average annual Load * Percent Runoff Captured by BMP *80% * Assumed Average Percent Removal

Note: 80% = 100%-20%, i.e. the captured runoff that was not infiltrated via incidental infiltration

Constituent	Range of Reported Removal Efficiencies from Literature[1]	Selected Removal Efficiency for Effectiveness Evaluation[2]	Selected Removal Efficiency for Enhanced Nitrogen Removal[3]
TSS	54-89	79	79
Total Zinc	48-96	77	77
Total Copper	33-92	72	72
Total Nitrogen	21-54	25	50

[1] Range of values from literature cited below:

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6. Geosyntec Consultants and Wright Water Engineers, Inc., 2008. Overview of Performance by BMP Category and Common Pollutant Type, International Stormwater BMP Database Update. June 2008
7. Geosyntec Consultants and Wright Water Engineers, Inc., 2010. Categorical Summary of BMP Performance for Nutrient Concentration Data Contained in the International Stormwater BMP Database. December, 2010

[2] Removal efficiency for TSS, Total Zinc, and Total Copper represent average of values from literature. Removal efficiency for TN is that expected from a 'standard biofilter', that is, one not designed for enhanced nitrogen removal

[3] Removal efficiency for TN represented as average value of removals from bioretention systems with an anaerobic zone for enhanced removal of nitrogen

- The total load reduction is calculated as the sum of the reductions from these two pathways. The percent load reduction is calculated by dividing the total load reduction by the annual pollutant load from the catchment

Step 4: Comparison of Annual Load Reductions

1) Load reductions are compared by subtracting the load reduction calculated for Biofiltration BMPs from the load reduction calculated for Retention BMPs to determine the 'deficit' load reduction.

Results

Step 1: Estimate the Catchment Annual Load

1) Determine developed runoff coefficients for single-family, multi-family, commercial, and industrial land use types

Land Use	Imperviousness	Runoff Coefficient (C)
Single Family Residential	0.3	0.36
Multi Family Residential	0.69	0.69
Commercial	0.85	0.82
Industrial	0.93	0.89

2) Calculate Average Annual Runoff Volume (cu-ft), and

3) Multiply average annual runoff volume by respective event mean concentrations (EMCs) for pollutants of concern to get average annual loads.

Land Use	Arithmetic Means from Lognormal EMC Statistics			
	TSS (mg/L)	Total Zinc (mg/L)	Total Copper (mg/L)	Total Nitrogen (mg/L as N)
Single Family Residential	124.2	71.9	18.7	3.74
Multi Family Residential	39.9	125.1	12.1	3.31
Commercial	67	237.1	31.4	3.99
Industrial	219.2	537.4	34.5	3.74

Land Use	Average Annual Runoff Volume (cu-ft)	Catchment Pollutant Loads (kg/yr)			
		TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	18,685	65,716	38	10	1,979
Multi Family Residential	36,134	40,826	128	12	3,387
Commercial	43,292	82,135	291	38	4,891
Industrial	46,871	290,933	713	46	4,964

Step 2: Estimate Retention BMP Load Reduction

1) Determine Retention BMP Design volume

Land Use	Design Volume (cu-ft)
Single Family Residential	967
Multi Family Residential	1869
Commercial	2239
Industrial	2424

2) Determine Retention BMP capture volume using CASQA 48-hour Drawdown Figure for Oxnard Gauge (CASQA, 2003)

Land Use	Design Volume (cu-ft)	Unit Basin Storage Volume (inches)	Approx % Capture
Single Family Residential	966	0.27	60.0%
Multi Family Residential	1,869	0.51	62.5%
Commercial	2,239	0.62	62.5%
Industrial	2,424	0.67	60.0%

3) Determine Annual Load Reduction

Land Use	Average Annual Pollutant Load Reduction (kg/yr) = Influent * Approx % Cap			
	TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	39,429	23	5.9	1,187
Multi Family Residential	25,516	80	7.7	2,117
Commercial	51,335	182	24.1	3,057
Industrial	174,560	428	27.5	2,978

Land Use	Percent of Total Annual Loads			
	TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	60.0%	60.0%	60.0%	60.0%
Multi Family Residential	62.5%	62.5%	62.5%	62.5%
Commercial	62.5%	62.5%	62.5%	62.5%
Industrial	60.0%	60.0%	60.0%	60.0%

Step 3: Estimate Biofiltration BMP Load Reduction

1) Determine Biofiltration BMP Design volume

Land Use	Design Volume (cu-ft)
Single Family Residential	1,450
Multi Family Residential	2,803
Commercial	3,359
Industrial	3,637

2) Determine BMP capture volume using CASQA 24-hour Drawdown Figure for Oxnard Gauge (CASQA, 2003)

Land Use	Design Volume (cu-ft)	Unit Basin Storage Volume (inches)	Approx % Capture
Single Family Residential	1,450	0.40	87.50%
Multi Family Residential	2,803	0.77	87.50%
Commercial	3,359	0.93	90.00%
Industrial	3,637	1.00	87.50%

3) Determine annual load reduction. Load reduction in Biofiltration BMPs can occur via two pathways: incidental infiltration and treatment.

Incidental Infiltration Scenario #1: 20% Volume Reduction

Land Use	Pollutant Load Reduction from 20% Incidental Infiltration (kg/yr)			
	TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	11,500	7	2	346
Multi Family Residential	7,144	22	2	593
Commercial	14,784	52	7	880
Industrial	50,913	125	8	869

Land Use	Pollutant Load Reduction from Standard Treatment (kg/yr)				Enhanced Nitrogen Load Reduction (kg/yr)[1]
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	36,341	21	5	346	693
Multi Family Residential	22,577	69	6	593	1,185
Commercial	46,719	161	20	880	1,761
Industrial	160,886	384	23	869	1,737

[1] Anticipated removal if an anaerobic zone is provided for Enhanced Nitrogen removal.

Land Use	Total Pollutant Load Reduction from Standard Treatment + Incidental Infiltration (20%) (kg/yr)				Enhanced Nitrogen Load Reduction + Incidental Infiltration (20%) (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	47,841	27	6.7	693	1,039
Multi Family Residential	29,721	91	8.4	1,185	1,778
Commercial	61,503	213	26.8	1,761	2,641
Industrial	211,799	509	31.0	1,737	2,606

Land Use	Percent of Total Annual Loads from Standard Treatment + Incidental Infiltration (20%)				Enhanced Nitrogen % Load Reduction + Incidental Infiltration (20%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	72.8%	71.4%	67.7%	35.0%	52.5%
Multi Family Residential	72.8%	71.4%	67.7%	35.0%	52.5%
Commercial	74.9%	73.4%	69.6%	36.0%	54.0%
Industrial	72.8%	71.4%	67.7%	35.0%	52.5%

Step 4: Comparison of Annual Load Reductions

Load reductions are compared by subtracting the load reduction calculated for Biofiltration BMPs from the load reduction calculated for Retention BMPs to determine the 'deficit' load reduction.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (20%) (kg/yr)				Enhanced Nitrogen + Incidental Infiltration (20%) Pollutant Load Reduction Deficit (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-8,412	-4	-0.8	495	148
Multi Family Residential	-4,205	-11	-0.6	931	339
Commercial	-10,168	-32	-2.7	1,296	416
Industrial	-37,239	-81	-3.5	1,241	372

Note: a negative deficit means Biofiltration has a higher pollutant load reduction than Retention.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (20%) (%)				Enhanced Nitrogen + Incidental Infiltration (20%) Pollutant Load Reduction Deficit (%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-12.8%	-11.4%	-7.7%	25.0%	7.5%
Multi Family Residential	-10.3%	-8.9%	-5.2%	27.5%	10.0%
Commercial	-12.4%	-10.9%	-7.1%	26.5%	8.5%
Industrial	-12.8%	-11.4%	-7.7%	25.0%	7.5%

Conclusion: Biofiltration BMPs sized for 1.5 times the SQDV, with an average incidental infiltration of 20% of the average annual runoff volume, which is a conservative estimate of incidental infiltration for all types of Biofiltration Treatment Measures, provide equivalent pollutant load reduction to Retention BMPs for TSS and metals.

Incidental Infiltration Scenario #2: 40% Volume Reduction

Land Use	Pollutant Load Reduction from 40% Incidental Infiltration (kg/yr)			
	TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	23,000	13	3	693
Multi Family Residential	14,289	45	4	1,185
Commercial	29,569	105	14	1,761
Industrial	101,827	250	16	1,737

Land Use	Pollutant Load Reduction from Standard Treatment (kg/yr)				Enhanced Nitrogen Load Reduction (kg/yr)[1]
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	27,256	15	3.7	260	519
Multi Family Residential	16,932	52	4.7	445	889
Commercial	35,039	121	14.9	660	1,321
Industrial	120,665	288	17.2	652	1,303

[1] Anticipated removal if an anaerobic zone is provided for Enhanced Nitrogen removal.

Land Use	Total Pollutant Load Reduction from Standard Treatment + Incidental Infiltration (40%) (kg/yr)				Enhanced Nitrogen Load Reduction + Incidental Infiltration (40%) (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	50,256	29	7.2	952	1,212
Multi Family Residential	31,221	97	9.0	1,630	2,074
Commercial	64,608	225	28.8	2,421	3,082
Industrial	222,491	538	33.3	2,389	3,040

Land Use	Percent of Total Annual Loads from Standard Treatment + Incidental Infiltration (40%)				Enhanced Nitrogen % Load Reduction + Incidental Infiltration (40%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	76.5%	75.4%	72.6%	48.1%	61.3%
Multi Family Residential	76.5%	75.4%	72.6%	48.1%	61.3%
Commercial	78.7%	77.6%	74.7%	49.5%	63.0%
Industrial	76.5%	75.4%	72.6%	48.1%	61.3%

Step 4: Comparison of Annual Load Reductions

Load reductions are compared by subtracting the load reduction calculated for Biofiltration BMPs from the load reduction calculated for Retention BMPs to determine the 'deficit' load reduction.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (40%) (kg/yr)				Enhanced Nitrogen + Incidental Infiltration (40%) Pollutant Load Reduction Deficit (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-10,827	-6	-1.2	235	-25
Multi Family Residential	-5,705	-17	-1.3	487	42
Commercial	-13,273	-44	-4.7	636	-24
Industrial	-47,931	-110	-5.8	589	-62

Note: a negative deficit means Biofiltration has a higher pollutant load reduction than Retention.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (40%) (%)				Enhanced Nitrogen + Incidental Infiltration (40%) Pollutant Load Reduction Deficit (%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-16.5%	-15.4%	-12.6%	11.9%	-1.3%
Multi Family Residential	-14.0%	-12.9%	-10.1%	14.4%	1.2%
Commercial	-16.2%	-15.1%	-12.2%	13.0%	-0.5%
Industrial	-16.5%	-15.4%	-12.6%	11.9%	-1.3%

Conclusion: Biofiltration BMPs sized for 1.5 times the SQDV, with an average incidental infiltration of 40% of the average annual runoff volume, which is representative of vegetated swales and filter strips, provide equivalent pollutant load reduction to Retention BMPs for all of the pollutants of concern.

Incidental Infiltration Scenario #3: 60% Volume Reduction

Land Use	Pollutant Load Reduction from 60% Incidental Infiltration (kg/yr)			
	TSS	Total Zinc	Total Copper	Total Nitrogen
Single Family Residential	34,501	20	5	1,039
Multi Family Residential	21,433	67	6	1,778
Commercial	44,353	157	21	2,641
Industrial	152,740	374	24	2,606

Land Use	Pollutant Load Reduction from Standard Treatment (kg/yr)				Enhanced Nitrogen Load Reduction (kg/yr)[1]
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	18,170	10	2	173	346
Multi Family Residential	11,288	34	3	296	593
Commercial	23,359	81	10	440	880
Industrial	80,443	192	11	434	869

[1] Anticipated removal if an anaerobic zone is provided for Enhanced Nitrogen removal.

Land Use	Total Pollutant Load Reduction from Standard Treatment + Incidental Infiltration (60%) (kg/yr)				Enhanced Nitrogen Load Reduction + Incidental Infiltration (60%) (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	52,671	30	7.7	1,212	1,385
Multi Family Residential	32,722	102	9.6	2,074	2,371
Commercial	67,712	238	30.7	3,082	3,522
Industrial	233,183	567	35.5	3,040	3,475

Land Use	Percent of Total Annual Loads from Standard Treatment + Incidental Infiltration (60%)				Enhanced Nitrogen % Load Reduction + Incidental Infiltration (60%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	80.2%	79.5%	77.6%	61.3%	70.0%
Multi Family Residential	80.2%	79.5%	77.6%	61.3%	70.0%
Commercial	82.4%	81.7%	79.8%	63.0%	72.0%
Industrial	80.2%	79.5%	77.6%	61.3%	70.0%

Step 4: Comparison of Annual Load Reductions

Load reductions are compared by subtracting the load reduction calculated for Biofiltration BMPs from the load reduction calculated for Retention BMPs to determine the 'deficit' load reduction.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (60%) (kg/yr)				Enhanced Nitrogen + Incidental Infiltration (60%) Pollutant Load Reduction Deficit (kg/yr)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-13,242	-7	-1.7	-25	-198
Multi Family Residential	-7,206	-22	-1.9	42	-254
Commercial	-16,378	-56	-6.7	-24	-465
Industrial	-58,623	-139	-8.1	-62	-496

Note: a negative deficit means Biofiltration has a higher pollutant load reduction than Retention.

Land Use	Biofiltration Pollutant Load Reduction Deficit - Standard Treatment + Incidental Infiltration (60%) (%)				Enhanced Nitrogen + Incidental Infiltration (60%) Pollutant Load Reduction Deficit (%)
	TSS	Total Zinc	Total Copper	Total Nitrogen	Total Nitrogen
Single Family Residential	-20.2%	-19.5%	-17.6%	-1.3%	-10.0%
Multi Family Residential	-17.7%	-17.0%	-15.1%	1.2%	-7.5%
Commercial	-19.9%	-19.2%	-17.3%	-0.5%	-9.5%
Industrial	-20.2%	-19.5%	-17.6%	-1.3%	-10.0%

Conclusion: Biofiltration BMPs sized for 1.5 times the SQDV, with an average incidental infiltration of 60% of the average annual runoff volume, which is representative of bioretention with an underdrain, is equivalent to or exceeds the pollutant load reduction of Retention BMPs for all of the pollutants of concern.

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APPENDIX E : BMP SIZING WORKSHEETS

E.1 Structural Treatment BMP Sizing Criteria

The BMP sizing criteria for determining the design volume or design flow for a proposed BMP are discussed in this appendix. These criteria must be used for all stormwater BMPs installed in new and re-development projects in Ventura County. This section outlines the rainfall analyses, Ventura County MS4 Permit sizing criteria, and recommended sizing methods for both volumetric and flow-based analysis.

Sizing Criteria

The type of rainfall analysis required depends on whether the BMP is a volume-based or flow-based BMP. This distinction between volume-based and flow-based controls is not always clear, especially in a sequence of BMPs or a treatment train. The following are general guidelines for each type of control.

- Volume-based BMPs are designed to treat a volume of runoff, which is detained for a certain period of time to allow for the settling of solids and associated pollutants. Volume-based BMPs included in this manual are bioretention, planter boxes, infiltration systems, and retention/detention BMPs.

- Flow-based BMPs treat water on a continuous flow basis. Flow-based BMPs included in this manual are vegetated swales, filter strips, filtration systems, and hydrodynamic devices.

The four volume-based and three flow-based BMP sizing criteria included in the Ventura County MS4 Permit (Order No. 09-0057) are included below.

The water quality design volume for volume-based BMPs must be determined using one of the following options:

1) The 85th percentile 24-hour runoff event determined as the maximized capture stormwater volume for the area using a 48 to 72-hour draw down time, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998); or

2) The volume of annual runoff based on unit basin storage water quality volume to achieve 80 percent or more volume treatment; or

3) The volume of runoff produced from a 0.75 inch storm event; or

4) 80 percent of the average runoff volume using an appropriate public domain continuous flow model [such as Storm Water Management Model (SWMM) or Hydrologic Engineering Center – Hydrologic Simulation Program – Fortran (HEC-HSPF)], using the local rainfall record and relevant BMP sizing and design data.

Flow-based BMPs must be designed to capture and treat the water quality design flow rate generated from one of the following criterion:

1) The flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity; or

2) The flow of runoff produced from a rain event equal to at least 2 times the 85th percentile hourly rainfall intensity as determined from local rainfall records; or

3) Eight percent of the 50-year storm design flow rate as determined from the method provided below.

These sizing methods are explained below.

Methods for Determining the Water Quality Design Volume

Method 1: Urban Runoff Quality Management (URQM) Approach

The volume-based BMP sizing methodology described in Urban Runoff Quality Management (WEF Manual of Practice No. 23/ASCE Manual of Practice No. 87, (1998), pages 175-178) estimates the "maximized stormwater quality capture volume." The URQM approach is based on the translation of rainfall to runoff using two regression equations. The first regression equation, which relates rainfall to runoff, was developed using two years of data from more than 60 urban watersheds nationwide. The second regression equation relates mean annual runoff-producing rainfall depths to the "Maximized Water Quality Capture Volume" which corresponds to the "knee of the cumulative probability curve". This second regression was based on analysis of long-term rainfall data from seven rain gages representing climatic zones across the country. T he Maximized Water Quality Capture Volume corresponds to approximately the 85th percentile runoff event, and ranges from 82 to 88%.

The two regression equations that form the URQM approach are as follows:

$$C = 0.858imp^3 - 0.78imp^2 + 0.774imp + 0.04 \quad \text{(Equation E-1)}$$

$$P_o = (a \cdot C) \cdot P_6 \quad \text{(Equation E-2)}$$

Where:

C	=	watershed runoff coefficient (unitless)
imp	=	watershed impervious ratio which is equal to the percent total imperviousness divided by 100 (ranges from 0 to 1)
P_o	=	maximized detention storage volume based on the volume capture ratio as its basis (watershed inches)

a	=	regression constant from least-squares analysis (unit less), a=1.582 and a=1.963 for 24 and 48 hour draw down, respectively
P_6	=	mean storm precipitation volume (watershed inches)

P_6 can be determined by two ways: Figure 5.3 in Urban Runoff Quality Management, or by performing analysis on local historical rainfall data. To determine the mean precipitation, EPA's Synoptic Rainfall Analysis Program – SYNOP – can be applied (see *Other Rainfall Analysis Methods* below).

The runoff coefficient equation in the URQM approach (Method 1) is not appropriate for the California BMP Handbook approach (Method 2), as Equation E-4 was developed in conjunction with the regression constants used in Method 1.

Method 2: Treatment of 80% or more of the Total Volume

Most water quality facilities are designed to treat only a portion of the runoff from a given site, as it is not economically feasible to capture 100% of the runoff. The percent of runoff treated by a basin is referred to as the "percent capture". There are a number of methods which allow calculation of the percent capture, including the California Stormwater Quality Association (CASQA) method (recommended by the 2002 Ventura County Manual), and using the EPA Stormwater Management Model (SWMM).

CASQA Method

The California Stormwater Quality Association (CASQA) BMP Handbook method estimates the basin volume to achieve various levels of volume capture (e.g., 80% for this sizing criterion). In the CASQA BMP Handbook New Development and Redevelopment (2003), a proprietary version of the Storage, Treatment, Overflow, Runoff Model (STORM) is used as the basis for the volume-based BMP sizing criteria. The model results are presented as the relationship between "unit basin storage volume" and "% volume capture" of the BMP", varying with drawdown time and runoff coefficient. Knowing the drawdown time, the runoff coefficient, and the desired percent capture will yield the "unit basin storage volume". The "unit basin storage volume" can then be used to size the BMP using the following equation (note that "unit basin storage volume" is given in inches, so units will have to be adjusted accordingly):

$$\text{BMP Volume} = \text{Unit Basin Storage Volume} \times \text{Tributary Area} \qquad \text{(Equation E-3)}$$

Results for several rain gauges are presented in Appendix D of the CASQA BMP Handbook New Development and Redevelopment (CASQA, 2003). Results are provided for a range of runoff coefficients and for 24 hour and 48 hour drawn down times. In order to use the curves provided in Appendix D, it is necessary to know the runoff coefficient for the area tributary to the BMP, the drawn down time (a.k.a. drain time) of the facility, and the percent capture goal (e.g., 80%).

Drawdown time is the time required to drain a facility that has reached its design capacity; usually expressed in hours. Drain time is important as it is a surrogate for residence time, which affects the particle settling in the basin. Estimates for design drain time vary, and ideally would be determined based on site-specific information on the size, shape, and density or settling velocity of suspended particulates in the runoff. Because this information is generally not available for a specific site, estimates of appropriate ranges for settling time have generally relied on settling column test information reported in the literature.

An important source of drain time information is settling column tests conducted by Grizzard et. al. (1986) as part of the Nationwide Urban Runoff Program (NURP). Grizzard found that settling times of 48 hours resulted in removals of 80% to 90% of total suspended solids (TSS). Rapid initial removal was also observed in stormwater samples with medium (100 to 215 mg/L) and high (721 mg/L) initial TSS concentrations. For example, at settling times of 24 hours, the 80% to 90% removals were already achieved in samples with medium and high initial TSS, whereas only 50% to 60% removal was achieved in those with low initial TSS.

Given the data provided above, a drain time of 36 to 48 hours is recommended for sizing volume-based BMPs. This is also consistent with the recommendation of vector control agencies that structures be designed to drain in less than 72 hours to minimize mosquito breeding.

The rain gauge that is recommended for use for the area permitted by the Ventura county MS4 Permit (Order No. 09-0057) is the Oxnard Equipment Yard Gauge (168), which has a 4 0 year rainfall record. The graph included in the CASQA handbook can be seen in Figure E-1 below.

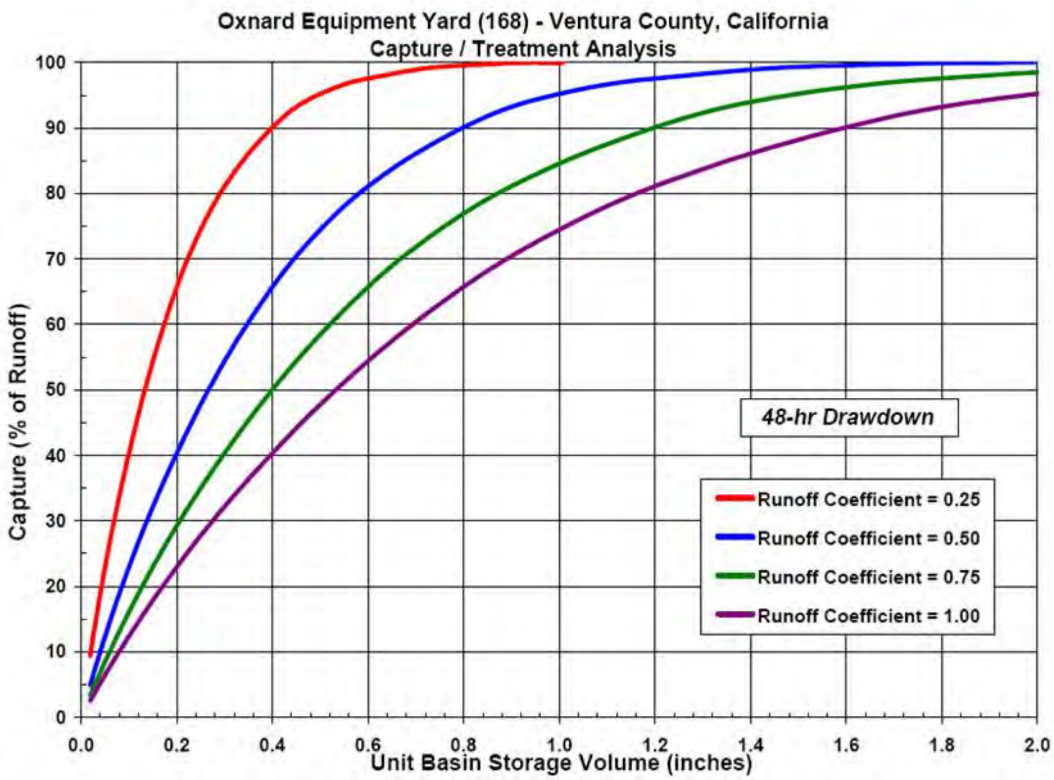

Figure E-1: CASQA 48-hour Drawdown Figure for Oxnard Gauge

This method has been modified for Ventura County. To use this method, follow the calculation procedure below. This refers to Figure E-3.

Ventura County Calculation Procedure

1) Review the area draining to the proposed treatment control measure. Determine the effective imperviousness (I_{WQ}) of the drainage area.

2) Estimate the total imperviousness (impervious percentage) of the site by the determining the weighted average of individual areas of like imperviousness.

3) Enter Figure E-2 along the horizontal axis with the value of total imperviousness calculated in Step 1. Move vertically up Figure E-2 until the appropriate curve (G-5.1 (filter strip) or G-5.2 (vegetated swale) employed individually or G-5.1 and G-5.2 employed together) is intercepted. Move horizontally across Figure E-2 until the vertical axis is intercepted. Read the Effective Imperviousness value along the vertical axis.

4) Note that if G-5.1 and/or G-5.2 are implemented on only a portion of the site, the site may be divided and effective imperviousness determined for the portion of the site for which site design controls have been implemented. The resulting effective imperviousness may be combined with total imperviousness of the

remainder of the site to determine a weighted average total imperviousness for the entire site.

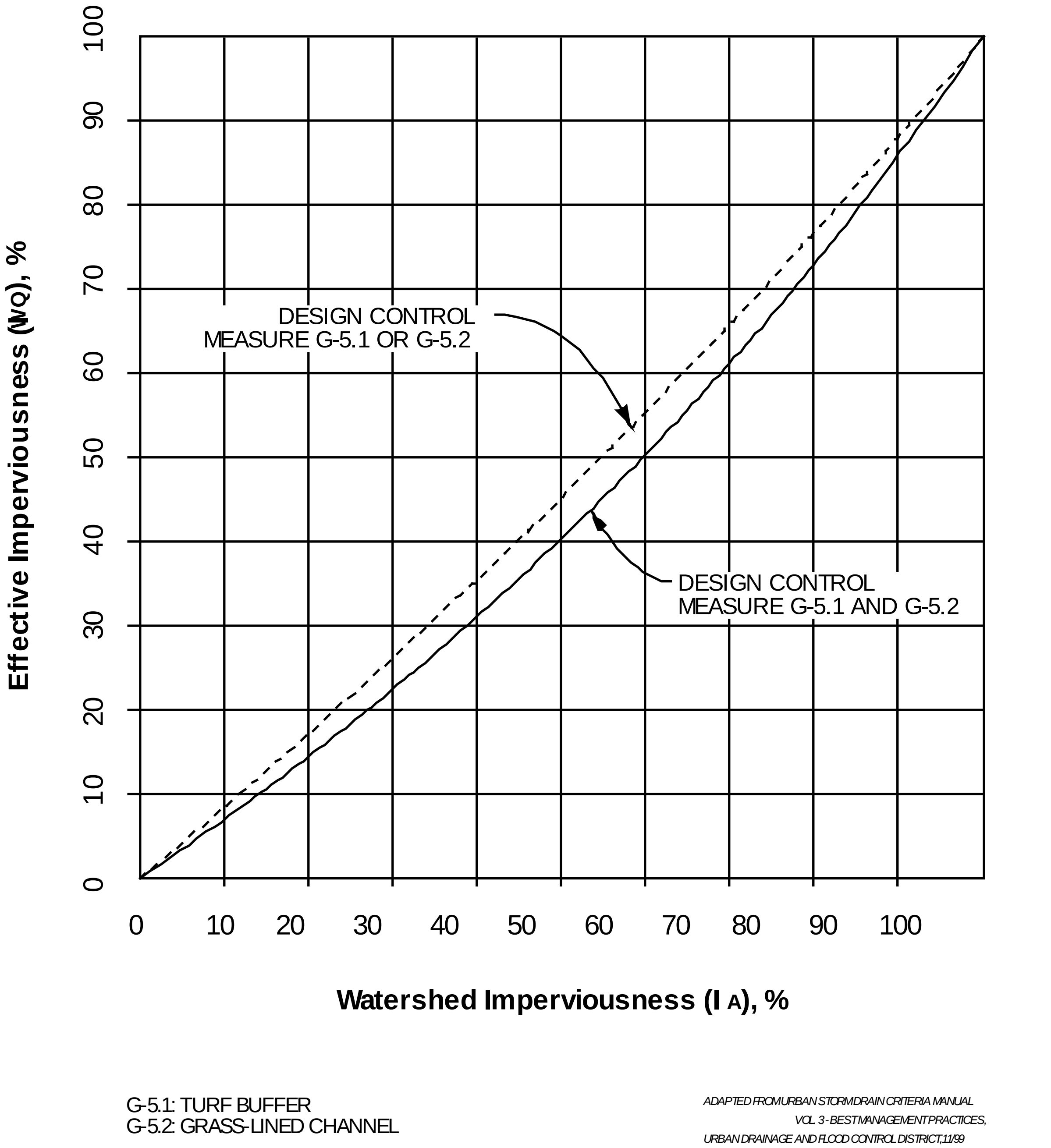

Figure E-2: Effective Imperviousness based on Watershed Imperviousness

5) Figure E-3 provides a direct reading of Unit Basin Storage Volumes required for 80% annual capture of runoff for values of "I_{WQ}" determined in Step 1. Enter the horizontal axis of Figure E-3 with the "I_{WQ}" value from Step 1. Move vertically up

Figure E-3 until the appropriate drawdown period line is intercepted. (The design drawdown period specified in the respective Fact Sheet for the proposed treatment control measure.) Move horizontally across Figure E-3 from this point until the vertical axis is intercepted. Read the Unit Basin Storage Volume along the vertical axis.

6) Figure E-3 is based on Precipitation Gage 168, Oxnard Airport. This gage has a data record of approximately 40 years of hourly readings and is maintained by Ventura County Flood Control District. Figure E-3 is for use only in the permit area specified in Regional Board Order No. 00-108, NPDES Permit No. CAS004002.

7) The SQDV for the proposed treatment control measure is then calculated by multiplying the Unit Basin Storage Volume by the contributing drainage area. Due to the mixed units that result (e.g., acre-inches, acre-feet) it is recommended that the resulting volume be converted to cubic feet for use during design.

Example Stormwater Quality Design Volume Calculation

1) Determine the drainage area contributing to control measure, A_t. Example: 10 acres.

2) Determine the area of impervious surfaces in the drainage area, A_i. Example: 6.4 acres.

3) Calculate the percentage of impervious, $I_A = (A_i / A_t)*100$

   Example:

   Percent Imperviousness = $(A_i / A_t)*100$ = (6.4 acres/10 acres)*100 = 64%

4) Determine Effective Imperviousness using Figure 3-4.

   I_{WQ} = 60%

5) Determine design drawdown period for proposed control measure.

6) Determine the Unit Basin Storage Volume for 80% Annual Capture, V_u using Figure E-3.

   For $I_{WQ}/100$ = 0.60 and drawdown = 40 hrs, V_u = 0.64 in.

7) Calculate the volume of the basin, V_b, where

   $V_b = V_u * A_t$. (Equation E-4)

Where

V_b = Volume of basin

RB-AR34930

V_u = Unit basin storage volume

A_t = Total tributary area

8) V_b = (0.64 in)(10 ac)(ft/12 in(43,560 ft^2 / ac) = 23,232 ft^3.

9) Solution: Si ze the proposed control measure for 23,232 ft^3 and 40-hour drawdown.

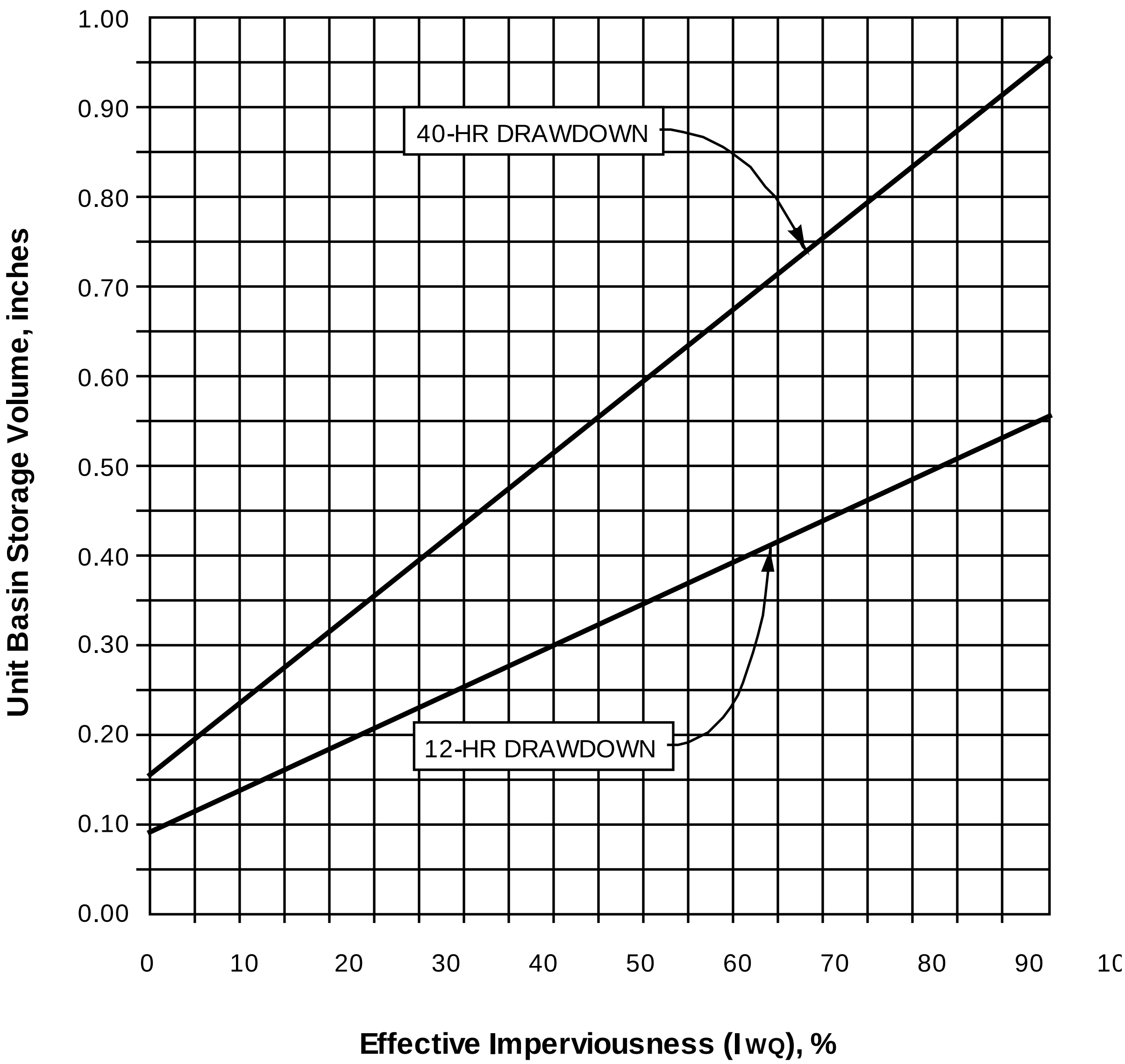

Figure E-3: Unit Basin Storage Volume for Design Volume Method 2

Method 3: 0.75 Inch Design Storm Approach

Equation E-8 can be used to determine the water quality design volume for Method 3.

Calculation Procedure

1) Determine the area from which runoff must be retained on-site (A_{retain}) using the method below:

   The allowable EIA for a project site can be calculated as follows:

   $EIA_{allowable} = (A_{project})*(\%_{allowable})$ (Equation E-5)

Where:

$EIA_{allowable}$	=	the maximum impervious area from which runoff can be treated and discharged off-site [and not retained on-site] (acres).
$A_{project}$	=	the total project area (acres). “Total project area” for new development and redevelopment projects is defined as the disturbed, developed, and undisturbed portions within the project’s property (or properties) boundary, at the project scale submitted for first approval.
$\%_{allowable}$	=	ranges from 5 percent to 30 percent, based on a project specific assessment of technical feasibility for retaining runoff and whether the project is located in an existing urban area.

The drainage area from which Project generated runoff must be retained on-site is the total impervious area minus the $EIA_{allowable}$, which can be calculated as follows:

$A_{retain} = TIA - EIA_{allowable} = (P*A_{project}) - EIA_{allowable}$ (Equation E-6)

Where:

A_{retain}	=	the drainage area from which runoff must be retained (acres)
TIA	=	total impervious area (acres)
$EIA_{allowable}$	=	the maximum impervious area from which runoff can be treated and discharged off-site [and not retained on-site] (acres).
P	=	imperviousness of project area (%)/100
$A_{project}$	=	the total project area (acres)

Calculation Procedure

1) Determine the area from which runoff must be retained on-site (A_{retain}) using method above.

2) Determine the runoff coefficient per the following method:

$C = 0.95*imp + C_p (1-imp)$ (Equation E-7)

Where:

C	=	runoff coefficient
imp	=	impervious fraction of watershed
C_p	=	pervious runoff coefficient, determined using table below

Table E-1: Pervious Runoff Coefficient Based on Ventura Soil Type

Ventura Soil Type (Soil Number)	Cp value
1	0.15
2	0.10
3	0.10
4	0.05
5	0.05
6	0
7	0

3) The volume can be calculated using equation E-8 below:

$SQDV = C*(0.75/12)*A_{retain}$ (Equation E-8)

Where:

SQDV	=	the water quality design volume (acre-feet)
C_{imp}	=	runoff coefficient, calculated by equation (4) above
0.75	=	the design rainfall depth (in) [based on sizing method (c)]
A_{retain}	=	the drainage area from which runoff must be retained (acres)

Method 4: 80 percent of the average runoff volume using an appropriate public domain continuous flow model

Models that can be used for this calculation include the Storm Water Management Model (SWMM) or Hydrologic Engineering Center – Hydrologic Simulation Program – Fortran (HEC-HSPF)], using the local rainfall record and relevant BMP sizing and design data.

Sizing Method 4 allows for alternative sizing methods to be used as long as the selected method produces a water quality design volume based on historical rainfall records that achieves 80% capture of the average runoff volume. While sizing Methods 2 and 3 are appropriate for low lying areas within Ventura County, continuous simulation (using historical rainfall record) is well suited to sizing BMPs in locations with higher average rainfall. This method is the recommended sizing method for Ventura County, using appropriate local data inputs. For BMP locations at higher elevations, with larger rainfall, Method 1 is also better suited to sizing volume-based BMPs using rainfall representative of the site where the BMP will be located.

Continuous runoff modeling takes a long, uninterrupted record of observed rainfall data and transforms it into a record of runoff data. This is done by use of a set of mathematical algorithms that represent the rainfall-runoff processes. E PA's Stormwater Management Model (U.S. EPA, 2000) (SWMM) is one type of continuous runoff model. The runoff module of SWMM subdivides each drainage area into two inclined planes, one for impervious areas and one for pervious areas. Manning's equation is applied to estimate runoff taking into account rainfall intensity, initial losses, evapotranspiration, and infiltration (for pervious areas). The width and length of each plane is selected based on the drainage area configuration and existing and proposed drainage features. Hourly rainfall data is the primary model input for generating runoff volumes and rates. Additional input data are required to characterize imperviousness, soils, topography, and losses associated with evapotranspiration, infiltration, and initial losses.

Sizing BMPs using this type of alternative should only be conducted by qualified personnel with a thorough understanding of the simulated hydrologic processes and operation of the selected hydrology model.

Methods for Determining the Water Quality Design Flow

Each of the flow-based sizing alternatives is described in detail below.

Method 1: Runoff Produced by 0.2 Inches per Hour Rainfall Intensity

The rainfall analysis for flow-based controls focuses on estimating the design rainfall intensity, which is then converted to a design flow rate using the rational method shown in Equation E-9.

$$SQDF = CiA \quad \text{(Equation E-9)}$$

Where:

SQDF	=	design flow rate (cfs)
C	=	runoff coefficient, calculated with the Ventura County Hydrology Manual method (see Equation E-5) (unitless)
i	=	rainfall intensity (in/hr) (0.2 in/hr)
A	=	watershed area (acres)

Note that 1 acre-in/hr = 1.0083 cfs; this conversion factor can be used with Equation D-9, but is not necessary as the uncertainty for the other parameters is generally well above 0.8%.

Method 2: Runoff Produced by Twice the 85th Percentile Rainfall Intensity

This method is analogous to the rational method used in Method 1, except that twice the historical 85th percentile rainfall intensity for the site location is used for the design rainfall intensity. This method is expected to result in a higher design rainfall intensity and design flow rate compared to Method 1 for most of the rain gages in the District.

Method 3: Runoff Produced by eight percent of the 50-year storm design flow rate

The Stormwater Quality Design Flow (SQDF) is defined to be equal to 8 percent of the peak rate of runoff flow from the 50-year storm as determined using the procedures set forth in the *Hydrology Manual*.

Calculation Procedure

1) The Stormwater Quality Design Flow (SQDF) in Ventura County is defined as SQDF

2) Calculate the peak rate of flow from the 50-year storm ($Q_{P,\ 50\ yr.}$) using the procedures set forth in the *Hydrology Manual* or as directed by the local agency Drainage Master Plan.

3) Convert $Q_{P,\ 50yr}$ (Step 2) to $Q_{P,\ SQDF}$ (Step 1).

$$Q_{P,\ SQDF} = 0.1 \times Q_{P,\ 50yr} \quad \text{(Equation E-10)}$$

Example Stormwater Quality Design Flow Calculation

The steps below illustrate calculation of SQDF:

1) Calculate the peak rate of flow from a 50-year storm.

$Q_{p,\ 50\ yr.}$ = 10 cfs from the *Ventura County Hydrology Manual*

4) Convert $Q_{p,50\ yr}$ (Step 2) to $Q_{p,\ SQDF}$ (Step 1)

   SQDF = 0.8 x 10 cfs (Equation E-11)

   SQDF = 0.8 cfs

Rainfall Analysis Methods

The rainfall analysis methods listed below have the benefits of including the most recent rainfall data. Additionally, if the site is not close to an isohyet map rainfall gauge, these methods may be more accurate due to the variability of rainfall due to changing microclimates caused by elevation and distance from the ocean.

A resource available for obtaining rainfall data in Ventura County is the data collected and compiled by the National Climatic Data Center (NCDC).

There are many NCDC stations within Ventura County that collect or have collected hourly precipitation data. Some of these stations are no longer in operation and others may not have a sufficiently long period of record over which precipitation data has been collected to be of use for properly sizing treatment BMPs. NCDC data may be obtained online at the NCDC website http://www.ncdc.noaa.gov/oa/ncdc.html.

Rainfall Analysis Using EPA'S SYNOP Program

US EPA's Synoptic Rainfall Data Analysis Program (SYNOP) aggregates hourly rainfall data into individual storm events and computes event descriptive statistics. The SYNOP program calculates the duration, volume, and intensity for individual storms as well as average annual statistics. Recurrence interval and probability results are also available as output options. The SYNOP program allows the user to screen out storms that are not expected to result in runoff (see step 2 below).

The SYNOP rainfall analysis is conducted to output event-specific data in addition to average annual statistics. The individual storm event data can be ranked to give the 85th percentile storm or averaged to give the mean storm size.

Steps for conducting SYNOP rainfall analysis are as follows:

1) Obtain the hourly rainfall data for the gage of interest from the NCDC or other agency.

2) Run SYNOP for the available rain gage data. Model input parameters include the inter-event time and a minimum storm event size. The inter-event time specifies the minimum duration in which precipitation does not occur, used to define separate storm events, while the minimum storm event is the depth of precipitation generated by a storm below which runoff generally does not occur. Typically, an inter-event time of 6 hours (USEPA, 1989), and a minimum storm

event size of 0.10 inches are used (i.e., storms of 0.10 inches or less are not considered to produce runoff typically). Model results include event-specific and annual statistics during the period of record analyzed.

3) Rank and average the SYNOP storm event output.

References

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E.2 INF-1 Infiltration Basin/ INF-2 Infiltration Trench/ INF-4 Drywell

This worksheet can be used for sizing INF-1 Infiltration Basins, INF-2 Infiltration Trenches, or INF-4 drywells. An infiltration basin is an earthen basin constructed into naturally pervious soils which retains the SQDV and allows the retained runoff to percolate into the underlying native soils over a specified period of time. Infiltration trenches are long, narrow, gravel-filled trenches, often vegetated, that infiltrate stormwater runoff from small drainage areas. Drywells are similar to infiltration trenches, but the geometry and materials are slightly different. A dry well may be either a small excavated pit filled with aggregate or a prefabricated storage chamber or pipe segment, with the depth of the drywell greater than the width.

Sizing Methodology

Infiltration facilities can be sized using one of two methods: a simple sizing method or a routing modeling method. With either method the SQDV volume must be completely infiltrated within 12 to 72 hours (see Appendix E, Section E.1 for a discussion on drawdown time and BMP performance). The simple sizing procedures provided below can be used for either infiltration basins, infiltration trenches (see INF-2: Infiltration Trench) or drywells (INF-4: Drywell). For the routing modeling method, refer to VEG-8 Sand Filters.

Step 1: Calculate the design volume

Infiltration facilities shall be sized to capture and infiltrate the SQDV volume (see Section 2 and Appendix E) with a 12 - 72 hour drawdown time (see Appendix E, Section E.1).

Step 2: Determine the Design Percolation Rate

The percolation rate will decline between maintenance cycles as particulates accumulate in the infiltrative layer and the surface becomes occluded. Additionally, monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For infiltration trenches, the design percolation rate discussed here is the percolation rate of the underlying soils, which will ultimately drive infiltration through the trench, and not the percolation rate of the filter media bed (refer to the "Geometry and Sizing" section of INF-2 for the recommended composition of the filter media bed for infiltration trenches). See INF-1: Infiltration Basin for guidance in developing design percolation rate correction factors.

Step 3: Calculate Surface Area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus (for infiltration trenches/ drywells with aggregate) the void spaces within the filter media based on the computed porosity of the media (normally about 32%).

1) Determine the maximum depth of runoff that can be infiltrated within the required drain time as follows:

$$d_{\max} = \frac{P_{design}}{12} t$$ (Equation E-12)

Where:

d_{max} = the maximum depth of water that can be infiltrated within the required drain time (ft)

P_{design} = design percolation rate of underlying soils (in/hr)

t = required drain time (hrs)

2) Choose the ponding depth (d_p) and/or trench depth (d_t) such that:

$$d_{\max} \geq d_p$$ For Infiltration Basins (Equation E-13)

$$d_{\max} \geq n_t d_t + d_p$$ For Infiltration Trenches or aggregate-filled Drywells (Equation E-14)

Where:

d_{max} = the maximum depth of water that can be infiltrated within the required drain time (ft)

d_p = ponding depth (ft)

n_t = trench/drywell fill aggregate porosity (unitless)

d_t = depth of trench/drywell filter media (ft)

3) Calculate infiltrating surface area (filter bottom area) required:

$$A = \frac{SQDV}{((TP_{design}/12) + d_p)}$$ For Infiltration Basins (Equation E-15)

$$A = \frac{SQDV}{((\ TP_{design}/12\ ) + n_t d_t + d_p)}$$ For Infiltration Trenches or aggregate-filled Drywells (Equation E-16)

Where:

$SQDV$ = stormwater quality design volume (ft^3)

n_t	=	trench fill aggregate porosity (unitless)
P_{design}	=	design percolation rate (in/hr)
d_p	=	ponding depth (ft)
d_t	=	depth of trench filter media (ft)
T	=	fill time (time to fill to max ponding depth with water) (hrs) [use 2 hours for most designs]

Step 4: Size the forebay (applies to infiltration basins and trenches)

Infiltration facilities require pre-treatment to reduce sediment load into the basin. If a separate pre-treatment unit is not used, a forebay should be constructed for the facility. If a forebay is used, all inlets must enter the sediment forebay. The sediment forebay must be sized to 25% of the basin volume. The forebay must have interior slopes no steeper than 4:1.

1) Calculate the volume of the sediment forebay:

$$V_{forebay} = 0.25 \times SQDV \qquad \text{(Equation E-17)}$$

Where:

$V_{forebay}$	=	Volume of sediment forebay
SQDV	=	Stormwater Quality Design Volume of Infiltration Basin

2) Select the depth of forebay, $d_{forebay}$. This is recommended to be…

3) Determine bottom surface area of forebay:

$$A_{forebay} = \frac{V_{forebay}}{d_{forebay}} \qquad \text{(Equation E-18)}$$

Where:

$A_{forebay}$	=	Bottom surface area of forebay
$V_{forebay}$	=	Volume of forebay
$d_{forebay}$	=	Depth of forebay

4) Size forebay outlet pipe. Pipe must 8 inches in diameter, minimum, and must be sized such that the forebay drains completely within 10 minutes.

Step 5: Provide conveyance capacity for filter clogging

The infiltration facility should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged. Spillway and overflow

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structures should be designed in accordance with applicable standards of the Ventura County Flood Control District or local jurisdiction.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1\text{-}imp)$	C =	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560\times C*P*A_{retain}$	SQDV=	ft^3
Step 2: Determine the design percolation rate		
2-1. Enter measured soil percolation rate (in/hr, 0.5 in/hr min.), $P_{measured}$	$P_{measured}$ =	in/hr
2-2. Determine percolation rate correction factor, S_A based on suitability assessment (see Section 6 INF-1)	S_A =	

2-3. Determine percolation rate correction factor, S_B based on design (see Section 6 INF-1)	S_b =
2-4. Calculate combined safety factor, $S = S_A \times S_b$	S =
2-5. Calculate the design percolation rate (in/hr), $P_{design} = P_{measured}/S$	P_{design} = in/hr
Step 3: Calculate the surface area	
3-1. Enter required drain time(hours,72 hrs max.), t	t = hrs
3-2. Calculate max. depth of runoff that can be infiltrated within the t (ft), $d_{max} = P_{design}\, t/12$	d_{max} = ft
3-3. For basins, select ponding depth (ft), d_p, such that $d_p \leq d_{max}$	d_p = ft
3-4. For trenches, enter trench fill aggregate porosity, n_t	n_t =
3-5. For trenches, enter depth of trench fill (ft), d_t	d_t = ft
3-5. For trenches, select ponding depth d_p such that $d_p \leq d_{max} - n_t d_t$	d_p= ft
3-6. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T	T = hrs
3-7. Calculate infiltrating surface area for infiltration basin (ft²): $A_b = SQDV/(T\, P_{design}/12+d_p)$ OR Calculate infiltrating surface area for infiltration trenches or aggregate- filled drywells (ft²): $A_t = SQDV/(T\, P_{design}/12+n_t d_t+dp)$	A_b = ft² A_t = ft²
Step 4: Size the forebay (infiltration basins or trenches)	
If a separate pre-treatment unit is designed for the infiltration facility, skip to Step 5. If not, continue through 4-1 through 4-4.	

4-1. Calculate the volume of the forebay (ft^3), $V_{forebay}$=0.25*SQDV	$V_{forebay}$= ft^3
4-2. Determine forebay depth (ft), $d_{forebay}$	$d_{forebay}$= ft
4-3. Calculate forebay bottom surface area (ft^2), $A_{forebay}=V_{forebay}/d_{forebay}$	$A_{forebay}$= ft^2
4-4. Provide outlet pipe such that the forebay drains to the infiltration facility within 10 minutes.	
Step 5: Provide conveyance capacity for filter clogging	
5-1.The infiltration facility should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged. Design emergency overflow in accordance with applicable standards of the Ventura County Flood Control District or local jurisdiction.	

Design Example

Step 1: Determine water quality design volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered to drain to an infiltration basin. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter Project area (acres), $A_{project}$	A =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	0.75	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560 \times C*P*A_{retain}$	SQDV =	8,500	ft^3

Step 2: Calculate Design Infiltration Rate

Infiltration facilities require a minimum soil infiltration rate of 0.5 in/hr. If the rate exceeds 2.4 in/hr as in this example, then the runoff should be fully treated in an upstream BMP prior to infiltration to protect the groundwater quality.

Step 2: Determine the design percolation rate			
2-1. Enter measured soil percolation rate (0.5 in/hr min.), $P_{measured}$	$P_{measured}$ =	4.0	in/hr
2-2. Determine percolation rate correction factor, S_A, based on suitability assessment (see Section 6 INF-1)	S_A =	3	
2-3. Determine percolation rate correction factor, S_B, based on design (see Section 6 INF-1)	S_b =	3	
2-4. Calculate combined safety factor, $S = S_A \, x \, S_b$	S =	9	
2-5. Calculate the design percolation rate, $P_{design} = P_{measured}/S$	P_{design} =	0.44	in/hr

Step 3: Determine Facility Size

The size of the infiltrating surface is determined by assuming the SQDV will fill the available ponding depth (plus the void spaces of the computed porosity (usually about 32%) of the gravel in the trench).

Step 3: Calculate the surface area			
3-1. Enter drawdown time (72 hrs max.), t_d	t =	72	hrs
3-2. Calculate max. depth of runoff that can be infiltrated within the t, $d_{max} = P_{design}\, t/12$	d_{max}=	2.4	ft
3-3. Enter trench fill aggregate porosity, n_t	n_t=	0.32	
3-4. Enter depth of trench fill, d_t	d_t =	4	ft
3-5. Select trench ponding depth d_p such that $d_p \leq d_{max} - n_t d_t$	d_p=	1.1	ft
3-6. Enter the time to fill infiltration basin or trench with water (Use 2 hours for most designs), T	T =	2	hrs

3-7. Calculate infiltrating surface area for infiltration basin: $A_b = SQDV/(T\ P_{design}/12+d_p)$	A_b = 7,250 ft^2

Step 4: Size the Forebay

A sediment forebay will be provided for this example as there is no separate pre-treatment unit provided.

Step 4: Size the forebay	
4-1. Calculate the volume of the forebay, $V_{forebay}$=0.25*SQDV	$V_{forebay}$= 2,100 ft^3
4-2. Determine forebay depth, $d_{forebay}$	$d_{forebay}$= 3 ft
4-3. Calculate forebay bottom surface area, $A_{forebay}=V_{forebay}/d_{forebay}$	$A_{forebay}$= 700 ft^2
4-4. Provide outlet pipe such that the forebay drains to the infiltration facility within 10 minutes.	

Step 5: Provide Conveyance Capacity for Flows Higher than Qwq

The infiltration facility should be placed off-line, but an emergency overflow for flows greater than the peak design storm must still be provided in the event the filter becomes clogged. Design emergency overflow in accordance with applicable standards of the Ventura County Flood Control District or local jurisdiction.

E.3 INF-3 Bioretention

Sizing Methodology

Bioretention areas can be sized using one of two methods: a simple sizing method or a routing method. The simple sizing procedure is summarized below. Continuous simulation modeling, routing spreadsheets, and/or other forms of routing modeling that incorporate rainfall-runoff relationships and infiltrative (flow) capacities of bioretention may be used to size facilities. Alternative sizing methodologies should be prepared with good engineering practices. For the routing modeling method, refer to the Sand Filter design guidance (FILT-1). A bioretention sizing worksheet and example are provided in this appendix. Planter boxes are sized the same as bioretention areas with underdrains using parameters appropriate for planter boxes.

With either method, the runoff entering the facility must completely drain the ponding area within 48 hours, and runoff must be completely infiltrated within 96 hours. Bioretention is to be sized, with or without underdrains, such that the SQDV will fill the available ponding depth, the void spaces in the planting soil, and the optional gravel layer below the media.

Step 1: Determine the stormwater quality design volume (SQDV)

Bioretention areas should be sized to capture and treat the water quality design volume (see Section E.1).

Step 2: Determine the Design Percolation Rate

The percolation rate will decline between maintenance cycles as particulates accumulate in the infiltrative layer and the surface becomes occluded. Additionally, monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For infiltrating bioretention facilities, the design percolation rate discussed here is the percolation rate of the underlying soils, which will drive infiltration through the facility. See INF-3: Bioretention for guidance in developing design percolation rate correction factors.

Step 3: Calculate the bioretention surface area

1) Determine the maximum depth of surface ponding that can be infiltrated within the required surface drain time:

$$d_{\max} = \frac{P_{design} \times t_{ponding}}{12\dfrac{in}{ft}}$$

Where:

$t_{ponding}$ = required drain time of surface ponding (48 hrs)

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

d_{max} = the maximum depth of surface ponding water that can be infiltrated within the required drain time (ft)

2) Choose surface ponding depth (dp) such that:

$$d_p \leq d_{\max} \qquad \text{(Equation E-19)}$$

Where:

d_p = selected surface ponding depth (ft)

d_{max} = the maximum depth of water that can be infiltrated within the required drain time (ft)

3) Choose thickness(es) of amended media and aggregate layer(s) and calculate total effective storage depth of the bioretention area as follows:

$$d_{effective} \leq d_p + n^*_{media} l_{media} + n_{gravel} l_{gravel} \qquad \text{(Equation E-20)}$$

Where:

$d_{effective}$ = total equivalent depth of water stored in bioretention area (ft)

d_p = surface ponding depth (ft)

n^*_{media} = available porosity of amended soil media (ft/ft), approximately 0.25 ft/ft accounting for antecedent moisture conditions

l_{media} = thickness of amended soil media layer (ft)

n_{gravel} = porosity of optional gravel layer (ft/ft), approximately 0.30 ft/ft

l_{gravel} = thickness of optional gravel layer (ft)

4) Check that entire effective depth (surface plus subsurface storage) infiltrates in no greater than 96 hours as follows:

$$t_{total} = \frac{d_{effective}}{P_{design}} \times 12 \frac{in}{ft} \leq 96\ hr \qquad \text{(Equation E-21)}$$

Where:

$d_{effective}$ = total equivalent depth of water stored in bioretention area (ft)

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

If $t_{total} > 96$ hrs, then reduce surface ponding depth and/or amended media thickness and/or gravel thickness and return to Step [A].

If $t_{total} \leq 96$ hrs, then proceed to Step [E].

5) Calculate required infiltrating surface area (filter bottom area):

$$A_{req} = \frac{SQDV}{d_{effective}} \quad \text{(Equation E-22)}$$

Where:

$SQDV$ = stormwater quality design volume (ft3)

Step 4: Calculate the bioretention total footprint

Calculate total footprint required by including a buffer for side slopes and freeboard; A_{req} is measured at the as the filter bottom area (toe of side slopes).

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560 \times C*P*A_{retain}$	SQDV=	ft^3

Step 2: Determine the design percolation rate		
2-1. Enter measured soil percolation rate (in/hr) (0.5 in/hr minimum), $P_{measured}$	$P_{measured}$ =	in/hr
2-2. Determine percolation rate correction factor, S_A based on suitability assessment (see Section 6 INF-3)	S_A =	

2-3. Determine percolation rate correction factor, S_B based on design (see Section 6 INF-3)	S_B =	
2-4. Calculate combined safety factor, $S = S_A \times S_b$	S =	
2-5. Calculate the design percolation rate (in/hr), $P_{design} = P_{measured}/S$	P_{design} =	in/hr
Step 3: Calculate Bioretention Infiltrating surface area		
3-1. Enter water quality design volume (ft^3), *SQDV*	SQDV =	ft^3
3-2. Enter design percolation rate (in/hr), P_{design}	P_{design} =	in/hr
3.3 Enter the required drain time (48 hours), $t_{ponding}$	$t_{ponding}$ =	hours
3-3. Calculate the maximum depth of surface ponding that can be infiltrated within the required drain time (ft): $d_{max} = (P_{design} \times t_{ponding})/12$	d_{max} =	ft
3-4. Select surface ponding depth (ft), d_p, such that $d_p \leq d_{max}$	d_p =	ft
3-5. Select thickness of amended media (ft,2 feet minimum, 3 preferred), l_{media}	l_{media} =	ft
3-6. Enter porosity of amended media (roughly 25% or 0.25 ft/ft), n_{media}	n_{media}=	ft/ft
3-7. Select thickness of optional gravel layer (ft), l_{gravel}	l_{gravel} =	ft
3-8. Enter porosity of gravel (roughly 30% or 0.3 ft/ft), n_{gravel}	n_{gravel}=	ft/ft
3-9. Calculate the total effective storage depth of bioretention facility (ft): $d_{effective} \leq (d_p + n_{media}l_{media} + n_{gravel}l_{gravel})$	$d_{effective}$=	ft

3-10. Check that the entire effective depth infiltrates in required drainage time, 96 hours: $t_{total} = (d_{effective}/P_{design}) \times 12$ If t_{total} > 96 hours, reduce surface ponding depth and/or amended media thickness and/or gravel thickness and return to 3-4. If $t_{total} \leq$ 96 hours, proceed to 3-11.	t_{total} = hours
3-11. C alculate the required infiltrating surface area (ft^2): $A_{req} = SQDV/d_{effective}$	A_{req} = ft^2
Step 4: Calculate Bioretention Area Total Footprint	
4-1. Calculate total footprint required by including a buffer for side slopes and freeboard (ft^2) [A_{req} is measured at the as the filter bottom area (toe of side slopes)], A_{tot}	A_{tot} = ft^2

Design Example

Bioretention areas have several components that allow the pretreatment, spreading, filtration, collection and discharge of the incoming flows.

Step 1: Determine water quality design volume

For this design example, a 10-acre site with soil type 4 and 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1\text{-}imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	0.75	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560\times C*P*A_{retain}$	SQDV=	8,500	ft^3

Step 2: Determine the design percolation rate

For this design example, a native soil percolation rate of 1.5 in/hr is assumed.

Step 2: Determine the design percolation rate			
2-1. Enter measured soil percolation rate (in/hr, 0.5 in/hr minimum), $P_{measured}$	$P_{measured}$ =	4.0	in/hr
2-2. Determine percolation rate correction factor, S_A, based on suitability assessment (see Section 6 INF-1)	S_A =	3	
2-3. Determine percolation rate correction factor, S_B, based on design (see Section 6 INF-1)	S_b =	3	
2-4. Calculate combined safety factor, $S = S_A \times S_b$	S =	9	
2-5. Calculate the design percolation rate (in/hr), $P_{design} = P_{measured}/S$	P_{design} =	0.44	in/hr

Step 3: Determine bioretention/ planter box area footprint

A bioretention area is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a plant mix filter bed (planting soil mixed with sand content = 70%) through which the stored runoff must percolate to obtain treatment.

Step 3: Calculate bioretention/planter box surface area			
3-1. Enter water quality design volume (ft^3), *SQDV*	SQDV =	8,500	ft^3
3-2. Enter design percolation rate (in/hr), P_{design}	P_{design} =	0.375	in/hr
3.3 Enter the required drain time (48 hours), $t_{ponding}$	$t_{ponding}$ =	48	hours
3-3. Calculate the maximum depth of surface ponding (ft) that can be infiltrated within the required drain time (48 hours): $d_{max} = (P_{design} \times t_{ponding})/12$	d_{max} =	1.5	ft
3-4. Select surface ponding depth d_p such that $d_p \leq d_{max}$	d_p =	1.5	ft
3-5. Select thickness of amended media (2 feet minimum, 3 preferred), l_{media}	l_{media} =	3	ft

Step 3: Calculate bioretention/planter box surface area	
3-6. Enter porosity of amended media (roughly 25% or 0.25 ft/ft), n_{media}	n_{media}= 0.25 ft/ft
3-7. Select thickness of optional gravel layer (ft), l_{gravel}	l_{gravel} = 1 ft
3-8. Enter porosity of gravel (roughly 30% or 0.3 ft/ft), n_{gravel}	n_{gravel}= 0.3 ft/ft
3-9. Calculate the total effective storage depth of bioretention facility (ft): $d_{effective} \leq (d_p + n_{media}l_{media} + n_{gravel}l_{gravel})$	$d_{effective}$= 2.6 ft
3-10. Check that the entire effective depth infiltrates in required drainage time, 96 hours: $t_{total} = (d_{effective}/P_{design}) \times 12$ If t_{total} > 96 hours, reduce surface ponding depth and/or amended media thickness and/or gravel thickness and return to 3-4. If $t_{total} \leq$ 96 hours, proceed to 3-11.	t_{total} = 82 hours
3-11. C alculate the required infiltrating surface area (ft²), $A_{req} = SQDV/d_{effective}$	A_{req} = 3,300 ft²

Step 4: Calculate Bioretention Area Total Footprint

For this design example, a natural-shaped bioretention area is assumed, with 3:1 side slopes. To calculate the total footprint, the side slopes would be added to the design geometry.

E.4 INF-5 Permeable Pavement

Sizing Methodology

Permeable pavement (including the base layers) shall be designed to drain in less than 72 hours. The basis for this is that soils must be allowed to dry out periodically in order to restore hydraulic capacity; this is essential in order to receive flows from subsequent storms, maintain infiltration rates, maintain adequate sub soil oxygen levels for healthy soil biota, and to provide proper soil conditions for biodegradation and retention of pollutants.

Permeable pavement must be built and designed by a licensed civil engineer in accordance with Ventura County roadway and pavement specifications.

Step 1: Calculate the design volume

Permeable pavement shall be sized to capture and treat the stormwater quality design volume, SQDV (see Section 2 and Appendix E).

Step 2: Determine the Design Percolation Rate

The percolation rate will decline between maintenance cycles as particulates accumulate in the infiltrative layer and the surface becomes occluded. Additionally, monitoring of actual facility performance has shown that the full-scale infiltration rate is far lower than the rate measured by small-scale testing. It is important that adequate conservatism is incorporated in the selection of design percolation rates. For infiltrating bioretention facilities, the design percolation rate discussed here is the percolation rate of the underlying soils, which will drive infiltration through the facility. See INF-5: Permeable Pavement for guidance in developing design percolation rate correction factors.

Step 3: Determine gravel drainage layer depth

Permeable pavement (including the base layers) shall be designed to drain in less than 72 hours. The basis for this is that soils must be allowed to dry out periodically in order to restore hydraulic capacity to receive flows from subsequent storms, maintain infiltration rates, maintain adequate sub soil oxygen levels for healthy soil biota, and to provide proper soil conditions for biodegradation and retention of pollutants.

1) Calculate the maximum depth of runoff, d_{max}, that can be infiltrated within the drawdown time:

$$d_{\max} = \frac{P_{design} \bullet t}{12} \qquad \text{(Equation E-23)}$$

Where:

d_{max} = maximum depth that can be infiltrated (ft)

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

t = drawdown time (72 hrs maximum) (hr)

1) Select the gravel drainage layer depth, *l*, such that:

$$d_{\max} \geq n \times l \quad \text{(Equation E-24)}$$

Where:

d_{max} = maximum depth that can be infiltrated (ft) (see 1) above)

n = gravel drainage layer porosity(unitless) (generally about 32% or 0.32 for gravel)

l = gravel drainage layer depth (ft)

Step 4: Determine infiltrating surface area

1) Calculate infiltrating surface area for permeable pavement, A:

$$A = \frac{SQDV}{\frac{TP_{design}}{12} + nl} \quad \text{(Equation E-25)}$$

Where:

P_{design} = design percolation rate of underlying soils (in/hr) (see Step 2, above)

n = gravel drainage layer porosity(unitless)[about 32% or 0.32 for gravel]

l = depth of gravel drainage layer (ft)

T = time to fill the gravel drainage layer with water (use 2 hours for most designs) (hr)

Step 5: Provide conveyance capacity for clogging

The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged. See INF-5 Permeable Pavement for overflow details.

Sizing Worksheet

Step 1: Determine water quality design volume	
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ = acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ %
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$= acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=
1-5. D etermine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA= acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} = acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =
1-9. Enter design rainfall depth of the storm (in), P_i	P_i = in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P = ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560 \times C*P*A_{retain}$	SQDV= ft^3
Step 2: Determine the design percolation rate	
2-1. Enter measured soil percolation rate (0.5 in/hr minimum), $P_{measured}$	$P_{measured}$ = in/hr
2-2. Determine percolation rate correction factor, S_A based on suitability assessment (see Section 6 INF-5)	S_A =

Step 2: Determine the design percolation rate	
2-3. Determine percolation rate correction factor, S_B based on design (see Section 6 INF-5)	S_B =
2-4. Calculate combined safety factor, $S = S_A \times S_b$	S =
2-5. Calculate the design percolation rate (in/hr), $P_{design} = P_{measured}/S$	P_{design} = in/hr
Step 3: Determine the Gravel Drainage Layer Depth	
3-1. Enter drawdown time (hours, 72 hrs max.), t	t = hours
3-2. Calculate max. depth of runoff (ft) that can be infiltrated within the t, $d_{max}=P_{design}t/12$	d_{max} = ft
3-3. Enter the gravel drainage layer porosity, n (typically 32% or 0.32 for gravel)	n =
3-4. Select the gravel drainage layer depth (ft) such that $d_{max} \geq n \times l$	l = ft
Step 4: Determine infiltrating surface area	
4-1. Enter gravel drainage layer porosity, n	n =
4-2. Enter depth of gravel drainage layer (ft), l	l = ft
4-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), T	T = hrs
4-4. Calculate infiltrating surface area (ft^3): $A=SQDV/((TP_{design}/12)+nl)$	A = ft^2
Step 5: Provide conveyance capacity for clogging	
5-1. The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged.	

Design Example

Step 1: Determine Water Quality Design Volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine Water Quality Design Volume			
1-1. Enter Project area (acres), $A_{project}$	A =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (%) (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowableble}$ =	5	
1-3. Determine the maximum allowable effective impervious area (acres), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	0.75	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560\times C*P*A_{retain}$	SQDV =	8,500	ft^3

Step 2: Calculate Design Percolation Rate

Permeable pavement with no underdrain requires a minimum soil infiltration rate of 0.5 in/hr. For this design example, a native soil percolation rate of 1.5 in/hr is assumed.

Step 2: Determine the design percolation rate			
2-1. Enter measured soil percolation rate (0.5 in/hr min.), $P_{measured}$	$P_{measured}$ =	4.0	in/hr
2-2. Determine percolation rate correction factor, S_A, based on suitability assessment (see Section 6 INF-1)	S_A =	3	
2-3. Determine percolation rate correction factor, S_B, based on design (see Section 6 INF-1)	S_b =	3	
2-4. Calculate combined safety factor, $S = S_A \times S_b$	S =	9	
2-5. Calculate the design percolation rate (in/hr), $P_{design} = P_{measured}/S$	P_{design} =	0.44	in/hr

Step 3: Determine maximum depth that can be infiltrated

Based on the design infiltration rate and the max drawdown, determine the maximum depth that can be infiltrated within the time constraints.

Step 3: Determine maximum depth that can be infiltrated			
3-1. Enter drawdown time (72 hrs max.), *t*	t =	72	hrs
3-2. Calculate max. depth of runoff (ft) that can be infiltrated within the t, $d_{max}=P_{design}t/12$	d_{max} =	2.6	ft
3-3. Enter the gravel drainage layer porosity, *n* (typically 32% or 0.32 for gravel)	n =	0.32	
3-4. Select the gravel drainage layer depth (ft) such that $d_{max} \geq n \times l$	l =	8	ft

Step 4: Determine the infiltrating surface area (pavement area)

Using the depth calculated in Step 3, the required infiltrating surface area of the pavement can be calculated.

Step 4: Determine the infiltrating surface area	
4-1. Enter gravel drainage layer porosity, *n*	n = 0.32
4-2. Enter depth of gravel drainage layer (ft), *l*	l = 8 ft
4-3. Enter the time to fill the gravel drainage layer with water (Use 2 hours for most designs), *T*	T = 2 hrs
4-4. Calculate infiltrating surface area (ft^3): $A=SQDV/(TP_{design}/12)+n*l))$	A = 1,630 ft^2

Step 5: Provide conveyance capacity for clogging

The permeable pavement must have an emergency overflow for storm events greater than the design and in the event the permeable pavement becomes clogged.

E.5 VEG-1 Bioretention/VEG-2 Planter Box

Sizing Methodology

Bioretention areas can be sized using one of two methods: a simple sizing method or a routing method. The simple sizing procedure is summarized below. Continuous simulation modeling, routing spreadsheets, and/or other forms of routing modeling that incorporate rainfall-runoff relationships and infiltrative (flow) capacities of bioretention may be used to size facilities. Alternative sizing methodologies should be prepared with good engineering practices. For the routing modeling method, refer to the Sand Filter design guidance (FILT-1). A bioretention sizing worksheet and example are provided in this appendix. Planter boxes are sized the same as bioretention areas with underdrains using parameters appropriate for planter boxes.

With either method, the runoff entering the facility must completely drain the ponding area within 48 hours, and runoff must be completely infiltrated within 96 hours. Bioretention is to be sized, with or without underdrains, such that the SQDV will fill the available ponding depth, the void spaces in the planting soil, and the optional aggregate layer.

Step 1: Determine the stormwater quality design volume (SQDV)

Bioretention areas should be sized to capture and treat the water quality design volume (see Section E.1).

Step 2: Determine the Design Percolation Rate

Sizing is based on the design saturated hydraulic conductivity (K_{sat}) of the amended soil layer. A target K_{sat} of 5 inches per hour is recommended for newly installed non-proprietary amended soil media. The media K_{sat} will decline between maintenance cycles as the surface becomes occluded and particulates accumulate in the amended soil layer. A factor of safety of 2.0 should be applied such that the resulting recommended design percolation rate is 2.5 inches per hour. This value should be used for sizing unless sufficient rationale is provided to justify a higher design percolation rate.

Step 3: Calculate the bioretention or planter box surface area

Determine the size of the required infiltrating surface by assuming the SQDV will fill the available ponding depth plus the void spaces in the media, based on the computed porosity of the filter media and optional aggregate layer.

1) Select a surface ponding depth (d_p) that satisfies geometric criteria and congruent with the constraints of the site. Selecting a deeper ponding depth (18 inches maximum) generally yields a smaller footprint, however requires greater consideration for public safety and energy dissipation.

2) Compute time for selected ponding depth to filter through media:

$$t_{ponding} = \frac{d_p}{K_{design}} 12 \frac{in}{ft} \leq 48 \text{ hours} \quad \text{(Equation E-26)}$$

Where:

$t_{ponding}$ = required drain time of surface ponding (48 hrs)

d_p = selected surface ponding water depth (ft)

K_{design} = design saturated hydraulic conductivity (in/hr) (see Step 2, above)

If $t_{ponding}$ exceeds 48 hours, return to (1) and reduce surface ponding or increase media K_{design}. Otherwise, proceed to next step.

Note: In nearly all cases, $t_{ponding}$ will not approach 48 hours unless a low Kdesign is specified.

3) Compute depth of water that may be considered to be filtered during the design storm event as follows:

$$d_{filtered} = Minimum\left[\frac{K_{design} \times T_{routing}}{12 \, {}^{in}\!/_{ft}}, \frac{d_p}{2}\right] \quad \text{(Equation E-27),}$$

Where:

$d_{filtered}$ = depth of water that may be considered to be filtered during the design storm event (ft) for routing calculations; this value should not exceed half of the surface ponding depth (d_p)

K_{design} = design saturated hydraulic conductivity (in/hr) (see Step 2, above)

$T_{routing}$ = storm duration that may be assumed for routing calculations; this should be assumed to be **3 hours** unless rationale for an alternative assumption is provided

d_p = selected surface ponding water depth (ft)

4) Calculate required infiltrating surface area (filter bottom area):

$$A_{req} = \frac{SQDV}{d_p + d_{filtered}} \quad \text{(Equation E-28)}$$

Where:

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A_{req}	=	required area at bottom of filter area (ft²); does not account for side slopes and freeboard
$SQDV$	=	stormwater quality design volume (ft³)
d_p	=	selected surface ponding water depth (ft)
$d_{filtered}$	=	depth of water that can be considered to be filtered during the design storm event (ft) for routing calculations (See previous step)

Step 4: Calculate the bioretention total footprint

Calculate total footprint required by including a buffer for side slopes and freeboard; A_{req} is measured at the filter bottom area (toe of side slopes).

Step 5: Calculate underdrain system capacity

Underdrains are required for planter boxes and bioretention with underdrains. For guidance on sizing, refer to step 5 of the worksheet below. Alternatively, the Ventura County Hydrology Manual can be used for pipe sizing guidance.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$	%
1-3. Determine the maximum allowed effective impervious area (ac), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1-imp)$	C =	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560 \bullet C*P*A_{retain}$	SQDV=	ft^3

Step 2: Determine the design percolation rate		
2-1. Enter the design saturated hydraulic conductivity of the amended filter media (2.5 in/hr recommended rate), K_{design}	K_{design} =	in/hr

Step 3: Calculate Bioretention/Planter Box surface area		
3-1. Enter water quality design volume (ft^3), *SQDV*	SQDV =	ft^3
3-2. Enter design saturated hydraulic conductivity (in/hr), K_{design}	K_{design} =	in/hr
3-3. Enter ponding depth (max 1.5 ft for Bioretention, 1 ft for Planter Box) above area, d_p	d_p =	ft
3-4. Calculate the drawdown time for the ponded water to filter through media (hours), $t_{ponding} = (d_p/K_{design}) \times 12$	$t_{ponding}$=	hrs
3-5. Enter the storm duration for routing calculations (use 3 hours unless there is rationale for an alternative), $T_{routing}$	$T_{routing}$ =	hrs
3-6. Calculate depth of water (ft) filtered by using the following two equations: $d_{filtered,1} = (K_{design} \times T_{routing})/12$ $d_{filteret,2} = d_p /2$	$d_{filtered,1}$ = $d_{filtered,2}$ =	ft ft
3.7 Enter the resultant depth (ft) (the lesser of the two calculated above), $d_{filtered}$	$d_{filtered}$ =	ft
3-8. Calculate the infiltrating surface area as follows (ft^2): $A_{req} = SQDV/(d_p + d_{filtered})$	A_{req} =	ft^2
Step 4: Calculate Bioretention Area Total Footprint		
4-1. Calculate total footprint required by including a buffer for side slopes and freeboard (ft^2) [A_{req} is measured at the as the filter bottom area (toe of side slopes)], A_{tot}	A_{tot} =	ft^2
Step 5: Calculate Underdrain System Capacity		
To calculate the underdrain system capacity, continue through steps 5-1 to 5-7.		

Step 5: Calculate Underdrain System Capacity		
5-1. Calculated filtered flow rate to be conveyed by the longitudinal drain pipe, $Q_f = K_{design} A_{req}/43,200$	Q_f =	cfs
5-2. Enter minimum slope for energy gradient, S_e	S_e =	
5-3. Enter Hazen-Williams coefficient for plastic, C_{HW}	C_{HW} =	
5-4. Enter pipe diameter (min 6 inches), D	D =	in
5-5. Calculate pipe hydraulic radius (ft), $R_h = D/48$	R_h =	ft
5-6. Calculate velocity at the outlet of the pipe (ft/s), $V_p = 1.318 C_{HW} R_h^{0.63} S_e^{0.54}$	V_p =	ft/s
5-7. Calculate pipe capacity (cfs), $Q_{cap} = 0.25\pi(D/12)^2 V_p$	Q_{cap} =	cfs

Design Example

Bioretention areas have several components that allow the pretreatment, spreading, filtration, collection and discharge of the incoming flows.

Step 1: Determine water quality design volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine Water Quality Design Volume			
1-1. Enter drainage area, A	A =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowableble}$ =	5	
1-3. Determine the maximum allowed effective impervious area, $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area, $TIA=A_{project}*Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained, $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm, P_i (in)	P_i =	0.75	in
1-10. Calculate rainfall depth, $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume, $SQDV = 43560 \cdot P*A_{retain}*C$	SQDV =	8,500	ft^3

Step 2: Determine the design percolation rate

For this design example, the recommended amended filter hydraulic conductivity is used, 2.5 in/hr.

Step 2: Determine the design percolation rate	
2-1. Enter the design saturated hydraulic conductivity of the amended filter media (2.5 in/hr recommended rate), K_{design}	K_{design} = 2.5 in/hr

Step 3: Determine bioretention/ planter box area footprint

A bioretention area is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a plant mix filter bed (planting soil mixed with sand content = 70%) through which the stored runoff must percolate to obtain treatment.

Step 3: Calculate Bioretention/Planter Box surface area			
3-1. Enter water quality design volume (ft^3), *SQDV*	SQDV =	8,500	ac-ft
3-2. Enter design saturated hydraulic conductivity (in/hr), K_{design}	K_{design} =	2.5	in/hr
3-3. Enter ponding depth (max 1.5 ft for Bioretention, 1 ft for Planter Box) above area, d_p	d_p =	1.5	ft
3-4. Calculate the drawdown time for the ponded water to filter through media (hours), $t_{ponding} = (d_p/K_{design}) \times 12$	$t_{ponding}$=	7.2	hrs
3-5. Enter the storm duration for routing calculations (use 3 hours unless there is rationale for an alternative), $T_{routing}$	$T_{routing}$ =	3	hrs
3-6. Calculate depth of water (ft) filtered by using the minimum of the following two equations: $d_{filtered,1} = (K_{design} \times T_{routing})/12$ $d_{filteret,2} = d_p /2$	$d_{filtered,1}$ = $d_{filtered,2}$ =	0.63 0.75	ft ft
3.7 Enter the resultant depth (the minimum of the two calculated above), $d_{filtered}$	$d_{filtered}$ =	0.63	ft
3-8. Calculate the infiltrating surface area as follows (ft^2): $A_{req} = SQDV/(d_p + d_{filtered})$	A_{req} =	4,000	ft^2

Step 4: Calculate Bioretention Area Total Footprint

For this design example, a natural-shaped bioretention area is assumed, with 3:1 side slopes. To calculate the total footprint, the side slopes would be added to the design geometry.

Step 5: Calculate filter longitudinal underdrain collection pipe

All underdrain pipes must be 6 inches or greater in diameter to facilitate cleaning.

Step 5: Calculate underdrain system (required for planter box)	
To calculate the underdrain system capacity, continue through steps 5-1 to 5-7. If you don't need to calculate the underdrain capacity, skip this step.	
5-1. Calculated filtered flow rate to be conveyed by the longitudinal drain pipe (cfs), $Q_f = K_{design} A_{req}/43{,}200$	$Q_f =$ 0.085 cfs
5-2. Enter minimum slope for energy gradient, S_e	$S_e =$ 0.005
5-3. Enter Hazen-Williams coefficient for plastic, C_{HW}	$C_{HW} =$ 140
5-4. Enter pipe diameter (min 6 in), D	$D =$ 6 in
5-5. Calculate pipe hydraulic radius (ft), $R_h = D/48$	$R_h =$ 0.13 ft
5-6. Calculate velocity at the outlet of the pipe (ft/s), $V_p = 1.318 C_{HW} R_h^{0.63} S_e^{0.54}$	$V_p =$ 2.9 ft/s
5-7. Calculate pipe capacity (cfs), $Q_{cap} = 0.25\pi(D/12)^2 V_p$	$Q_{cap} =$ 0.57 cfs

E.6 VEG-3 Vegetated Swale

Sizing Methodology

The flow capacity of a vegetated swale is a function of the longitudinal slope (parallel to flow), the resistance to flow (i.e. Manning's roughness), and the cross sectional area. The cross section is normally approximately trapezoidal and the area is a function of the bottom width and side slopes. The flow capacity of vegetated swales should be such that the design water quality flow rate will not exceed a flow depth of 2/3 the height of the vegetation within the swale or 4 inches at the water quality design flow rate. Once design criteria have been selected, the resulting flow depth for the design water quality design flow rate is checked. If the depth restriction is exceeded, swale parameters (e.g. longitudinal slope, width) are adjusted to reduce the flow depth.

Procedures for sizing vegetated swales are summarized below. A vegetated swale sizing worksheet and example are also provided.

Step 1: Select design flows

The swale sizing is based on the stormwater quality design flow SQDF (see Section E.1).

Step 2: Calculate swale bottom width

The swale bottom width is calculated based on Manning's equation for open-channel flow. This equation can be used to calculate discharges as follows:

$$Q = \frac{1.49 A R^{0.67} S^{0.5}}{n}$$

(Equation E-29)

Where:

Q	=	flow rate (cfs)
n	=	Manning's roughness coefficient (unitless)
A	=	cross-sectional area of flow (ft^2)
R	=	hydraulic radius (ft) = area divided by wetted perimeter
S	=	longitudinal slope (ft/ft)

For shallow flow depths in swales, channel side slopes are ignored in the calculation of bottom width. Use the following equation (a simplified form of Manning's formula) to estimate the swale bottom width:

$$b = \frac{SQDF * n_{wq}}{1.49 y^{0.67} s^{0.5}}$$ (Equation E-30)

Where:

b	=	bottom width of swale (ft)
$SQDF$	=	stormwater quality design flow (cfs)
n_{wq}	=	Manning's roughness coefficient for shallow flow conditions = 0.2 (unitless)
y	=	design flow depth (ft)
s	=	longitudinal slope (along direction of flow) (ft/ft)

Proceed to Step 3 if the bottom width is calculated to be between 2 and 10 feet. A minimum 2-foot bottom width is required. Therefore, if the calculated bottom width is less than 2 feet, increase the width to 2 feet and recalculate the design flow depth y using the Equation 4-13, where Q_{wq}, n_{wq}, and s are the same values as used above, but b = 2 feet.

The maximum allowable bottom width is 10 feet; therefore if the calculated bottom width exceeds 10 feet, then one of the following steps is necessary to reduce the design bottom width:

1) Increase the longitudinal slope (s) to a maximum of 6 feet in 100 feet (0.06 feet per foot).
2) Increase the design flow depth (y) to a maximum of 4 inches.
3) Place a divider lengthwise along the swale bottom (Figure 3-1) at least three-quarters of the swale length (beginning at the inlet), without compromising the design flow depth and swale lateral slope requirements. Swale width can be increased to an absolute maximum of 16 feet if a divider is provided.

Step 3: Determine design flow velocity

To calculate the design flow velocity through the swale, use the flow continuity equation:

$$V_{wq} = SQDF/A_{wq}$$ (Equation E-31)

Where:

V_{wq}	=	design flow velocity (fps)
$SQDF$	=	stormwater quality design flow (cfs)

A_{wq}	=	$by + Zy^2$ = cross-sectional area (ft^2) of flow at design depth, where Z = side slope length per unit height (e.g., Z = 3 if side slopes are 3H:1V)

If the design flow velocity exceeds 1 foot per second, go back to Step 2 and modify one or more of the design parameters (longitudinal slope, bottom width, or flow depth) to reduce the design flow velocity to 1 foot per second or less. If the design flow velocity is calculated to be less than 1 foot per second, proceed to Step 4. *Note: It is desirable to have the design velocity as low as possible, both to improve treatment effectiveness and to reduce swale length requirements.*

Step 4: Calculate swale length

Use the following equation to determine the necessary swale length to achieve a hydraulic residence time of at least 7 minutes:

$$L = 60 t_{hr} V_{wq} \quad \text{(Equation E-32)}$$

Where:

L	=	minimum allowable swale length (ft)
t_{hr}	=	hydraulic residence time (min)
V_{wq}	=	design flow velocity (fps)

The minimum swale length is 100 feet; therefore, if the swale length is calculated to be less than 100 feet, increase the length to a minimum of 100 feet, leaving the bottom width unchanged. If a larger swale can be fitted on the site, consider using a greater length to increase the hydraulic residence time and improve the swale's pollutant removal capability. If the calculated length is too long for the site, or if it would cause layout problems, such as encroachment into shaded areas, proceed to Step 5 to further modify the layout. If the swale length can be accommodated on the site (meandering may help), proceed to Step 6.

Step 5: Adjust swale layout to fit on site

If the swale length calculated in Step 4 is too long for the site, the length can be reduced (to a minimum of 100 feet) by increasing the bottom width up to a maximum of 16 feet, as long as the 10 minute retention time is retained. However, the length cannot be increased in order to reduce the bottom width because Manning's depth-velocity-flow rate relationships would not be preserved. If the bottom width is increased to greater than 10 feet, a low flow dividing berm is needed to split the swale cross section in half to prevent channelization.

Length can be adjusted by calculating the top area of the swale and providing an equivalent top area with the adjusted dimensions.

1) Calculate the swale treatment top area based on the swale length calculated in Step 4:

$$A_{top} = (b_i + b_{slope})L_i \qquad \text{(Equation E-33)}$$

Where:

A_{top} = top area (ft²) at the design treatment depth

b_i = bottom width (ft) calculated in Step 2

b_{slope} = the additional top width (ft) above the side slope for the design water depth (for 3:1 side slopes and a 4-inch water depth, b_{slope} = 2 feet)

L_i = initial length (ft) calculated in Step 4

2) Use the swale top area and a reduced swale length L_f to increase the bottom width, using the following equation:

$$L_f = A_{top} / (b_f + b_{slope}) \qquad \text{(Equation E-34)}$$

Where:

L_f = reduced swale length (ft)

b_f = increased bottom width (ft).

3) Recalculate V_{wq} according to Step 3 using the revised cross-sectional area A_{wq} based on the increased bottom width b_f. Revise the design as necessary if the design flow velocity exceeds 1 foot per second.

4) Recalculate to assure that the 10 minute retention time is retained.

Step 6: Provide conveyance capacity for flows higher than SQDF

Vegetated swales may be designed as flow-through channels that convey flows higher than the water quality design flow rate, or they may be designed to incorporate a high-flow bypass upstream of the swale inlet. A high-flow bypass usually results in a smaller swale size. If a high-flow bypass is provided, this step is not needed. If no high-flow bypass is provided, proceed with the procedure below. Flow splitter structure design is described in Appendix G.

1) Check the swale size to determine whether the swale can convey the flood control design storm peak flows (Refer to the Ventura County Hydrology Manual, 2006).

2) The peak flow velocity of the flood control design storm (e.g., flood control design storm – see Ventura County Hydrology Manual, 2006)) must be less than 3.0 feet per second. If this velocity exceeds 3.0 feet per second, return to Step 2 and

increase the bottom width or flatten the longitudinal slope as necessary to reduce the flood control design storm peak flow velocity to 3.0 feet per second or less. If the longitudinal slope is flattened, the swale bottom width must be recalculated (Step 2) and must meet all design criteria.

Sizing Worksheet

Step 1: Determine water quality design flow		
1-1. Enter Project area (acres), $A_{project}$	A_{design} =	acres
1-2. Enter impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp =	
1-3. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-4. Calculate runoff coefficient, $C = 0.95*imp + C_p (1\text{-}imp)$	C =	
1-5. Enter design rainfall intensity (in/hr), *i*	i =	in/hr
1-6. Calculate water quality design flow (cfs), *SQDF= CiA*	SQDF =	cfs
Step 2: Calculate swale bottom width		
2-1. Enter water quality design flow (cfs), *SQDF*	SQDF =	cfs
2-2. Enter Manning's roughness coefficient for shallow flow conditions, $n_{wq} = 0.2$	n_{wq} =	
2-3. Calculate design flow depth (ft), *y*	y =	ft
2-4. Enter longitudinal slope (ft/ft) (along direction of flow), *s*	s =	ft/ft
2-5. Calculate bottom width of swale (ft), $b = (SQDF*n_{wq})/(1.49y^{0.67}s^{0.5})$	b =	ft
2-6. If *b* is between 2 and 10 feet, go to Step 3		
2-7. If b is less than 2 ft, assume b = 2 ft and recalculate flow depth, $y = ((SQDF*n_{wq})/(2.98\, s^{0.5}))^{1.49}$	y =	ft

2-8. If b is greater than 10 ft, one of the following design adjustments must be made (recalculate variables as necessary): • Increase the longitudinal slope to a maximum of 0.06 ft/ft. • Increase the design flow depth to a maximum of 4 in (0.33 ft). • Place a divider lengthwise along the swale bottom (Figure 3-1) at least three-quarters of the swale length (beginning at the inlet). Swale width can be increased to an absolute maximum of 16 feet if a divider is provided.		
Step 3: Determine design flow velocity		
3-1. Enter side slope length per unit height (H:V) (e.g. 3 if side slopes are 3H :1V), *Z*	Z =	
3-2. Enter bottom width of swale (ft), *b*	b =	ft
3-3. Enter design flow depth (ft), *y*	y =	ft
3-4. Calculate the cross-sectional area of flow at design depth (ft^2), $A_{wq} = by + Zy^2$	A_{wq} =	ft^2
3-5. Calculate design flow velocity (ft/s), $V_{wq} = SQDF/ A_{wq}$	V_{wq} =	ft/s
3-6. If the design flow velocity exceeds 1 ft/s, go back to Step 2 and change one or more of the design parameters to reduce the design flow velocity. If design flow velocity is less than 1 ft/s, proceed to Step 4.		
Step 4: Calculate swale length		
4-1. Enter hydraulic residence time (minutes, minimum 7 min), t_{hr}	t_{hr} =	min
4-2. Calculate swale length (ft), $L = 60t_{hr}V_{wq}$	L =	ft

Step 4: Calculate swale length		
4-3. If L is too long for the site, proceed to Step 5 to adjust the swale layout If L is greater than 100 ft and will fit within the constraints of the site, skip to Step 6 If L is less than 100 ft, increase the length to a minimum of 100 ft, leaving the bottom width unchanged, and skip to Step 6		
Step 5: Adjust swale layout to fit within site constraints		
5-1. Enter the bottom width calculated in Step 2 (ft), $b_i = b$	b_i =	ft
5-2. Enter design flow depth (ft), y	y=	ft
5-3. Enter the swale side slope ratio (H:V), Z	Z =	ft:ft
5-4. Enter the additional top width above the side slope for the design water depth (ft), $b_{slope} = 2Zy$	b_{slope} =	ft
5-5. Enter the initial length calculated in Step 4 (ft), $Li = L$	L_i =	ft
5-6. Calculate the top area at the design treatment depth (ft²), $A_{top} = (b_i + b_{slope}) \times L_i$	A_{top} =	ft²
5-7. Choose a reduced swale length based on site constraints (ft), L_f	L_f =	ft
5-8. Calculate the increased bottom width (ft), $b_f = (A_{top}/L_f) - b_{slope}$	b_f =	ft
5-9. Recalculate the cross-sectional area of flow at design depth (ft2), $A_{wq,f} = b_f y + Zy^2$	$A_{wq,f}$ =	ft²
5-10. Recalculate design flow velocity (ft/s), $V_{wq} = SQDF/ A_{wq}$ Revise design as necessary if design flow velocity exceeds 1 ft/s.	V_{wq} =	ft/s

5-11. Recalculate the hydraulic residence time (min), $t_{hr} = L_f/(60V_{wq})$ Ensure that t_{hr} is greater or equal to 10 minutes.	t_{hr} = min
5-12. When V_{wq} and t_{hr} are recalculated to meet requirements, proceed to Step 6.	
Step 6: Provide conveyance capacity for flows higher than SQDF (if swale is on-line)	
6-1. If the swale already includes a high-flow bypass to convey flows higher than the water quality design flow rate, skip this step and verify that all parameters meet design requirements to complete sizing	
6-2. If swale does not include a high-flow bypass, determine that the swale can convey flood control design storm peak flows. Calculate the capital peak flow velocity per Ventura County requirements (ft/s), V_p	V_p = ft/s
6-3. If V_p > 3.0 feet per second, return to Step 2 and increase the bottom width or flatten the longitudinal slope as necessary to reduce the flood control design storm peak flow velocity to 3.0 feet per second or less. If the longitudinal slope is flattened, the swale bottom width must be recalculated (Step 2) and must meet all design criteria.	

Design Example

Step 1: Determine water quality design Flow

For this design example, a 10-acre site with Type 4 soil and 60% total imperviousness is considered. Flow-based sizing Method 1 is assumed. Therefore, the design intensity is 0.2 in/hr.

Step 1: Determine water quality design flow			
1-1. Enter Project area (acres), $A_{project}$	A =	10	acres
1-2. Enter impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp =	0.60	
1-3. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-4. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1\text{-}imp)$	C =	0.59	
1-5. Enter design rainfall intensity (in/hr), *i*	i =	0.2	in/hr
1-6. Calculate water quality design flow (cfs), *SQDF= CiA*	*SQDF*=	1.18	cfs

Step 2: Calculate Swale Bottom Width

The swale bottom width is calculated based on Manning's equation. The grass height in the swale will be maintained at 6-inches. The design flow depth is assumed to be 2/3 of the grass height, or 4 inches (0.33 ft). The default Manning's roughness coefficient is assumed appropriate for expected vegetation density and design depth. The slope was assumed to be 0.04.

Step 2: Calculate swale bottom width			
2-1. Enter water quality design flow (cfs), *SQDF*	SQDF =	1.18	cfs
2-2. Enter Manning's roughness coefficient for shallow flow conditions, n_{wq} = 0.2	n_{wq} =	0.2	
2-3. Calculate design flow depth (ft), *y*	*y* =	0.33	ft
2-4. Enter longitudinal slope (along direction of flow) (ft/ft), *s*	s =	0.04	ft/ft
2-5. Calculate bottom width of swale (ft),	b =	5.0	ft

Step 2: Calculate swale bottom width	
$b = Q_{wq}n_{wq} / 1.49y^{0.67}s^{0.5}$	
2-6. If *b* is between 2 and 10 feet, go to Step 3	
2-7. If *b* is less than 2 ft, assume *b* = 2 ft and recalculate flow depth, $y = (Q_{wq}n_{wq} / 2.98s^{0.5})^{1.49}$	Not applicable
2-8. If *b* is greater than 10 ft, one of the following design adjustments must be made (and recalculate as necessary): Increase the longitudinal slope to a maximum of 0.06 ft/ft. Increase the design flow depth to a maximum of 4 in (0.33 ft). Place a divider lengthwise along the swale bottom (Figure 3-1) at least three-quarters of the swale length (beginning at the inlet). Swale width can be increased to an absolute maximum of 16 feet if a divider is provided.	Not applicable

Step 3: Determine Design Flow Velocity

For this design example, it is assumed the side slopes will be designed as 3H: 1V, so Z = 3.

Step 3: Determine design flow velocity			
3-1. Enter side slope length per unit height (H:V) (e.g. 3 if side slopes are 3H :1V), *Z*	Z =	3	
3-2. Enter bottom width of swale (ft), *b*	b =	5.0	ft
3-3. Enter design flow depth (ft), *y*	y =	0.33	ft
3-4. Calculate the cross-sectional area of flow at design depth (ft²), $A_{wq} = by + Zy^2$	A_{wq} =	2.0	ft^2
3-5. Calculate design flow velocity (ft/s), $V_{wq} = SQDF / A_{wq}$	V_{wq} =	0.59	ft/s
3-6. If the design flow exceeds 1 ft/s, go back to Step 2 and change one or more of the design parameters to reduce the design flow velocity. If design flow velocity is less than 1 ft/s, proceed to Step 4.			

Step 4: Calculate Swale Length

Using the design flow velocity and a minimum residence time of 7 minutes, the length of the swale is calculated as follows. The swale length must be a minimum of 100 ft.

Step 4: Calculate swale length			
4-1. Enter hydraulic residence time (min 7 min), t_{hr} (min)	t_{hr} =	10	min
4-2. Calculate swale length, $L = 60 t_{hr} V_{wq}$	L =	354	ft
4-3. If *L* is too long for the site, proceed to Step 5 to adjust the swale layout If *L* is greater than 100 ft and will fit within the constraints of the site, skip to Step 6 If *L* is less than 100 ft, increase the length to a minimum of 100 ft, leaving the bottom width unchanged, and skip to Step 6	Not Applicable		

Site constraints only allow a swale length of 300 feet. Therefore proceed to Step 5 to adjust the swale length.

Step 5: Adjust Swale Layout to Fit Within Site Constraints

To adjust swale length to 300 feet, the bottom width needs to be increased (up to a maximum of 16 ft if a divider is provided).

Step 5: Adjust swale layout to fit within site constraints			
5-1. Enter the bottom width calculated in Step 2 (ft), $b_i = b$	b_i =	5.0	ft
5-2. Enter design flow depth (ft), *y*	y=	0.33	ft
5-3. Enter the swale side slope ratio (H:V), *Z*	Z =	3	ft:ft
5-4. Enter the additional top width above the side slope for the design water depth (ft), $b_{slope} = 2Zy$	b_{slope} =	2	ft
5-5. Enter the initial length calculated in Step 4 (ft), $Li = L$	L_i =	354	ft
5-6. Calculate the top area at the design treatment depth (ft^2), $A_{top} = (b_i + b_{slope}) \times L_i$	A_{top} =	2,480	ft^2

5-7. Choose a reduced swale length based on site constraints (ft), L_f	L_f = 300 ft
5-8. Calculate the increased bottom width (ft), $b_f = (A_{top}/L_f) - b_{slope}$	b_f = 6.3 ft
5-9. Recalculate the cross-sectional area of flow at design depth (ft2), $A_{wq,f} = b_f y + Zy^2$	$A_{wq,f}$ = 2.4 ft²
5-10. Recalculate design flow velocity (ft/s), $V_{wq} = SQDF/ A_{wq}$ Revise design as necessary if design flow velocity exceeds 1 ft/s.	V_{wq} = 0.49 ft/s
5-11. Recalculate the hydraulic residence time (min), $t_{hr} = L_f/(60V_{wq})$ Ensure that t_{hr} is greater or equal to 10 minutes.	t_{hr} = 10.2 min
5-12. When V_{wq} and t_{hr} are recalculated to meet requirements, proceed to Step 6.	

Since the new length and width yields V_{wq} and t_{hr} which meet requirements, continue to Step 6.

Step 6: Provide Conveyance Capacity for Flows Higher than SQDF

The swale will be offline such that all flows greater than SQDF will be bypassed.

E.7 VEG-4 Filter Strip

Sizing Methodology

The flow capacity of a vegetated filter strips (filter strips) is a function of the longitudinal slope (parallel to flow), the resistance to flow (e.g., Manning's roughness), and the width and length of the filter strip. The slope shall be small enough to ensure that the depth of water will not exceed 1 inch over the filter strip. Similarly, the flow velocity shall be less than 1 ft/sec. Procedures for sizing filter strips are summarized below. A filter strip sizing example is also provided.

Step 1: Calculate the design flow rate

The design flow is calculated based on the stormwater quality design flow rate, SQDF, as described in Section E.1.

Step 2: Calculate the minimum width

Determine the minimum width (i.e. perpendicular to flow) allowable for the filter strip and design for that width or larger.

$$W_{min} = (SQDF) / (q_{a,min}) \quad \text{(Equation E-35)}$$

Where

W_{min}	=	minimum width of filter strip
$SQDF$	=	stormwater quality design flow (cfs)
$q_{a,min}$	=	minimum linear unit application rate, 0.005 cfs/ft

Step 3: Calculate the design flow depth

The design flow depth (d_f) is calculated based on the width and the slope (parallel to the flow path) using a modified Manning's equation as follows:

$$d_f = 12 * [SQDF * n_{wq} / 1.49 W_{trib} s^{0.5}]^{0.6} \quad \text{(Equation E-36)}$$

Where:

d_f	=	design flow depth (inches)
$SQDF$	=	stormwater quality design flow (cfs)
W_{trib}	=	width (perpendicular to flow = width of impervious surface contributing area (ft))
s	=	slope (ft/ft) of strip parallel to flow, average over the whole width

n_{wq} = Manning's roughness coefficient (0.25-0.30)

If d_f is greater than 1 inch (0.083 ft), then a shallower slope is required, or a filter strip cannot be used.

Step 4: Calculate the design velocity

The design flow velocity is based on the design flow, design flow depth, and width of the strip:

$$V_{wq} = SQDF/\ (d_f\ W_{trib}) \qquad \text{(Equation E-37)}$$

Where:

$d_{f,ft}$ = design flow depth (ft) (d_f/12)

$SQDF$ = stormwater quality design flow (cfs)

W_{trib} = width (perpendicular to flow = width of impervious surface contributing area (ft))

Step 5: Calculate the desired length of the filter strip

Determine the required length (L) to achieve a desired minimum residence time of 7 minutes using:

$$L = 60 t_{hr} V_{wq} \qquad \text{(Equation E-38)}$$

Where:

L = minimum allowable strip length (ft)

t_{hr} = hydraulic residence time (s)

V_{wq} = design flow velocity (fps)

Sizing Worksheet

Step 1: Calculate the design flow		
1-1. Enter Project area (acres), $A_{project}$	A_{design} =	acres
1-2. Enter impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp =	
1-3. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-4. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1\text{-}imp)$	C =	
1-5. Enter design rainfall intensity (in/hr), *i*	i =	in/hr
1-6. Calculate water quality design flow (cfs), *SQDF= CiA*	SQDF =	cfs
Step 2: Calculate the minimum width		
2-1. Enter the stormwater quality design flow (cfs), *SQDF*	SQDF =	cfs
2-2. Enter the minimum linear unit application rate (0.005 cfs/ft), $q_{a,min}$	$q_{a,min}$=	cfs/ft
2-3. Calculate the minimum width of filter strip (ft), W_{min}	W_{min}=	ft
Step 3: Calculate the design flow depth		
3-1. Enter filter strip longitudinal slope, *s* (ft/ft)	*s* =	ft/ft
3-2. Enter Manning roughness coefficient (0.25-0.30), n_{wq}	n_{wq} =	
3-3. Enter width of impervious surface contributing area (perpendicular to flow), *W* (ft)	W =	ft

Step 3: Calculate the design flow depth	
3-4. Calculate average depth of water using Manning equation (inches), $d_f = 12^* [SQDF^* n_{wq}/1.49 W_{trib}\, s^{0.5}]^{0.6}$	d_f = inches
3-5. If d_f > 1" (0.083 ft), go back step 3-1 and decrease the slope	
3-6. If the slope cannot be changed due to construction constraints, go to step 3-3 and increase the width perpendicular to flow.	
Step 4: Calculate the design velocity	
4-1. Enter depth of water (ft), $d_{f,ft} = d_f/12$	d_f = ft
4-2. Enter width of strip (ft), W	W = ft
4-3. Calculate design flow velocity (ft/s), $V_{wq} = SQDF/(d_{f,ft}W)$	V_{wq}= ft/s
4-4. If the V_{wq} >1 ft/s, go back to step 3-1 and decrease the slope.	
Step 5: Calculate the length of the filter strip	
5-1. Enter desired residence time (minimum 7 minutes), t	t = min
5-2. Enter design flow velocity (ft/s), V_{wq}	V_{wq}= ft/s
5-3. Calculate length of the filter strip (ft), $L = 60tV_{wq}$	L = ft
5-4. If L < 4 ft, go to step 3-1 and increase the slope	

Design Example

Step 1: Determine water quality design Flow

For this design example, a 10-acre site with Type 4 soil and 60% total imperviousness is considered. Flow-based sizing Method 1 is used, as described in Section E.1.

Step 1: Calculate the design flow			
1-1. Enter Project area (acres), $A_{project}$	A_{design} =	10	acres
1-2. Enter impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp =	0.60	
1-3. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-4. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1\text{-}imp)$	C =	0.59	
1-5. Enter design rainfall intensity (in/hr), *i*	i =	0.2	in/hr
1-6. Calculate water quality design flow (cfs), *SQDF= CiA*	SQDF =	1.18	cfs

Step 2: Calculate the minimum width of filter strip

Determine the minimum width (i.e. perpendicular to flow) allowable for the filter strip and design for that width or larger.

Step 2: Calculate the minimum width			
2-1. Enter the stormwater quality design flow (cfs), *SQDF*	SQDF =	1.18	cfs
2-2. Enter the minimum linear unit application rate (0.005 cfs/ft), $q_{a,min}$	$q_{a,min}$=	0.005	cfs/ft
2-3. Calculate the minimum width of filter strip (ft), $W_{min}=SQDF/q_{a,min}$	W_{min}=	240	ft

Step 3: Calculate the Design Flow Depth

A slope of 3% was assumed for the filter strip (2-4% recommended). The design water depth should not exceed 1 inch. For this design example a manning's coefficient of 0.27 was used.

Step 3: Calculate the design flow depth	
3-1. Enter filter strip longitudinal slope, *s* (ft/ft)	s = 0.03 ft/ft
3-2. Enter Manning roughness coefficient (0.25-0.30), n_{wq}	n_{wq} = 0.27
3-3. Enter width of strip (=impervious surface contributing area perpendicular to flow), at least W_{min} (ft), *W*	W = 240 ft
3-4. Calculate average depth of water using Manning equation (inches), $d_f = 12 * [SQDF * n_{wq} / 1.49 W s^{0.5}]^{0.6}$	d_f = 0.51 in
3-5. If d_f > 1" (0.083 ft), go back step 3-1 and decrease the slope	
3-6. If the slope cannot be changed due to construction constraints, go to step 3-3 and increase the width perpendicular to flow.	

Step 4: Calculate the Design Velocity

The designed flow velocity should not exceed 1 foot/second across the filter strip.

Step 4: Calculate the design velocity	
4-1. Enter depth of water (ft), $d_{f,ft} = d_f / 12$	d_f = 0.043 ft
4-2. Enter width of strip (ft), *W*	W= 240 ft
4-3. Calculate design flow velocity (ft/s), $V_{wq} = SQDF/(d_{f,ft} W)$	V_{wq} = 0.11 ft/s
4-4. If the V_{wq} >1 ft/s, go back to step 3-1 and decrease the slope.	

Step 5: Calculate the Length of the Filter Strip

The filter strip should be at least 4 feet long (in the direction of flow) and accommodate a minimum residence time of 7 minutes to provide adequate water quality treatment.

Step 5: Calculate the length of the filter strip	
5-1. Enter desired residence time (minimum 10 minutes), *t*	t = 10 min
5-2. Enter design flow velocity (ft/s), V_{wq}	V_{wq}= 0.11 ft/s
5-3. Calculate length of the filter strip (ft), $L = 60tV_{wq}$	L = 66 ft
5-4. If $L < 4$ ft, go to step 3-1 and increase the slope	

E.8 TCM-1 Dry Extended Detention Basin

Sizing Methodology

Dry extended detention (ED) basins are basins designed such that the stormwater quality design volume, SQDV, is detained for 36 to 48 hours. This allows sediment particles and associated pollutants to settle and be removed from stormwater. Procedures for sizing extended detention basins are summarized below. A sizing example is also provided.

Step 1: Calculate the design volume

Dry extended detention facilities shall be sized to capture and treat the water quality design volume (see Section E.1).

Step 2: Calculate the volume of the active basin

The total basin volume shall be increased an ad ditional 20% of the stormwater quality design volume to account for sediment accumulation, at a minimum. If t he basin is designed only for water quality treatment then the basin volume would be 120% of the stormwater quality design volume, SQDV. Freeboard is in additional to the total basin volume. Calculate the volume of the active basin, V_a:

$$V_a = 1.20 * SQDV \quad \text{(Equation E-39)}$$

Step 3: Determine detention basin location and preliminary geometry based on site constraints

Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. The cross-sectional geometry across the width of the basin shall be approximately trapezoidal with a maximum side slope of 4:1 (H:V) on interior slopes and 3:1 (H:V) on exterior slopes unless specifically permitted by Ventura County (see Side Slopes below). Shallower side slopes are necessary if the basin is designed to have recreational uses during dry weather conditions.

1) Calculate the width of the basin footprint, W_{tot}, as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}} \quad \text{(Equation E-40)}$$

Where:

A_{tot} = total surface area of the basin footprint (ft^2)

L_{tot} = total length of the basin footprint (ft)

2) Calculate the length of the active volume surface area including the internal berm but excluding the freeboard, L_{av-tot}:

$$L_{av-tot} = L_{tot} - 2Zd_{fb} \quad \text{(Equation E-41)}$$

Where:

Z = interior side slope as length per unit height

d_{fb} = freeboard depth

3) Calculate the width of the active volume surface area including the internal berm but excluding freeboard, W_{av-tot}:

$$W_{av-tot} = W_{tot} - 2Zd_{fb} \quad \text{(Equation E-42)}$$

4) Calculate the total active volume surface area including the internal berm and excluding freeboard, A_{av-tot}:

$$A_{av-tot} = L_{av-tot} \times W_{av-tot} \quad \text{(Equation E-43)}$$

5) Calculate the area of the berm, A_{berm}:

$$A_{berm} = W_{berm} \times L_{berm} \quad \text{(Equation E-44)}$$

Where:

W_{berm} = width of the internal berm

L_{berm} = length of the internal berm

6) Calculate the surface area excluding the internal berm and freeboard, A_{av}:

$$A_{av} = A_{av=tot} - A_{berm} \quad \text{(Equation E-45)}$$

Step 4: Determine Dimensions of Forebay

5-15% of the basin active volume, V_a, is required to be within the active volume of the forebay.

1) Calculate the active volume of forebay, V_1:

$$V_1 = \frac{V_a \times \%V_1}{100} \quad \text{(Equation E-46)}$$

Where:

$\%V_1$ = percent of V_a in forebay (%)

V_a = active volume (ft^3)

2) Calculate the surface area for the active volume of forebay, A_1:

$$A_1 = \frac{V_1}{d_1} \quad \text{(Equation E-47)}$$

Where:

d_1 = average depth for the active volume of forebay (ft)

3) Calculate the length of forebay, L_1:

$$L_1 = \frac{A_1}{W_1} \quad \text{(Equation E-48)}$$

Where:

W_1 = width of forebay (ft)

Step 5: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

1) Calculate the active volume of Cell 2, V_2:

$$V_2 = V_a - V_1 \quad \text{(Equation E-49)}$$

Where:

V_a = total basin active volume (ft^3)

V_1 = volume of forebay (ft^3)

2) Calculate the surface area, A_2, for the active volume of Cell 2:

$$A_2 = A_{av} - A_1 \quad \text{(Equation E-50)}$$

Where:

A_{av} = basin surface area excluding berm and freeboard (ft^2)

A_1 = surface area of forebay (ft^2)

3) Calculate the average depth, d_2, for the active volume of Cell 2:

$$d_2 = \frac{V_2}{A_2} \quad \text{(Equation E-51)}$$

4) Calculate the length of Cell 2, L_2:

$$L_2 = \frac{A_2}{W_2}$$ (Equation E-52)

Where:

W_2 = width of Cell 2 (ft)

5) Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen. Calculate the length-to width, LW_{mid2}, ratio of Cell 2 at half of d_2 follows:

$$LW_{mid\,2} = \frac{L_{mid\,2}}{W_{mid\,2}}$$ (Equation E-53)

Where:

$W_{mid2} = W_2 - Zd_2$ and (Equation E-54)

$L_{mid2} = L_2 - Zd_2$ (Equation E-55)

W_{mid2} = width of Cell 2 at half of d_2 (ft)

L_{mid2} = length of Cell 2 at half of d_2 (ft)

Z = interior side slope as length per unit height (H:V)

Step 6: Ensure Design Requirements and Site Constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or alternative treatment BMP.

Step 7: Size Outlet Structure

The total drawdown time for the basin should be 36-48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 24-32 hours, and the top half (full to half-full) in 12-16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm. See Section 6 for outlet structure sizing methodologies.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter Project area (acres), $A_{project}$	A =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowed effective impervious area (ac), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1-imp)$	C =	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560 \bullet C*P*A_{retain}$	SQDV =	ft^3
Step 2: Calculate the volume of the active basin		
2-1. Calculate basin active volume (includes water quality design volume + sediment storage volume) (ft^3), $V_a = 1.20 \times SQDV$	V_a =	ft^3

Step 3: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints		
3-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.		
3-2. Enter the total surface area of the basin footprint based on site constraints (ft^2), A_{tot}	A_{tot} =	ft^2
3-3. Enter the length of the basin footprint based on site constraints (ft), L_{tot}	L_{tot} =	ft
3-4. Calculate the width of the basin footprint (L:W = 1.5:1 min) (ft), $W_{tot} = A_{tot} / L_{tot}$	W_{tot} =	ft
3-5. Enter interior side slope as length per unit height (H:V, min = 3), Z	Z =	
3-6. Enter desired freeboard depth (ft), d_{fb} (min: 2 ft on-line; 1 ft offline)	d_{fb} =	ft
3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ =	ft
3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ =	ft
3-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \times W_{av\text{-}tot}$	$A_{av\text{-}tot}$ =	ft^2
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	ft
3-11. Enter the length of the internal berm (ft), $L_{berm} = W_{av\text{-}tot}$	L_{berm} =	ft
3-12. Calculate the area of the berm (ft^2), $A_{berm} = W_{berm} \times L_{berm}$	A_{berm} =	ft^2
3-13. Calculate the surface area excluding the internal berm and freeboard (ft^2), $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} =	ft^2

Step 4: Determine Dimensions of forebay		
4-1. Enter the percent of V_a in forebay (5-15% required), *%V₁* → $\%V_1$	$\%V_1$ =	%
4-2. Calculate the active volume of forebay, $V_1 = (V_a \bullet \%V_1)/100$	V_1 =	ft^3
4-3. Enter a desired average depth for the active volume of forebay, d_1	d_1 =	ft
4-4. Calculate the surface area for the active volume of forebay, $A_1 = V_1 / d_1$	A_1 =	ft^2
4-5. Enter the width of forebay, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	ft
4-6. Calculate the length of forebay (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 =	ft
Step 5: Determine Dimensions of Cell 2		
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	ft^3
5-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$	A_2 =	ft^2
5-3. Calculate the average depth for the active volume of Cell 2, $d_2 = V_2 / A_2$	d_2 =	ft
5-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	ft
5-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	ft
5-6. Calculate the width of Cell 2 at half of d_2, $W_{mid2} = W_2 - Zd_2$	W_{mid2} =	ft
5-7. Calculate the length of Cell 2 at half of d_2, $L_{mid2} = L_2 - Zd_2$	L_{mid2} =	ft

5-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$	LW_{mid2} =
Step 6: Ensure Design Requirements and Site Constraints are Achieved	
6-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or alternative treatment BMP.	
Step 7: Size Outlet Structure	
7-1. The total drawdown time for the basin should be 36-48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 24-32 hours, and the top half (full to half-full) in 12-16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm. See Section 6 for outlet structure sizing methodologies.	
Step 8: Determine Emergency Spillway Requirements	
8-1. For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.	

Design Example

Step 1: Determine water quality design volume

For this design example, a 10-acre residential development with a 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter Project area (acres), $A_{project}$	A =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowed effective impervious area (ac), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area (acres), $TIA = A_{project} * Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain} = TIA - EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	0.75	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume (ft^3), $SQDV = 43560 \bullet C * P * A_{retain}$	SQDV =	8,500	ft^3

Step 2: Calculate Volume of the Active Basin and the Forebay Basin

Step 2: Calculate the design volume of the active basin	
2-1. Calculate basin active design volume (includes water quality design volume + sediment storage volume), $V_a = 1.20*SQDV$	V_a = 10,000 ft^3

Step 3: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints

The detention basin in this example has an internal berm separating the forebay (Cell 1) and the main basin (Cell 2). The internal berm elevation is 2 ft below the elevation of the SUSMP volume within the entire basin. The berm length is equal to the width of the basin when filled to the active design volume.

Step 3: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints	
3-1. Based on site constraints, determine the basin geometry and the storage available by developing an elevation-storage relationship for the basin. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.	
3-2. Enter the total surface area of the basin footprint based on site constraints, A_{tot}	A_{tot} = 8,000 ft^2
3-3. Enter the length of the basin footprint based on site constraints, L_{tot} (L:W = 1.5:1 min)	L_{tot} = 200 ft
3-4. Calculate the width of the basin footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = 40 ft
3-5. Enter interior side slope as length per unit height (min = 3), Z	Z = 3
3-6. Enter desired freeboard depth, d_{fb} (min: 2 ft on-line; 1 ft offline)	d_{fb} = 2 ft
3-7. Calculate the length of the active volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ = 188 ft

Step 3: Determine Detention Basin Location and Preliminary Geometry Based on Site Constraints			
3-8. Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ =	28	ft
3-9. Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \bullet W_{av\text{-}tot}$	$A_{av\text{-}tot}$ =	5,300	ft^2
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
3-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} =	28	ft
3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} =	170	ft^2
3-13. Calculate the surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} =	5,130	ft^2

Step 4: Calculate Dimensions of Cell 1

Calculate the dimensions of the forebay (Cell 1) based on the active design volume for Cell 1 (25% of V_a) and a desired average depth, d_1. The width of the forebay, W_1, is equivalent to the length of the berm, L_{berm}, and the width of Cell 2, W_2.

Step 4: Determine Dimensions of forebay			
4-1. Enter the percent of V_a in forebay (5-15% required), $\%V_1$	$\%V_1$ =	25	%
4-2. Calculate the active volume of forebay (including sediment storage), $V_1 = (V_a \bullet \%V_1)/100$	V_1 =	2,500	ft^3
4-3. Enter a desired average depth for the active volume of forebay, d_1	d_1 =	5	ft
4-4. Calculate the surface area for the active volume of forebay, $A_1 = V_1 / d_1$	A_1 =	500	ft^2

4-5. Enter the width of forebay, $W_1 = W_{wq\text{-}tot} = L_{berm}$	W_1 = 28 ft
4-6. Calculate the length of forebay (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 = 18 ft

Step 5: Calculate the Dimensions of Cell 2

Calculate the dimensions of the main basin (Cell 2) based on the active design volume for Cell 2 and a desired average depth, d_2. A calculation of the length, L_{mid2}, and width, W_{mid2}, at half basin depth, d_2, is conducted in order to verify that the length-to-width ratio at half d_2 is greater than 1.5:1.

Step 5: Calculate the dimensions of Cell 2			
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	7,500	ft^3
5-2. Calculate the surface area of the active volume of Cell 2, $A_2 = A_{av} - A_1$	A_2 =	4,630	ft^2
5-3. Calculate the average depth of the active volume of Cell 2, $d_2 = V_2 / A_2$	d_2 =	1.6	ft
5-4. Enter the width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	28	ft
5-5. Calculate the length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	166	ft
5-6. Calculate the width of Cell 2 at half of d_2, $W_{mid2} = W_2 - Zd_2$	W_{mid2} =	23	ft
5-7. Calculate the length of Cell 2 at half of d_2, $L_{mid2} = L_2 - Zd_2$	L_{mid2} =	161	ft
5-8. Verify that the length-to-width ratio of Cell 2 at half of d_2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the basin should be chosen, $LW_{mid2} = L_{mid2} / W_{mid2}$	LW_{mid2} =	7	

Step 6: Ensure Design Requirements and Site Constraints are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or an alternative treatment BMP.

Step 7: Size Outlet Structure

The total drawdown time for the basin should be 36-48 hours. The outlet structure shall be designed to release the bottom 50% of the detention volume (half-full to empty) over 24-32 hours, and the top half (full to half-full) in 12-16 hours. A primary overflow should be sized to pass the peak flow rate from the developed capital design storm. See Section 6 for outlet structure sizing methodologies.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

E.9 TCM-2 Wet Detention Basin

Sizing Methodology

Wet Detention basins may be designed with or without extended detention above the permanent pool. The extended detention portion of the wet detention basin above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin). If there is no extended detention provided, wet detention basins shall be sized to provide a minimum wet pool volume equal to the stormwater quality design volume plus an additional 5% for sediment accumulation. I f extended detention is provided above the permanent pool, the sizing is dependent of the functionality of the basin; the basin may function as water quality treatment only or water quality plus peak flow attenuation.

If and the basin is designed for water quality treatment only, then the permanent pool volume shall be a minimum of 10 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) shall make up the remaining 90 percent. If extended detention is provided above the permanent pool and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume shall be equal to the water quality treatment volume, and the surcharge volume shall be sized to attenuate peak flows in order to meet the peak runoff discharge requirements. The extended detention portion of the wet detention basin above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin).

Step 1: Calculate the design volume

Wet detention basins shall be sized with a permanent pool volume equal to the SQDV volume (see Section 2 and Appendix E).

Step 2: Determine the active design volume for the wet detention basin without extended detention

The active volume of the wet detention basin, V_a, shall be equal to the SQFV plus an additional 5% for sediment accumulation.

$$V_a = 1.05 \times SQDV \qquad \text{(Equation E-56)}$$

Step 3: Determine pond location and preliminary geometry based on site constraints

Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. Note that a more natural geometry may be used and is in many cases recommended; the preliminary basin geometry calculations should be used for sizing purposes only.

1) Calculate the width of the pond footprint, W_{tot}, as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}}$$ (Equation E-57)

Where:

A_{tot} = total surface area of the pond footprint (ft^2)

L_{tot} = total length of the pond footprint (ft)

7) Calculate the length of the active volume surface area including the internal berm but excluding the freeboard, $L_{av\text{-}tot}$:

$$L_{av-tot} = L_{tot} - 2Zd_{fb}$$ (Equation E-58)

Where:

Z = interior side slope as length per unit height

d_{fb} = freeboard depth

8) Calculate the width of the active volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot}$:

$$W_{av-tot} = W_{tot} - 2Zd_{fb}$$ (Equation E-59)

9) Calculate the total active volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot}$:

$$A_{av-tot} = L_{av-tot} \times W_{av-tot}$$ (Equation E-60)

10) Calculate the area of the berm, A_{berm}:

$$A_{berm} = W_{berm} \times L_{berm}$$ (Equation E-61)

Where:

W_{berm} = width of the internal berm

L_{berm} = length of the internal berm

11) Calculate the active volume surface area excluding the internal berm and freeboard, A_{wq}:

$$A_{wq} = A_{wq=tot} - A_{berm}$$ (Equation E-62)

Step 4: Determine Dimensions of Forebay

The wet detention basin shall be divided into two cells separated by a berm or baffle. The forebay shall contain between 5 and 10 percent of the total volume. The berm or baffle volume shall not count as part of the total volume. Calculate the active volume of forebay, V_1:

$$V_1 = \frac{V_a \times \%V_1}{100} \quad \text{(Equation E-63)}$$

Where:

$\%V_1$ = percent of SQDV in forebay (%)

1) Calculate the surface area for the active volume of forebay, A_1:

$$A_1 = \frac{V_1}{d_1} \quad \text{(Equation E-64)}$$

Where:

d_1 = average depth fo rhte active volume of forebay (ft)

2) Calculate the length of forebay, L_1. Note, inlet and outlet should be configured to maximize the residence time.

$$L_1 = \frac{A_1}{W_1} \quad \text{(Equation E-65)}$$

Where:

W_1 = width of forebay (ft), $W_1 = W_{av\text{-}tot} = L_{berm}$

Step 5: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

3) Calculate the active volume of Cell 2, V_2:

$$V_2 = V_a - V_1 \quad \text{(Equation E-66)}$$

4) The minimum wetpool surface area includes 0.3 acres of wetpool per acre-foot of permanent wetpool volume. Calculate A_{min2}:

$$A_{min2} = (V_2 \times 0.3\ \frac{acres}{acre-feet}) \quad \text{(Equation E-67)}$$

5) Calculate the actual wetpool surface area, A_2:

$$A_2 = A_{av} - A_1 \quad \text{(Equation E-68)}$$

Verify that A_2 is greater than A_{min2}. If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.

6) Calculate the top length of Cell 2, L_2:

$$L_2 = \frac{A_2}{W_2} \qquad \text{(Equation E-69)}$$

Where:

W_2 = width of Cell 2 (ft), $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$

7) Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen.

$$LW_2 = \frac{L_2}{W_2} \qquad \text{(Equation E-70)}$$

8) Calculate the emergent vegetation surface area, A_{ev}:

$$A_{ev} = \frac{A_2 \bullet \%A_{ev}}{100} \qquad \text{(Equation E-71)}$$

Where:

$\%A_{ev}$ = percent of surface area that will be planted with emergent vegetation

9) Calculate the volume of the emergent vegetation shallow zone (1.5 – 3 ft), V_{ev}:

$$V_{ev} = A_{ev} \bullet d_{ev} \qquad \text{(Equation E-72)}$$

Where:

d_{ev} = average depth of the emergent vegetation shallow zone (1.5 – 3 ft)

10) Calculate the length of the emergent vegetation shallow zone, L_{ev}:

$$L_{ev} = \frac{A_{ev}}{W_{ev}} \qquad \text{(Equation E-73)}$$

Where:

W_{ev} = width of the emergent vegetation shallow zone (ft), $W_{ev} = W_2$

11) Calculate the volume of the deep zone, V_{deep}:

$$V_{deep} = V_2 - V_{ev} \qquad \text{(Equation E-74)}$$

12) Calculate the surface area of the deep (>3 ft) zone, A_{deep}:

$$A_{deep} = A_2 - A_{ev} \quad \text{(Equation E-75)}$$

13) Calculate the average depth of the deep zone (4-8 ft), d_{deep}:

$$d_{deep} = \frac{V_{deep}}{A_{deep}} \quad \text{(Equation E-76)}$$

14) Calculate length of the deep zone, L_{deep}:

$$L_{deep} = \frac{A_{deep}}{W_{deep}} \quad \text{(Equation E-77)}$$

Where:

W_{deep} = width of the deep zone (ft), $W_{deep} = W_2$

Step 6: Ensure design requirements and site constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the BMP.

Step 7: Size Outlet Structure

For extended detention wet detention basin, outlet structures shall be designed to provide 12 to 48 hour emptying time for the water quality volume above the permanent pool.

The basin outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter drainage area, A	A =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowed effective impervious area, $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area, $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained, $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1-imp)$	C =	
1-9. Enter design rainfall depth of the storm, P_i (in)	P_i =	in
1-10. Calculate rainfall depth, $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume, $SQDV = 43560 \bullet P*A_{retain}*C$	SQDV =	ft^3
Step 2: Determine active design volume for the wet pond without extended detention		
2-1. Calculate the active design volume (without extended detention), $V_a = 1.05*SQDV$	V_a =	ft^3

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints	
3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.	
3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot}	A_{tot} = ft²
3-3. Enter the length of the pond footprint based on site constraints, L_{tot}	L_{tot} = ft
3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = ft
3-5. Enter interior side slope as length per unit height (min = 3), Z	Z =
3-6. Enter desired freeboard depth, d_{fb} (1 ft min)	d_{fb} = ft
3-7. Calculate the length of the water quality volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ = ft
3-8. Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ = ft
3-9. Calculate the total water quality volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \bullet W_{av\text{-}tot}$	$A_{av\text{-}tot}$ = ft²
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} = ft
3-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} = ft
3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} = ft²

3-13. Calculate the water quality volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} = ft^2
Step 4: Determine Dimensions of forebay	
4-1. Enter the percent of V_a in forebay (5-10% required), $\%V_1$	$\%V_1$ = %
4-2. Calculate the active volume of forebay (includes sediment storage volume), $V_1 = (V_a \bullet \%V_1)/100$	V_1 = ft^3
4-3. Enter desired average depth of forebay (5-9 ft including sediment storage of 1 ft), d_1	d_1 = ft
4-4. Calculate the surface area for the active volume of forebay, $A_1 = V_1 / d_1$	A_1 = ft^2
4-5. Enter the width of forebay, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 = ft
4-6. Calculate the length of forebay (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 = ft
Step 5: Determine Dimensions of Cell 2	
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 = ft^3
5-2. Determine minimum wetpool surface area, $A_{min2} = V_2 \bullet 0.3$	A_{min2} = ft^2
5-3. Determine actual wetpool surface area, $A_2 = A_{av} - A_1$	A_2 = ft^2
5-4. • If A_2 is greater than A_{min2} then move on to step 5-5. • If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.	
5-5. Enter width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 = ft

5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 = ft
5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =
5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), $\%A_{ev}$	$\%A_{ev}$ = %
5-9. Calculate emergent vegetation surface area, $A_{ev} = (A_2 \bullet \%A_{ev})/100$	A_{ev} = ft^2
5-10. Enter average depth of emergent vegetation shallow zone (1.5 – 3 ft), d_{ev}	d_{ev} = ft
5-11. Calculate volume of emergent vegetation shallow zone (1.5 – 3 ft), $V_{ev} = A_{ev} \bullet d_{ev}$	V_{ev} = ft^3
5-12. Enter width of emergent vegetation shallow zone, $W_{ev} = W_2$	W_{ev}= ft
5-13. Calculate length of emergent vegetation shallow zone, $L_{ev} = A_{ev} / W_{ev}$	L_{ev} = ft
5-14. Calculate volume of deep zone, $V_{deep} = V_2 - V_{ev}$	V_{deep} = ft^3
5-15. Calculate surface area of deep (>3 ft) zone, $A_{deep} = A_2 - A_{ev}$	A_{deep} = ft^2
5-16. Calculate average depth of deep zone (4 - 8 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} = ft
5-17. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} = ft
5-18. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	L_{deep} = ft

Step 6: Ensure Design Requirements and Site Constraints are Achieved
6-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the BMP.
Step 7: Size Outlet Structure
7-1. The basin outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.
Step 8: Determine Emergency Spillway Requirements
8-1. For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Design Example

Wet detention basin siting requires the following considerations prior to construction: (1) availability of base flow – wet detention basins require a regular source of water if water level is to be maintained, (2) surface space availability – large footprint area is required, and (3) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wet detention basin in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 20-acre residential development with a 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter drainage area, A	A =	20	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowed effective impervious area, $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	1.0	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area, $TIA=A_{project}*Imp$	TIA=	12	acres
1-6. Determine the total area from which runoff must be retained, $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	11	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm, P_i (in)	P_i =	0.75	in
1-10. Calculate rainfall depth, $P = P_i/12$	P =	0.06	ft

1-11. Calculate water quality design volume, *SQDV* = 43560•*P***A*$_{retain}$**C*	SQDV = 17,000 ft^3

Step 2: Determine Active Design Volume for a Wet Detention Basin without Extended Detention

If there is no extended detention provided, wet detention basins shall be sized to provide a minimum wet pool volume equal to the water quality design volume plus an additional 5% for sediment accumulation.

Step 2: Determine Active Design Volume for a Wet Detention Basin without Extended Detention	
2-1. Calculate the active design volume (without extended detention), $V_a = 1.05*SQDV$	V_a = 17,800 ft^3

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the basin is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints	
3-1. Based on site constraints, determine the pond geometry and the storage available by developing an elevation-storage relationship for the pond. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2.	
3-2. Enter the total surface area of the pond footprint based on site constraints, A_{tot}	A_{tot} = 7,500 ft^2
3-3. Enter the length of the pond footprint based on site constraints, L_{tot}	L_{tot} = 150 ft
3-4. Calculate the width of the pond footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = 50 ft
3-5. Enter interior side slope as length per unit height (min = 3), Z	Z = 3

Step 3: Determine Pond Location and Preliminary Geometry Based on Site Constraints			
3-6. Enter desired freeboard depth, d_{fb} (1 ft min)	d_{fb} =	2	ft
3-7. Calculate the length of the water quality volume surface area including the internal berm but excluding freeboard, $L_{av\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{av\text{-}tot}$ =	138	ft
3-8. Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, $W_{av\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{av\text{-}tot}$ =	38	ft
3-9. Calculate the total water quality volume surface area including the internal berm and excluding freeboard, $A_{av\text{-}tot} = L_{av\text{-}tot} \bullet W_{av\text{-}tot}$	$A_{av\text{-}tot}$ =	4,940	ft^2
3-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
3-11. Enter the length of the internal berm, $L_{berm} = W_{av\text{-}tot}$	L_{berm} =	38	ft
3-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} =	230	ft^2
3-13. Calculate the water quality volume surface area excluding the internal berm and freeboard, $A_{av} = A_{av\text{-}tot} - A_{berm}$	A_{av} =	4,710	ft^2

Step 4: Determine Dimensions of forebay

It should be assumed that the forebay should be 5-10% of the total active design volume, V_a.

Step 4: Determine Dimensions of Cell 1			
4-1. Enter the percent of V_a in forebay (5-10% required), $\%V_1$	$\%V_1$ =	20	%
4-2. Calculate the active volume of forebay (includes sediment storage volume), $V_1 = (V_a \bullet \%V_1)/100$	V_1 =	3,560	ft^3
4-3. Enter desired average depth of forebay (5-9 ft including sediment storage of 1 ft), d_1	d_1 =	8	ft

4-4. Calculate the surface area for the active volume of forebay, $A_1 = V_1 / d_1$	A_1 =	440	ft²
4-5. Enter the width of forebay, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	38	ft
4-6. Calculate the length of forebay (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 =	12	ft

Step 5: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths and surface areas for the emergent vegetation shallow zone and the deep zone.

Step 5: Determine Dimensions of Cell 2			
5-1. Calculate the active volume of Cell 2, $V_2 = V_a - V_1$	V_2 =	14,200	ft³
5-2. Determine minimum wetpool surface area, $A_{min2} = V_2 \bullet 0.3$	A_{min2} =	4,270	ft²
5-3. Determine actual wetpool surface area, $A_2 = A_{av} - A_1$	A_2 =	4,270	ft²
5-4. If A_2 is greater than A_{min2} then move on to step 5-5. If A_2 is less than A_{min2}, then modify input parameters to increase A_2 until it is greater than A_{min2}. If site constraints limit this criterion, then another site for the pond should be chosen.			
5-5. Enter width of Cell 2, $W_2 = W_1 = W_{av\text{-}tot} = L_{berm}$	W_2 =	38	ft
5-6. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	110	ft
5-7. Verify that the length-to-width ratio of Cell 2 is at least 1.5:1 with ≥ 2:1 preferred. If the length-to-width ratio is less than 1.5:1, modify input parameters until a ratio of at least 1.5:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	2.9	
5-8. Enter percent of surface area that will be planted with emergent vegetation (25-75%), $\%A_{ev}$	$\%A_{ev}$ =	25	%

Step 5: Determine Dimensions of Cell 2			
5-9. Calculate emergent vegetation surface area, $A_{ev} = (A_2 \bullet \%A_{ev})/100$	A_{ev} =	1,070	ft^2
5-10. Enter average depth of emergent vegetation shallow zone (1.5 – 3 ft), d_{ev}	d_{ev} =	2	ft
5-11. Calculate volume of emergent vegetation shallow zone (1.5 – 3 ft), $V_{ev} = A_{ev} \bullet d_{ev}$	V_{ev} =	2,130	ft^3
5-12. Enter width of emergent vegetation shallow zone, $W_{ev} = W_2$	W_{ev}=	38	ft
5-13. Calculate length of emergent vegetation shallow zone, $L_{ev} = A_{ev} / W_{ev}$	L_{ev} =	56	ft
5-14. Calculate volume of deep zone, $V_{deep} = V_2 - V_{ev}$	V_{deep} =	13,100	ft^3
5-15. Calculate surface area of deep (>3 ft) zone, $A_{deep} = A_2 - A_{ev}$	A_{deep} =	3,200	ft^2
5-16. Calculate average depth of deep zone (4 - 8 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} =	4.1	ft
5-17. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} =	28	ft
5-18. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	L_{deep} =	114	ft

Step 6: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location for the BMP.

Step 7: Size Outlet Structure

The basin outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Step 8: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the water quality design storm. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

E.10 TCM-3 Constructed Wetland

Sizing Methodology

In most cases, the constructed treatment wetland permanent pool shall be sized to be greater than or equal to the stormwater quality design volume. If extended detention is provided above the permanent pool and the wetland is designed for water quality treatment only, then the permanent pool volume shall be a minimum of 80 percent of the stormwater quality design volume and the surcharge volume (above the permanent pool) shall make up the remaining 20 percent and provide at least 12 hours of detention. If extended detention is provided and the basin is designed for water quality treatment and peak flow attenuation, then the permanent pool volume shall be equal to the water quality treatment volume and the surcharge volume shall be sized to attenuate peak flows to meet the peak runoff discharge requirements. The extended detention portion of the wetland above the permanent pool, if provided, functions like a dry extended detention (ED) basin (see VEG-5: Dry Extended Detention Basin).

Step 1: Calculate the design volume

Constructed wetlands shall be sized to be greater than or equal to the SQDV volume (see Section 2 and Appendix E).

Step 2: Determine the Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints

Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. T he equations provided below assume a trapezoidal geometry for cell 1 (Forebay) and cell 2, and assumes that the wetland does not have extended detention.

1) Calculate the width of the wetland footprint, W_{tot}, as follows:

$$W_{tot} = \frac{A_{tot}}{L_{tot}} \qquad \text{(Equation E-78)}$$

Where:

A_{tot} = total surface area of the wetland footprint (ft^2)

L_{tot} = total length of the wetland footprint (ft)

12) Calculate the length of the water quality volume surface area including the internal berm but excluding the freeboard, L_{wq-tot}:

$$L_{wq-tot} = L_{tot} - 2Zd_{fb} \qquad \text{(Equation E-79)}$$

Where:

Z = interior side slope as length per unit height

d_{fb} = freeboard depth

13) Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, W_{wq-tot}:

$$W_{wq-tot} = W_{tot} - 2Zd_{fb}$$ (Equation E-80)

14) Calculate the total water quality volume surface area including the internal berm and excluding freeboard, A_{wq-tot}:

$$A_{wq-tot} = L_{wq-tot} \times W_{wq-tot}$$ (Equation E-81)

15) Calculate the area of the berm, A_{berm}:

$$A_{berm} = W_{berm} \times L_{berm}$$ (Equation E-82)

Where:

W_{berm} = width of the internal berm

L_{berm} = length of the internal berm

16) Calculate the water quality surface area excluding the internal berm and freeboard, A_{wq}:

$$A_{wq} = A_{wq=tot} - A_{berm}$$ (Equation E-83)

Step 3: Determine Dimensions of Forebay

30-50% of the SQDV is required to be within the active volume of forebay.

1) Calculate the active volume of forebay, V_1:

$$V_1 = \frac{SQDV \times \%V_1}{100}$$ (Equation E-84)

Where:

$\%V_1$ = percent of SQDV in forebay (%)

2) Calculate the surface area for the active volume of forebay, A_1:

$$A_1 = \frac{V_1}{d_1}$$ (Equation E-85)

Where:

d_1 = average depth fo rhte active volume of forebay (2 -4 ft) (ft)

3) Calculate the length of forebay, L_1. Note, inlet and outlet should be configured to maximize the residence time.

$$L_1 = \frac{A_1}{W_1} \quad \text{(Equation E-86)}$$

Where:

W_1 = width of forebay (ft), $W_1 = W_{av\text{-}tot} = L_{berm}$

Step 4: Determine Dimensions of Cell 2

Cell 2 will consist of the remainder of the basin's active volume.

1) Calculate the active volume of Cell 2, V_2:

$$V_2 = SQDV - V_1 \quad \text{(Equation E-87)}$$

2) Calculate the surface area of Cell 2, A_2:

$$A_2 = A_{wq} - A_1 \quad \text{(Equation E-88)}$$

3) Calculate the top length of Cell 2, L_2:

$$L_2 = \frac{A_2}{W_2} \quad \text{(Equation E-89)}$$

Where:

W_2 = width of Cell 2 (ft), $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$

4) Verify that the length-to-width ratio of Cell 2, LW_2, is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen.

$$LW_2 = \frac{L_2}{W_2} \quad \text{(Equation E-90)}$$

5) Calculate the very shallow zone surface area, A_{vs}:

$$A_{vs} = \frac{A_2 \bullet \%A_{vs}}{100} \quad \text{(Equation E-91)}$$

Where:

$\%A_{vs}$ = percent of surface area of very shallow zone

6) Calculate the volume of the shallow zone, V_{vs}:

$$V_{vs} = A_{vs} \bullet d_{vs}$$ (Equation E-92)

Where:

d_{vs} = average depth of the very shallow zone (0.1 – 1 ft)

7) Calculate the length of the very shallow zone, L_{vs}:

$$L_{vs} = \frac{A_{vs}}{W_{vs}}$$ (Equation E-93)

Where:

W_{vs} = width of the very shallow zone (ft), $W_{vs} = W_2$

8) Calculate the surface area of the shallow zone, A_s:

$$A_s = \frac{A_2 \bullet \%A_s}{100}$$ (Equation E-94)

Where:

$\%A_s$ = percent of surface area of shallow zone

9) Calculate the volume of the shallow zone, V_s:

$$V_s = A_s \bullet d_s$$ (Equation E-95)

Where:

d_s = average depth of shallow zone (1 - 3 ft)

10) Calculate length of the shallow zone, L_s:

$$L_s = \frac{A_s}{W_s}$$ (Equation E-96)

Where:

W_s = width of the shallow zone (ft), $W_s = W_2$

11) Calculate the surface area of the deep zone, A_{deep}:

$$A_{deep} = A_2 - A_{vs} - A_s$$ (Equation E-97)

12) Calculate the volume of the deep zone, V_{deep}:

$$V_{deep} = V_2 - V_{vs} - V_s$$ (Equation E-98)

13) Calculate the average depth of the deep zone (3-5 ft), d_{deep}:

$$d_{deep} = \frac{V_{deep}}{A_{deep}}$$ (Equation E-99)

14) Calculate length of the deep zone, L_{deep}:

$$L_{deep} = \frac{A_{deep}}{W_{deep}}$$ (Equation E-100)

Where:

W_{deep} = width of the deep zone (ft), $W_{deep} = W_2$

Step 5: Ensure design requirements and site constraints are achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the basin is inadequate to meet the design requirements, choose a new location or alternative treatment BMP.

Step 6: Size Outlet Structure

For wetlands with detention, the outlet structures shall be designed to provide 12 hours emptying time for the water quality volume or the required detention necessary for achieving the peak runoff discharge requirements if the extended detention is designed for flow attenuation.

The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for on-line basins or flows greater than the peak runoff discharge rate for the 100-year, 24-hr design storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point. For sites where the emergency spillway discharges to a steep slope, an emergency overflow riser, in addition to the spillway should be provided.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter drainage area, A	A =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowed effective impervious area, $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area, $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained, $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\ (1-imp)$	C =	
1-9. Enter design rainfall depth of the storm, P_i (in)	P_i =	in
1-10. Calculate rainfall depth, $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume, $SQDV = 43560 \bullet P*A_{retain}*C$	SQDV =	ft^3
Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints		
2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention.		

2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot}	A_{tot} = ft²
2-3. Enter the length of the wetland footprint based on site constraints, L_{tot}	L_{tot} = ft
2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = ft
2-5. Enter interior side slope as length per unit height (min = 3), Z	Z =
2-6. Enter desired freeboard depth, d_{fb}	d_{fb} = ft
2-7. Calculate the length of the water quality volume surface area including the internal berm but excluding freeboard, $L_{wq\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{wq\text{-}tot}$ = ft
2-8. Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, $W_{wq\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{wq\text{-}tot}$ = ft
2-9. Calculate the total water quality volume surface area including the internal berm and excluding freeboard, $A_{wq\text{-}tot} = L_{wq\text{-}tot} \bullet W_{wq\text{-}tot}$	$A_{wq\text{-}tot}$ = ft²
2-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} = ft
2-11. Enter the length of the internal berm, $L_{berm} = W_{wq\text{-}tot}$	L_{berm} = ft
2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} = ft²
2-13. Calculate the water quality volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq\text{-}tot} - A_{berm}$	A_{wq} = ft²
Step 3: Determine Dimensions of forebay	
3-1. Enter the percent of SQDV in forebay (30-50% required), $\%V_1$	$\%V_1$ = %
3-2. Calculate the active volume of forebay (includes water quality volume + sediment storage volume),	V_1 = ft³

$V_1 = (SQDV \bullet \%V_1) / 100$		
3-3. Enter desired average depth of forebay1 (2-4 ft including sediment storage of 1 ft), d_1	$d_1 =$	ft
3-4. Calculate the surface area for the water quality volume of forebay, $A_1 = V_1 / d_1$	$A_1 =$	ft^2
3-5. Enter the width of forebay, $W_1 = W_{av\text{-}tot} = L_{berm}$	$W_1 =$	ft
3-6. Calculate the length of forebay (Note: inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	$L_1 =$	ft
Step 4: Determine Dimensions of Cell 2		
4-1. Calculate the active volume of Cell 2, $V_2 = SQDV - V_1$	$V_2 =$	ft^3
4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$	$A_2 =$	ft^2
4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$	$W_2 =$	ft
4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	$L_2 =$	ft
4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	$LW_2 =$	
4-6. Enter percent of surface area of very shallow zone, $\%A_{vs}$	$\%A_{vs} =$	%
4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \bullet \%A_{vs})/100$	$A_{vs} =$	ft^2
4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs}	$d_{vs} =$	ft
4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \bullet d_{vs}$	$V_{vs} =$	ft^3
4-10. Enter width of very shallow zone, $W_{vs} = W_2$	$W_{vs} =$	ft

4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$	L_{vs} = ft
4-12. Enter percent of surface area of shallow zone, $\%A_s$	$\%A_s$ = %
4-13. Calculate surface area of shallow zone, $A_s = (A_2 \bullet \%A_s)/100$	A_s = ft²
4-14. Enter average depth of shallow zone (1 - 3 ft), d_s	d_s = ft
4-15. Calculate volume of shallow zone, $V_s = A_s \bullet d_s$	V_s = ft³
4-16. Enter width of shallow zone, $W_s = W_2$	W_s = ft
4-17. Calculate length of shallow zone, $L_s = A_s / W_s$	L_s = ft
4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$	A_{deep} = ft²
4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$	V_{deep} = ft³
4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} = ft
4-21. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} = ft
4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	L_{deep} = ft
Step 5: Ensure Design Requirements and Site Constraints are Achieved	
5-1. Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland or select an alternative treatment BMP.	

Step 6: Size Outlet Structure
6-1. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flow from the capital storm for on-line basins.
Step 7: Determine Emergency Spillway Requirements
7-1. For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point.

Design Example

Wetland siting requires the following considerations prior to construction: (1) availability of base flow – stormwater wetlands require a regular source of water to support wetland biota, (2) slope stability – stormwater wetlands are not permitted near steep slope hazard areas, (3) surface space availability – large footprint area is required, and (4) compatibility with flood control – basins must not interfere with flood control functions of existing conveyance and detention structures.

The wetland in this example does not have extended detention. An internal berm separates the forebay (Cell 1) and the main basin (Cell 2). The berm is at the elevation of the active volume (SQDV plus sediment storage volume) design surface which is also the permanent wetpool elevation.

Step 1: Determine Water Quality Design Volume

For this design example, a 20-acre residential development with a 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter drainage area, A	A =	20	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowed effective impervious area, $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	1.0	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. Determine the Project Total Impervious area, $TIA=A_{project}*Imp$	TIA=	12	acres
1-6. Determine the total area from which runoff must be retained, $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	11	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1\text{-}imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm, P_i (in)	P_i =	0.75	in

1-10. Calculate rainfall depth, $P = P_i/12$	P = 0.06 ft
1-11. Calculate water quality design volume, $SQDV = 43560 \cdot P * A_{retain} * C$	SQDV = 17,000 ft^3

Step 2: Determine Pond Location and Preliminary Geometry Based on Site Constraints

A total footprint area and total length available for the wetland is provided. This step calculates the total active volume surface area which is equivalent to the permanent wetpool surface area. This step also calculates the dimensions of the internal berm.

Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints	
2-1. Based on site constraints, determine the wetland geometry and the storage available by developing an elevation-storage relationship for the wetland. For this simple example, assume a trapezoidal geometry for cell 1 (forebay) and cell 2. The wetland does not have extended detention.	
2-2. Enter the total surface area of the wetland footprint based on site constraints, A_{tot}	A_{tot} = 7,500 ft^2
2-3. Enter the length of the wetland footprint based on site constraints, L_{tot}	L_{tot} = 200 ft
2-4. Calculate the width of the wetland footprint, $W_{tot} = A_{tot} / L_{tot}$	W_{tot} = 38 ft
2-5. Enter interior side slope as length per unit height (min = 3), Z	Z = 3
2-6. Enter desired freeboard depth, d_{fb}	d_{fb} = 2 ft
2-7. Calculate the length of the water quality volume surface area including the internal berm but excluding freeboard, $L_{wq\text{-}tot} = L_{tot} - 2Zd_{fb}$	$L_{wq\text{-}tot}$ = 188 ft
2-8. Calculate the width of the water quality volume surface area including the internal berm but excluding freeboard, $W_{wq\text{-}tot} = W_{tot} - 2Zd_{fb}$	$W_{wq\text{-}tot}$ = 26 ft

Step 2: Determine Wetland Location, Wetland Type and Preliminary Geometry Based on Site Constraints			
2-9. Calculate the total water quality volume surface area including the internal berm and excluding freeboard, $A_{wq\text{-}tot} = L_{wq\text{-}tot} \bullet W_{wq\text{-}tot}$	$A_{wq\text{-}tot}$ =	4,900	ft^2
2-10. Enter the width of the internal berm (6 ft min), W_{berm}	W_{berm} =	6	ft
2-11. Enter the length of the internal berm, $L_{berm} = W_{wq\text{-}tot}$	L_{berm} =	26	ft
2-12. Calculate the area of the berm, $A_{berm} = W_{berm} \bullet L_{berm}$	A_{berm} =	160	ft^2
2-13. Calculate the active volume surface area excluding the internal berm and freeboard, $A_{wq} = A_{wq\text{-}tot} - A_{berm}$	A_{wq} =	4,740	ft^2

Step 3: Determine Dimensions of Forebay

It should be assumed that the forebay should be 30-50% of the SQDV.

Step 3: Determine Dimensions of forebay			
3-1. Enter the percent of SQDV in forebay (30-50% required), $\%V_1$	$\%V_1$ =	30	%
3-2. Calculate the active volume of forebay (including sediment storage), $V_1 = (SQDV \bullet \%V_1)/100$	V_1 =	5,100	ft^3
3-3. Enter desired average depth of forebay (2-4 ft including sediment storage of 1 ft), d_1	d_1 =	4	ft
3-4. Calculate the surface area for the water quality volume of forebay, $A_1 = V_1 / d_1$	A_1 =	1,275	ft^2
3-5. Enter the width of forebay, $W_1 = W_{av\text{-}tot} = L_{berm}$	W_1 =	38	ft
3-6. Calculate the length of forebay (<u>Note:</u> inlet and outlet should be configured to maximize the residence time), $L_1 = A_1 / W1$	L_1 =	34	ft

Step 4: Determine Dimensions of Cell 2

Verify that the surface area and length-to-width ratio of Cell 2 meet the design criteria. Calculate volumes, depths and surface areas for the very shallow, shallow and deep zones.

Step 4: Determine Dimensions of Cell 2			
4-1. Calculate the active volume of Cell 2, V_2 = SQDV - V_1	V_2 =	11,900	ft^3
4-2. Calculate surface area of Cell 2, $A_2 = A_{wq} - A_1$	A_2 =	3,460	ft^2
4-3. Enter width of Cell 2, $W_2 = W_1 = W_{wq\text{-}tot} = L_{berm}$	W_2 =	26	ft
4-4. Calculate top length of Cell 2, $L_2 = A_2 / W_2$	L_2 =	130	ft
4-5. Verify that the length-to-width ratio of Cell 2 is at least 3:1 with ≥ 4:1 preferred. If the length-to-width ratio is less than 3:1, modify input parameters until a ratio of at least 3:1 is achieved. If the input parameters cannot be modified as a result of site constraints, another site for the pond should be chosen, $LW_2 = L_2 / W_2$	LW_2 =	5	
4-6. Enter percent of surface area of very shallow zone, $\%A_{vs}$	$\%A_{vs}$ =	15	ft^2
4-7. Calculate very shallow zone surface area, $A_{vs} = (A_2 \bullet \%A_{vs})/100$	A_{vs} =	520	ft^2
4-8. Enter average depth of very shallow zone (0.1 - 1 ft), d_{vs}	d_{vs} =	1	ft
4-9. Calculate volume of very shallow zone, $V_{vs} = A_{vs} \bullet d_{vs}$	V_{vs} =	520	ft^3
4-10. Enter width of very shallow zone, $W_{vs} = W_2$	W_{vs} =	26	ft
4-11. Calculate length of very shallow zone, $L_{vs} = A_{vs} / W_{vs}$	L_{vs} =	20	ft
4-12. Enter percent of surface area of shallow zone, $\%A_s$	$\%A_s$ =	55	
4-13. Calculate surface area of shallow zone, $A_s = (A_2 \bullet \%A_s)/100$	A_s =	1,900	ft^2
4-14. Enter average depth of shallow zone (1 - 3 ft), d_s	d_s =	3	ft
4-15. Calculate volume of shallow zone, $V_s = A_s \bullet d_s$	V_s =	5,700	ft^3
4-16. Enter width of shallow zone, $W_s = W_2$	W_s =	26	ft
4-17. Calculate length of shallow zone, $L_s = A_s / W_s$	L_s =	220	ft

Step 4: Determine Dimensions of Cell 2			
4-18. Calculate surface area of deep zone, $A_{deep} = A_2 - A_{vs} - A_s$	A_{deep} =	1,040	ft^2
4-19. Calculate volume of deep zone, $V_{deep} = V_2 - V_{vs} - V_s$	V_{deep} =	5,680	ft^3
4-20. Calculate average depth of deep zone (3 - 5 ft), $d_{deep} = V_{deep} / A_{deep}$	d_{deep} =	5	ft
4-21. Enter width of deep zone, $W_{deep} = W_2$	W_{deep} =	26	ft
4-22. Calculate length of deep zone, $L_{deep} = A_{deep} / W_{deeo}$	L_{deep} =	40	ft

Step 5: Ensure Design Requirements and Site Conditions are Achieved

Check design requirements and site constraints. Modify design geometry until requirements are met. If the chosen site for the wetland is inadequate to meet the design requirements, choose a new location for the wetland or select an alternative treatment BMP.

Step 6: Size Outlet Structure

6-1. The wetland outlet pipe shall be sized, at a minimum, to pass flows greater than the stormwater quality design peak flow for off-line basins or flow from the capital storm for on-line basins.

Step 7: Determine Emergency Spillway Requirements

For online basins, an emergency overflow spillway should be sized to pass flows greater than the design peak runoff discharge rate for the 100-yr, 24-hr storm in order to prevent overtopping of the walls or berms in the event that a blockage of the riser occurs. For offline basins, an emergency spillway or riser should be sized to pass the 100-yr, 24-hr post-development peak storm water runoff discharge rate directly to the downstream conveyance system or another acceptable discharge point.

E.11 TCM-4 Sand Filters

Sizing Methodology

A sand filter is designed with two parts: (1) a temporary storage reservoir to store runoff, and (2) a sand filter bed through which the stored runoff must percolate. Usually the storage reservoir is simply placed directly above the filter, and the floor of the reservoir pond is the top of the sand bed. For this case, the storage volume also determines the hydraulic head over the filter surface, which increases the rate of flow through the sand.

Two methods are available for sizing sand filters: a simple method and a routing modeling method. The simple method uses standard values to define filter hydraulic characteristics for determining the sand surface area. Th is method is useful for planning purposes, for a first approximation to begin iterations in the detailed method, or when use of the detailed computer model is not desired or not available. The simple method very often results in a larger filter than the routing method.

Background

Sand filter design is based on Darcy's law:

$$Q = KiA \qquad \text{(Equation E-101)}$$

Where:

Q	=	water quality design flow (cfs)
K	=	hydraulic conductivity (fps)
A	=	surface area perpendicular to the direction of flow (ft^2)
i	=	hydraulic gradient (ft/ft) for a constant head and constant media depth, computed as follows:

$$i = \frac{h+l}{l} \qquad \text{(Equation E-102)}$$

Where:

h	=	average depth of water above the filter (ft), defined for this design as $d/2$
d	=	maximum storage depth above the filter (ft)
l	=	thickness of sand media (ft)

Darcy's law underlies both the simple and the routing methods of design. T he filtration rate V, or more correctly, $1/V$, is the direct input in the sand filter design. The relationship between the filtration rate V and hydraulic conductivity K is revealed by equating Darcy's law and the equation of continuity, $Q = VA$. Specifically:

$Q = KiA$ and $Q = VA$

So, $VA = KiA$

Or: $V = Ki$ (Equation E-103)

Where,

V = filtration rate (ft/s)

Note that $V \neq K$. That is, the filtration rate is not the same as the hydraulic conductivity, but they do have the same units (distance per time). K can be equated to V by dividing V by the hydraulic gradient i, which is defined above.

The hydraulic conductivity K does not change with head nor is it dependent on the thickness of the media, only on the characteristics of the media and the fluid. A design hydraulic conductivity of 1 inch per hour (2 feet per day) used in this simple sizing method is based on bench-scale tests of conditioned rather than clean sand (KCSWDM, 2005) and represents the average sand bed condition as silt is captured and held in the sand bed.

Unlike the hydraulic conductivity, the filtration rate V changes with head and media thickness, although the media thickness is constant in the sand filter design.

Simple Sizing Method

The simple sizing method does not route flows through the filter. It determines the size of the filter based on the simple assumption that inflow is immediately discharged through the filter as if there were no storage volume. An adjustment factor (0.7) is applied to compensate for the greater filter size resulting from this method. Even with the adjustment factor, the simple method generally produces a larger filter size than the routing method.

Step 1: Determine the water quality design volume

Sand filters should be sized to capture and treat the stormwater quality design volume (see Section E.1).

Step 2: Determine maximum storage depth of water

Determine the maximum water storage depth (d) above the sand filter. This depth is defined as the depth at which water begins to overflow the reservoir pond, and it depends on the site topography and hydraulic constraints. The depth is chosen by the designer, but shall be 6 feet or less.

Step 3: Calculate the sand filter area

Determine the sand filter area using the following equation:

$$A_{sf} = \frac{V_{wq} RL}{Kt(h+L)} \quad \text{(Equation E-104)}$$

Where,

A_{sf}	=	surface area of the sand filter bed (ft^2)
V_{wq}	=	water quality design volume (ft^3)
R	=	routing adjustment factor (use R = 0.7)
L	=	sand bed depth (ft)
K	=	design hydraulic conductivity (use 2 ft/day)
t	=	drawdown time (use 1 day)
h	=	average depth of water above the filter (ft), (use $d/2$ with d from Step 1)

Routing Method

A continuous runoff model, such as US EPA's Storm Water Management Model (SWMM) Model, can be used to optimally size a sand filter. A continuous simulation model consists of three components: a representative long term period of rainfall data (≈ 20 years or greater) as the primary model input; a model component representing the tributary area to the sand filter that takes into account the amount of impervious area, soil types of the pervious area, vegetation, evapotranspiration, etc.; and a component that simulates the sand filter. Using this method, the filter should be sized to capture and treat the WQ design volume from the post-development tributary area.

The continuous simulation model routes predicted tributary runoff to the sand filter, where treatment is simulated as a function of the infiltrative (flow) capacity of the sand filter and the available storage volume above the sand filter. In a continuous runoff model such as SWMM, the physical parameters of the sand filter are represented with stage-storage-discharge relationships. Due to the computational power of ordinary desktop computers, long-term continuous simulations generally take only minutes to run. This allows the modeler to run several simulations for a range of sand filter sizes, varying either the surface area of the filter (and resulting flow capacity) or the storage capacity above the sand filter, or both. Sufficient continuous model simulations should be completed so that results encompass the WQ design volume capture goal.

Model results should be plotted for both varying storage depths above the filter and for varying filter surface area (and resulting flow capacity) while keeping all other parameters constant. The resulting relationship of percent capture as a function of sand filter flow and storage capacity can be used to optimally size a sand filter based on site conditions and restraints.

In addition to continuous simulation modeling, routing spreadsheets and/or other forms of routing modeling that incorporate rainfall-runoff relationships and infiltrative (flow) capacities of sand filters may be used to size facilities. Alternative sizing methodologies should be prepared with good engineering practices.

Sizing Worksheet

Step 1: Determine water quality design volume		
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	%
1-3. Determine the maximum allowed effective impervious area (ac), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	
1-5. Determine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p\,(1-imp)$	C =	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	ft
1-11. Calculate water quality design volume (ft^3), $SQDV=43560\bullet C*P*A_{retain}$	SQDV=	ac-ft
Step 2: Determine maximum storage depth of water		
2-1. Determine the maximum storage depth (max 6 ft) of water above the sand filter, *d* (ft)	*d* =	ft

Step 3: Calculate sand filter area		
3-1. Enter water quality design volume, *SQDV*	SQDV =	ft^3
3-2. Enter routing adjustment factor (use R =0.7), R	R =	
3-3. Enter thickness of sand filter (min. 2 ft, 3 ft preferred), L	L =	ft
3-4. Enter design hydraulic conductivity of media (use 2 ft/day), K_{des}	K =	ft/day
3-5. Enter drawdown time, t	t =	day
3-6. Calculate average depth of water above the filter, $h = d/2$	h =	ft
3-7. Calculate sand filter area, $A_{sf} = (SQDV*RL)/(Kt\ (h+L))$	A_{sf} =	ft^2
Step 4: Determine filter dimensions		
4-1. Sand filter area, A_{sf}	A_{sf} =	ft^2
4-2. Enter geometric configuration, LR:W ratio (2:1 or greater), L_R	L_R =	
4-3. Select the width of the sand filter, W	W =	ft
4-4. Calculate the length of the sand filter, $L=WL_R$	L =	ft
4-5. Calculate rate of filtration, $r_{wq} = K_i$; where $i = \frac{h+l}{l}$	r_{wq} =	ft/d
Step 5: Calculate filter longitudinal underdrain collection pipe		
5-1. Calculated filtered flow rate, $Q_f = r_{wq}A_{sf}/86400$	Q_f =	cfs
5-2. Enter minimum slope for energy gradient, S_e	S_e =	

5-3. Enter Hazen-Williams coefficient for plastic, *C*	C =
5-4. Enter pipe diameter (6” min.), *D*	D = in
5-5. Calculate pipe hydraulic radius, $R_h = D/48$	R_h = ft
5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h0.63S_e0.54$	V_p = ft/s
5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$	Q_{cap} = cfs
Step 7: Provide conveyance capacity for filter clogging	
7-1. The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged.	

Design Example

Step 1: Determine water quality design volume

For this design example, a 10-acre site with soil type 4 and 60% total impervious area is considered. The 85th percentile storm event for the project location is 0.75 inches.

Step 1: Determine water quality design volume			
1-1. Enter Project area (acres), $A_{project}$	$A_{project}$ =	10	acres
1-2. Enter the maximum allowable percent of the Project area that may be effective impervious area (refer to permit), ranges from 5-30%, $\%_{allowable}$	$\%_{allowable}$ =	5	
1-3. Determine the maximum allowed effective impervious area (ac), $EIA_{allowable} = (A_{project})*(\%_{allowable})$	$EIA_{allowable}$=	0.5	acres
1-4. Enter Project impervious fraction, *Imp* (e.g. 60% = 0.60)	Imp=	0.6	
1-5. D etermine the Project Total Impervious area (acres), $TIA=A_{project}*Imp$	TIA=	6	acres
1-6. Determine the total area from which runoff must be retained (acres), $A_{retain}=TIA-EIA_{allowable}$	A_{retain} =	5.5	acres
1-7. Determine pervious runoff coefficient using Table E-1, C_p	C_p =	0.05	
1-8. Calculate runoff coefficient, $C = 0.95*imp + C_p (1-imp)$	C =	0.59	
1-9. Enter design rainfall depth of the storm (in), P_i	P_i =	0.75	in
1-10. Calculate rainfall depth (ft), $P = P_i/12$	P =	0.06	ft
1-11. Calculate water quality design volume (ft3), $SQDV=43560 \bullet C*P*A_{retain}$	SQDV=	0.20	ac-ft

Step 1a: Determine maximum storage depth of water

Determine the maximum storage depth of water above the sand filter.

Step 1a: Determine maximum storage depth of water			
1a-1. Determine the maximum storage depth (max 6 ft) of water above the sand filter, *d* (ft)	*d* =	6	ft

Step 2: Calculate Sand Filter Area

A sand filter is designed with two components: (1) temporary storage reservoir to store runoff, and (2) a sand filter bed through which the stored runoff must percolate getting treatment.

The simple sizing method does not rout flows through the filter. The size of the filter is determined based on the simple assumption that inflow is immediately discharged through the filter. The adjustment factor, R, is applied to compensate for the greater filter size resulting from this method.

Step 2: Calculate sand filter area			
2-1. Enter water quality design volume, *SQDV*	SQDV =	0.20	ac-ft
2-2. Enter routing adjustment factor (use R =0.7), *R*	*R* =	0.7	
2-3. Enter thickness of sand filter (min. 2 ft, 3 ft preferred), *L*	*L* =	2	ft
2-4. Enter design hydraulic conductivity (use 2 ft/day), *K*	*K* =	2	ft/day
2-5. Enter drawdown time (use 1 day), *t*	*t* =	2	day
2-6. Calculate average depth of water above the filter, $h = d/2$	h =	3	ft
2-7. Calculate sand filter area, $A_{sf} = (SQDV*RL)/(Kt\,(h+L))$	A_{sf} =	0.014	acre

Step 3: Determine Filter Dimensions

Step 3: Determine filter dimensions			
3-1. Sand filter area in ft², $A_{sf(feet)}=A_{sf(acre)}*43{,}560$	A_{sf} =	610	ft²
3-2. Enter geometric configuration, LR:W ratio (2:1 min.), L_R	L_R =	2	
3-3. Calculate the width of the sand filter, *W*	W =	18	ft

Step 3: Determine filter dimensions			
3-4. Calculate the length of the sand filter, L	$L =$	36	ft
3-5. Calculate rate of filtration, $r_{wq} = Ki$, where $i = \frac{h+l}{l}$	$r_{wq} =$	2.3	ft/d

Step 4: Calculate Filter Longitudinal Underdrain Collection Pipe

All underdrain pipes must be 6 inches or greater to facilitate cleaning.

Step 5: Calculate filter longitudinal underdrain collection pipe			
5-1. Calculated filtered flow rate, $Q_f = r_{wq}A_{sf}/86400$	$Q_f =$	0.01	cfs
5-2. Enter minimum slope for energy gradient, Se	$S_e =$	0.005	
5-3. Enter Hazen-Williams coefficient for plastic, C	$C =$	140	
5-4. Enter pipe diameter (6" min), D	$D =$	6	in
5-5. Calculate pipe hydraulic radius, $R_h = D/48$	$R_h =$	0.13	
5-6. Calculate velocity at the outlet of the pipe, $V_p = 1.318CR_h^{0.63}S_e^{0.54}$	$V_p =$	2.9	ft/s
5-7. Calculate pipe capacity, $Q_{cap} = 0.25\pi(D/12)^2V_p$	$Q_{cap} =$	0.57	cfs

Step 5: Provide Conveyance Capacity for Filter Clogging

The sand filters should be placed off-line, but an emergency overflow must still be provided in the event the filter becomes clogged.

APPENDIX F : FLOW SPLITTER DESIGN SPECIFICATIONS

F.1 Flow Splitter Introduction

Flow splitters must be provided for off-line facilities to divert the water quality design flow to the BMP and bypass higher flows. In most cases, it is a designer's choice whether storm water treatment BMPs described in this manual are designed as on-line or off-line; exceptions are vegetated strip filters, permeable pavement, and building BMPs which are designed on-line.

A crucial factor in designing flow splitters is to ensure that low flows are delivered to the treatment facility up to the water quality design flow rate. Above this rate, additional flows remain in the storm drain or are diverted to a bypass drain with minimal increase in head at the flow splitter structure to avoid surcharging the water quality facility under high flow conditions.

Flow splitters are typically manholes or vaults with baffles. In place of baffles, the splitter mechanism may be a half tee section with a solid top and an orifice in the bottom of the tee section. A full tee option may also be used (see "Design Criteria" below). Two possible design options for flow splitters are shown in the figures in this Appendix. Other equivalent designs that achieve the result of splitting low flows, up to the WQ design flow, into the WQ treatment facility and divert higher flows around the facility are also acceptable.

Flow splitters may be modeled using standard level pool routing techniques, as described in the Handbook of Applied Hydrology (Ven te Chow; 1964) and elsewhere. The stage/discharge relationship of the outflow pipes shall be determined using backwater analysis techniques. Weirs shall be analyzed as sharp-crested weirs.

Design Criteria

1) A flow splitter shall be designed to deliver the required water quality design flow rate to the storm water treatment facility.

17) The top of the weir shall be located at the water surface for the design flow. Remaining flows enter the bypass line.

18) The maximum head shall be minimized for flow in excess of the water quality design flow. Specifically, flow to the treatment facility at the flood control design storm water surface shall not increase the design water quality design flow by more than 10%.

19) Example designs are shown in the figures in this Appendix. Equivalent designs are also acceptable.

20) Special applications, such as roads, may require the use of a modified flow splitter. The baffle wall may be fitted with a notch and adjustable weir plate to proportion runoff volumes other than high flows.

21) For ponding facilities, backwater effects must be included in designing the height of the standpipe in the manhole.

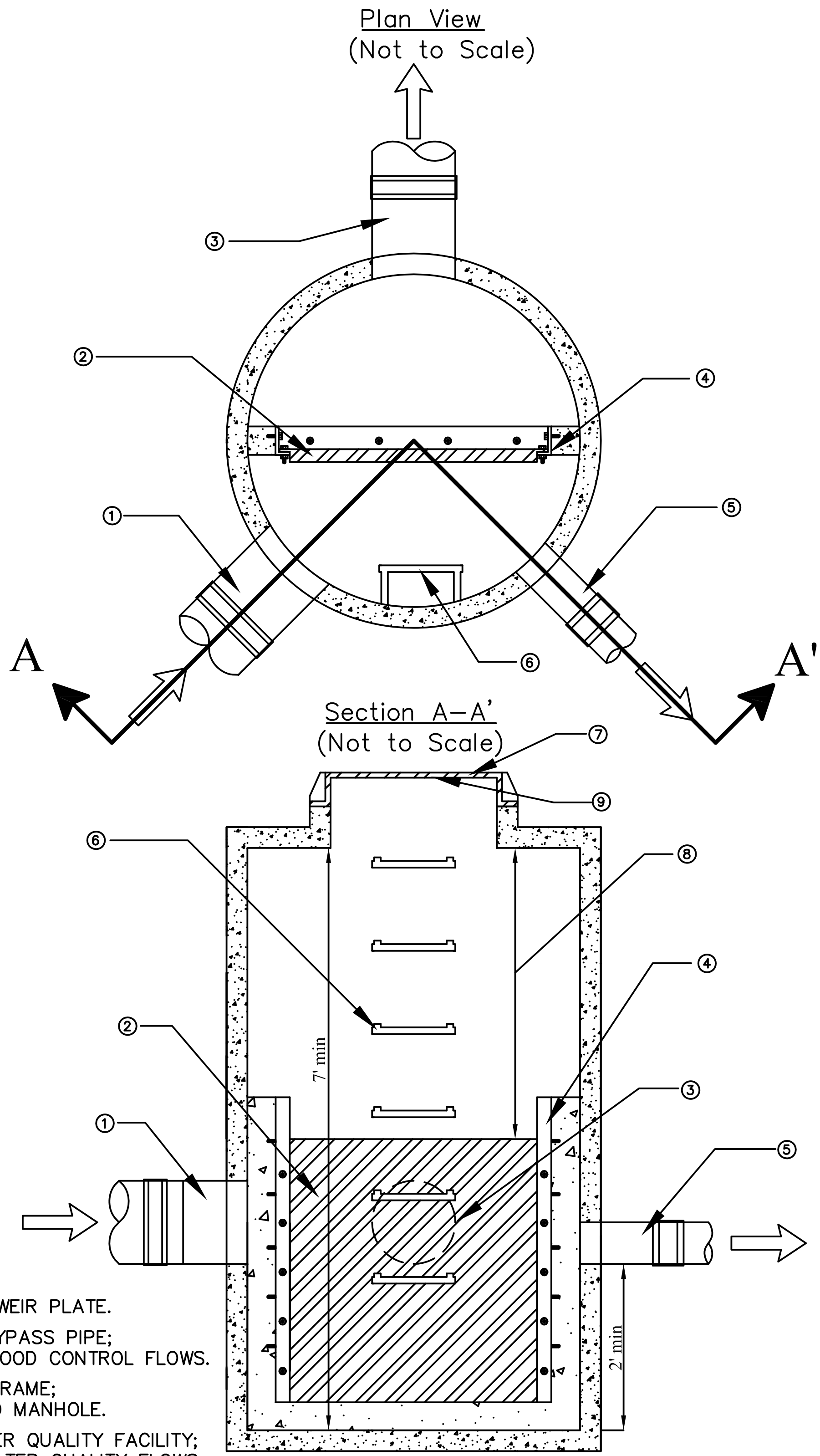
22) Ladder or step and handhold access shall be provided. If the weir wall is higher than 36 inches, two ladders, on the either side of the wall, are required.

F.2 Material Requirements

1) The splitter baffle shall be installed in a standard manhole or vault. The baffle wall shall be made of material resistant to corrosion (minimum 4-inch thick reinforced concrete, Type 302 or Type 316 stainless steel plate, or equivalent).

23) The minimum clearance between the top of the baffle wall and the bottom of the manhole or vault cover shall be 4 feet; otherwise, dual access points shall be provided.

24) All metal parts shall be corrosion resistant. Examples of preferred materials include aluminum, stainless steel, and plastic. Zinc and galvanized materials are not permitted because of aquatic toxicity. P ainting metal parts shall not be allowed because of poor longevity.



NOTES:

1. INLET PIPE.
2. ADJUSTABLE WEIR PLATE.
3. HIGH FLOW BYPASS PIPE; SIZED FOR FLOOD CONTROL FLOWS.
4. WEIR PLATE FRAME; ANCHORED TO MANHOLE.
5. PIPE TO WATER QUALITY FACILITY; SIZED FOR WATER QUALITY FLOWS.
6. ACCESS STEPS.
7. 24" ROUND FRAME AND SOLID LID.
8. 4' MIN DISTANCE OR PROVIDE SEPARATE ACCESS ON BOTH SIDES OF WEIR.
9. AFFIX PERMANENT IDENTIFICATION TAG.

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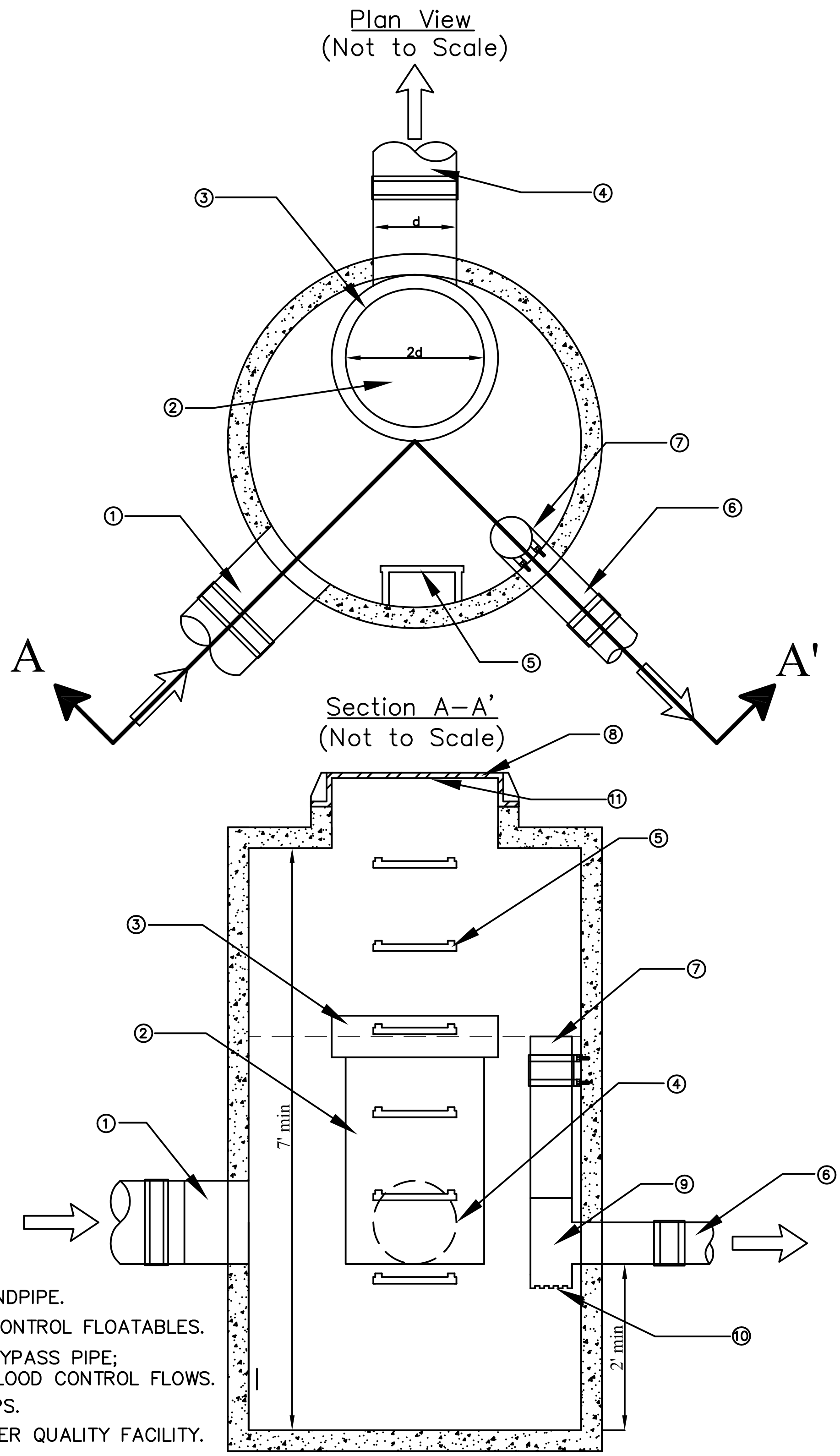
Figure F-1: Flow Splitter Option A



NOTES:

① INLET PIPE.
② BYPASS STANDPIPE.
③ BAFFLE TO CONTROL FLOATABLES.
④ HIGH FLOW BYPASS PIPE; SIZED FOR FLOOD CONTROL FLOWS.
⑤ ACCESS STEPS.
⑥ PIPE TO WATER QUALITY FACILITY.
⑦ RISER PIPE; TOP OF PIPE AT DESIGN ELEVATION FOR WATER QUALITY FLOWS.
⑧ 24" ROUND FRAME AND SOLID LID.
⑨ REMOVABLE "TEE" SECTION FOR CLEANOUT.
⑩ RISER PIPE ORIFICE SIZED FOR WATER QUALITY FLOWS.
⑪ AFFIX PERMANENT IDENTIFICATION TAG.

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Figure F-2: Flow Splitter Option B

APPENDIX G: DESIGN CRITERIA CHECKLISTS FOR STORMWATER RUNOFF BMPS

BIO-1 Bioretention Checklist

- ☐ Has the bioretention facility been sized to treat the water quality design volume, SQDV (see worksheet)?
- ☐ Does the bioretention have a maximum ponding depth of 18 in.?
- ☐ Is the planting soil depth at least 2 feet?
- ☐ Has an underdrain been provided if native soil permeability is less than 0.5 in/hr and infiltration is not possible/allowed?
- ☐ Has a gravel drainage layer been provided if native soil permeability is greater than 0.5 in/hr and infiltration is possible/allowed?
- ☐ Does the bioretention ponding depth drain below the planting soil in less than 48 hours?
- ☐ Is the gravel drainage layer sized to adequately meet the maximum drawdown time of 96 hours?
- ☐ Has the bioretention facility been properly sized as recommended in the manual?
- ☐ Does the flow entrance meet specifications (dispersed, low velocity flow; dispersed flow across pavement; flow spreading trench; cuts or wheel slots for parking lots)?
- ☐ Does the pipe flow entrance include erosion protection material to dissipate flow energy?
- ☐ Is the flow path unblocked by trees and shrubs?
- ☐ Is the underdrain at least 6 inches in diameter?
- ☐ Is the underdrain pipe made of accepted material (slotted PVC pipe conforming to ASTM C 3034 or equivalent HDPE pipe conforming to AASHTO 252M)?
- ☐ Does the slotted pipe have correct sizing and spacing of slots?
- ☐ Is the underdrain sloped at 0.5% or more?
- ☐ Are rigid observation pipes connected to underdrain every 250 to 300 feet of installed pipe?
- ☐ Do the observation pipe wells/clean outs extend 6 inches above top elevation of bioretention facility mulch and are they capped as required?

- ☐ Does the gravel underdrain bedding consist of the correct aggregate?
- ☐ If geotextile fabric is placed between the planting media and gravel layer, does it meet the specifications outlined in the manual?
- ☐ Does the gravel underdrain bedding extend at least 6 inches below the underdrain pipe (if needed) and does it provide 1 foot depth around top and sides of pipe?
- ☐ Does the underdrain drain freely to the accepted discharge point?
- ☐ Is an overflow device consisting of vertical PVC pipe included in design?
- ☐ Has the overflow device been installed at the 18-inch ponding depth?
- ☐ Is the overflow riser at least 6 inches in diameter?
- ☐ Has the inlet to the riser been positioned at least 6 inches above the planting media and capped with a spider cap?
- ☐ If bioretention is close to roads or infrastructure, have infiltration pathways been restricted with geomembrane (at least 30 mm) or clay liners?
- ☐ Is planting soil composed of correct aggregate (60-70% sand; 30-40% compost) and free of stones, stumps and roots?
- ☐ Does compost have acceptable characteristics?
- ☐ Is constructed bioretention facility covered with well-aged mulch, free of seeds, weeds, soil and roots, and at least 2-3 inches thick?
- ☐ Is all bioretention vegetation tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 72 hours?
- ☐ Have an adequate number of different plant species been incorporated into the bioretention (It is recommended that 3 tree, 3 shrub, and 3 herbaceous groundcover species be included)?
- ☐ Have native plants been used to the maximum extent practicable?

BIO- 2 Planter Box Checklist

- ☐ Is the planter box tributary area less than 15,000 ft2?
- ☐ Is the groundwater level at least 2 feet below the bottom of the planter box?
- ☐ Is there adequate relief between land surface and stormwater conveyance system to permit vertical percolation?
- ☐ Is the planter box located in an area with adequate sunlight to support selected vegetation?
- ☐ Is the planter box sized to treat the water quality design volume, Vwq (see worksheet)?
- ☐ Does the planter box have a maximum ponding depth of 12 inches?
- ☐ Is the planting soil depth at least 2 feet (3 feet preferred)?
- ☐ Does the ponded water drain below the planting soil in less than 48 hours?
- ☐ Has the distance between the downspouts and the overflow outlet been maximized?
- ☐ Has the planter box been sized the same as a Bioretention facility with planter box parameters?
- ☐ Has the planter box been constructed with an appropriate non-leaching permanent material?
- ☐ Has the planter box structure been adequately sealed to ensure that water exits only via the underdrain?
- ☐ Has an underdrain been provided?
- ☐ If the entrance to the planter box is piped, has erosion protection been included in the design (erosion protection includes rock, splash blocks, etc.)?
- ☐ Is the entrance flow path unimpeded by woody plants (trees, shrubs)?
- ☐ Is the underdrain at least 6 inches in diameter?
- ☐ Is the underdrain pipe made of accepted material (slotted PVC pipe conforming to ASTM C 3034 or equivalent HDPE pipe conforming to AASHTO 252M)?
- ☐ Does the slotted pipe have correct sizing and spacing of slots?
- ☐ Is the underdrain sloped at 0.5% or more?

☐ Are rigid observation pipes connected to underdrain every 250 to 300 feet of installed pipe?

☐ Do the observation pipe wells/clean outs extend 6 inches above top elevation of the planter box mulch and are they capped as required?

☐ Does the gravel underdrain bedding consist of the correct aggregate?

☐ Does the gravel underdrain bedding extend at least 6 inches below the underdrain and does it provide 1 foot depth around top and sides of pipe?

☐ If geotextile fabric is used in the underdrain design, does it meet minimum materials requirements?

☐ Is the underdrain elevated from the bottom of the planter box by 6 inches?

☐ Does the underdrain drain freely to the intended discharge point?

☐ Is an overflow device consisting of vertical PVC pipe included in design?

☐ Is the overflow riser at least 6 inches in diameter?

☐ Is the inlet to the riser 6 inches above planting soil and capped with a spider cap?

☐ Has a waterproof barrier consisting of a 30 mil geomembrane or equivalent been provided to protect foundations from moisture?

☐ Is planting soil composed of correct aggregate (60-70% sand; 30-40% compost) and gradation, and free of stones, stumps and roots?

☐ Does compost have acceptable characteristics (see planting/storage media)?

☐ Is planter box covered with well-aged mulch, free of seeds, weeds, grass clippings, bark, soil and roots, and at least 2-3 inches thick?

☐ Do all soil minerals meet requirements?

☐ Is all planter box vegetation tolerant of summer drought, ponding fluctuations, and saturated soil conditions for 48 to 72 hours?

☐ Have an adequate number of different plant species been incorporated into the planter box design (It is recommended that 3 tree, 3 shrub, and 3 herbaceous groundcover species be included)?

☐ Have native plants been used to the maximum extent practicable?

☐ Have only slow-release fertilizers been included in the design?

☐ Have arrangements been made to replace planter box mulch layer annually?

- ☐ Have low-maintenance plants been selected for design?
- ☐ Has an effort been made to ensure that no treated wood or galvanized metal is used anywhere within the planter box design?

BIO-3 Proprietary Biotreatment Device Checklist

☐ Has the proprietary biotreatment device been selected from the list provided in the manual of from another Ventura County- approved list?

☐ Has the vendor been contacted for the latest design guidance on cartridge selection?

☐ Has the proprietary biotreatment device been installed as directed by the vendor?

☐ Have appropriate maintenance and operation arrangements been made to ensure upkeep of the device?

☐ Has the biotreatment device been sized to capture and treat the water quality design flow?

BIO-4 Vegetated Swale Checklist

- ☐ Does the climate provide adequate conditions for maintaining a vegetative cover? Has adequate vegetation been chosen given the climate?
- ☐ Is the grade in the area shallow so as to not allow ponding?
- ☐ Is the swale compatible with existing flood control functions?
- ☐ Has the swale been designed with a depth of one foot or less?
- ☐ Is the overall depth from the top of the side walls to the bottom of the swale at least 12 inches?
- ☐ Is the swale bottom width at least 2 feet?
- ☐ Is the swale bottom width no greater than 10 feet, or 16 feet with a dividing berm?
- ☐ If the swale is required to convey flood flows in addition to the water quality design flow, has the swale been designed for the flood control design storm and does it include 2 feet of freeboard?
- ☐ Have gradual meandering bends been incorporated into the design?
- ☐ Is the longitudinal slope (in direction of flow) between 1% and 6%?
- ☐ Has an underdrain been provided if soils are poorly drained and longitudinal slope is less than 1.5%? Has a soils report been provided if this is the case?
- ☐ If the longitudinal slope is greater than 6%, have appropriate check dams with vertical drops of 12 inches or less been provided in the design to reduce the slope?
- ☐ Is the horizontal slope at the bottom of the swale flat to discourage channeling?
- ☐ Has the swale been designed so that the water depth does not exceed 4 inches or 2/3 the height of vegetation (2 inches in frequently mowed turf swales?
- ☐ Does the swale length provide a minimum hydraulic residence time of 7 minutes?
- ☐ If soil and slope conditions require it, has an acceptable low flow drain been installed?
- ☐ Has the swale been designed to convey the SQDF?

- ☐ Has the swale been sized as recommended in Chapter 6 (also see worksheet, Appendix E)?
- ☐ Has the swale been designed as a flow-through channel or has a high-flow bypass been incorporated into the design for flows higher than the water quality design flow?
- ☐ Has inflow been directed towards the upstream end of the swale or, at a minimum, evenly over the length of the swale?
- ☐ If the swale is online, has it been designed to convey flows up to the post-development 100 year 24 hour storm, with freeboard, and velocities below 3 ft/s?
- ☐ If the swale is off-line, has it been designed to convey the water quality design flow rate using a flow splitter with velocities below 1 ft/s?
- ☐ If check dams are incorporated in the design, have flow spreaders been added at the toe of each vertical drop?
- ☐ If curb cuts are used, has pavement been placed 1 – 2 inches above the elevation of the vegetated area?
- ☐ Is the swale inflow designed to function long term with minimal maintenance?
- ☐ Has flow spreading at the inlet of the swale been achieved by a leveled anchored flow spreader or similar method?
- ☐ Does the flow spreader project a minimum of 2 inches above the ground surface with appropriately spaced notches and extend horizontally beyond facility to prevent erosion
- ☐ If an underdrain is required, does it meet appropriate criteria (PVC or equivalent, correct slot spacing and sizing, 6 inches minimum in diameter, sloped at 0.5%)?
- ☐ Is there gravel bedding at least 6 inches below and 1 foot to the top and sides of the underdrain?
- ☐ If a geotextile is included in the design, does it meet requirements?
- ☐ Does gravel drainage layer meet recommended criteria?
- ☐ Does swale divider, if included, meet criteria (minimum height of 1 inch above flow, slopes no steeper than 2H:1V, stable foundation)?

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- ☐ Has swale soil been amended with compost if organic content is less than 10%?
- ☐ Have appropriate, hardy and native plants been used to the maximum extent practical?
- ☐ Is vegetative cover at least 4 inches in height (ideally 6 inches)?
- ☐ Has the swale been located away from trees that may drop leaves or provide insufficient sunlight?

BIO-5 Vegetated Filter Strip Checklist

- ☐ Is the slope of the filter strip designed to avoid both erosive flows and ponding?
- ☐ Has the strip been designed to evenly distribute flow across width and promote sheet flow?
- ☐ Does the width of the filter strip extend across the full width of the tributary area?
- ☐ Is the upstream boundary of the filter located contiguous to developed area?
- ☐ If filter strip is used for water quality purposes, is the length between 15 and 150 feet (25 feet preferred)? If the strip is used for pretreatment, is it at least 4 feet in length?
- ☐ Is the slope of the strip parallel to the direction of flow between 2% and 6%?
- ☐ Is the lateral slope (perpendicular to flow) of the strip 4% or less?
- ☐ Is grading across strip even?
- ☐ Has the top of the strip been installed 2 to 5 inches below any adjacent pavement (a beveled transition is also acceptable)?
- ☐ Are the top and toe of the slope as flat as possible (graded flat for engineered filter strips) to encourage sheet flow and prevent erosion?
- ☐ Has the design flow been calculated using the SQDF (see worksheet)?
- ☐ Has the design flow depth been calculated using a m odified Manning's equation (see worksheet)?
- ☐ Have the design velocity and length been calculated using the design flow and design flow depth as recommended (see worksheet)?
- ☐ Has a flow spreader been implemented to uniformly distribute contributing flow along width of filter strip?
- ☐ If a gravel flow spreader is used, is it at least 6 inches deep, 12 inches wide and a minimum or 1 inch below the paved surface?
- ☐ Has the gravel flow spreader been leveled even where ground is not level?
- ☐ If the gravel flow spreader is placed along a roadway, have LA county design specifications been consulted and implemented?

- ☐ If a notched curb spreader and through-curb spreader are used, have they been used in conjunction with a gravel spreader?
- ☐ Have curb port/interrupted curb openings been spaced at intervals of at least every 6 feet?
- ☐ Do the curb port/interrupted curb openings have a width of at least 11 inches?
- ☐ Does 15% or more of the curb length consist of open ports and does each port discharge no more than 10% of the flow?
- ☐ Have energy dissipaters (such as a riprap pad) been used if a sudden slope drop occurs?
- ☐ Has access been provided at the upper edge of filter strip for mowing equipment and to enable maintenance of spreader?
- ☐ Is the design water depth 1 inch or less?
- ☐ Does the design velocity not exceed 1 foot per second?
- ☐ If the organic content of the filter strip soil does not exceed 10%, has the soil been amended with at least 2 inches of well-rotted acceptable compost at a depth of 6 inches?
- ☐ Is filter strip uniformly graded and densely vegetated with erosion-resistant grasses (preferably native or adapted species)?
- ☐ Has irrigation been provided to establish grasses?
- ☐ Have maintenance arrangements been made to maintain grass at a height of 2 to 4 inches?
- ☐ Have trees and shrubs been limited along the filter strip?
- ☐ Has an effort been made to ensure that no treated wood or galvanized metal is used anywhere within the design?

BIO-6 Green Roof Checklist

- ☐ Is the roof shallow enough to support a green roof (<25% slope)?
- ☐ Are the roof supports sufficient to support additional weight of soil, water, vegetation, and a drainage layer (if needed) [a licensed structural engineer should be consulted]?
- ☐ Has an appropriate waterproof membrane been placed below the green roof?
- ☐ Has an appropriate drainage layer been incorporated in the design (if required)?
- ☐ Has an appropriate soil mix been used in the design to allow for drainage, support vegetative growth, and that is not excessively heavy when wet?
- ☐ Has vegetation been carefully selected to improve aesthetics, resist erosion, withstand extreme environments, and tolerate drought without the need for fertilizers and pesticides and without a lot of maintenance requirements (see Appendix H for a recommended plant list)?
- ☐ Have native plants been chosen to the maximum extent practical?
- ☐ If trees or shrubs are incorporated, has an adequate soil depth been provided and is the additional soil depth supported by the roof structure?
- ☐ Has irrigation been provided to establish vegetation?
- ☐ Does vegetation cover 90% of the total area?
- ☐ Is the green roof located in an area without excessive shade to avoid poor vegetative growth?
- ☐ Is there an appropriate drain pipe or gutter to convey any runoff from roof to a stormwater BMP or stormwater conveyance system?

FILT-1 Sand Filter Checklist

- ☐ Has sand filter been located away from trees and areas that could contribute eroded sediment?
- ☐ If there is a chance for sediment to be present in flow to be treated, has pretreatment been provided?
- ☐ Does site have adequate relief to permit vertical percolation through sand filter and into conveyance system?
- ☐ Has pretreatment (vegetated swale or filter strip, hydrodynamic separator) been adequately provided to reduce the sediment load entering the filter?
- ☐ Has the sand filter been sized to capture the SQDV?
- ☐ Has the sand filter been designed with a 1 .5:1 length to width ratio or greater?
- ☐ Is the filter bed depth at least 2 feet (3 feet preferred)?
- ☐ Is the depth of water storage over the filter bed 6 feet or less?
- ☐ Is the overflow structure designed to pass the water quality design storm?
- ☐ Has the sizing of the filter been determined using the adapted Darcy's Law equation recommended in the sizing methodology section in Chapter 6 (also see worksheet, Appendix E)?
- ☐ Does the sand meet the recommended specifications (0.2-0.35 mm diameter, Cu < 3, ASTM C 33 size gradation, etc.)?
- ☐ Has an underdrain been employed in the design? [Examples: central underdrain w/lateral pipes, longitudinal pipes, single pipe for small filters]
- ☐ Is the underdrain placed in an 8 inch minimum gravel backfill or drain rock bed?
- ☐ Are all underdrain pipes and connectors 6 inches or greater with clean-out risers of equal diameter?
- ☐ Have clean-out risers been placed at the terminal ends of all pipes and extend to the surface of the filter?
- ☐ Has a valve box been provided for access to the clean-outs and is it water tight?
- ☐ Are underdrain pipes laid with perforations downward, and are perforations at least ½ inch in diameter?

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- ☐ Are all lateral collection pipes within 9 feet or less of each other (perpendicular distance)?
- ☐ Have all pipes been placed with a minimum slope of 0.5%?
- ☐ Is the invert of the underdrain outlet above the seasonal high groundwater level?
- ☐ Is gravel backfill present around the underdrain pipe at least 6 inches below and to the sides of the pipe and 8 inches above the pipe?
- ☐ Does the bottom gravel have a diameter of at least 2 times the size of the perforated openings to the drainage system and meet other specifications (specific gravity of 2.5 or more, rounded, free of debris)?
- ☐ Has an appropriate geotextile layer (see underdrain section) or 2-inch transition layer been placed between the sand layer and the drain rock/ gravel backfill layer?
- ☐ Has a flow spreader been installed at the inlet along one side of the filter (long side of the filter if L: W is 2:1 or greater; 20% of perimeter for curved or irregular shape)?
- ☐ Has erosion protection been provided along the first foot of the sand bed adjacent to the flow spreader (i.e. geotextile weighted with sand bags; quarry spalls)?
- ☐ Has no topsoil, clay, or sod (except sod grown in sand) has been added to the sand filter bed?
- ☐ Has vegetation been selected properly (i.e. must withstand drought, heavy saturation, etc.)?
- ☐ Are no permanent structures built on top of the sand filter bed?
- ☐ No large shrubs or trees should be planted in sand filter bed or within 15 feet of inlet or outlet pipes
- ☐ Have native plants been used to the maximum extent practicable?
- ☐ Has an emergency overflow structure been provided?
- ☐ Are interior side slopes above water quality design depth no steeper than 3:1 H:V?
- ☐ Are exterior side slopes no steeper than 2:1 H:V?
- ☐ If pond walls are vertical retaining walls, do they meet recommended specifications (see side slopes section)?

- ☐ Do embankments meet appropriate criteria [top width or 20 feet, constructed on native consolidated soil, in accordance with standard specifications, proper excavation, constructed of appropriate compacted soil]?
- ☐ Are maintenance access roads/ramps to filter provided?
- ☐ Have trees and shrubs been planted further than 10 feet away from inlet and outlet pipes (50 feet for 'water-seeking' plants such as willows and poplars)?
- ☐ Have prohibited non-native plants been removed from the site?
- ☐ Has an effort been made to ensure that no treated wood or galvanized metal is used anywhere within the planter box design?

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FILT-2 Cartridge Media Filter

- ☐ Has the vendor been contacted for the latest design guidance on cartridge selection?
- ☐ Has the cartridge media filter been provided with a system to completely drain the system and prevent vector annoyances?
- ☐ Has the cartridge media filter been sized to capture and treat the SQDF?
- ☐ Have site considerations been taken into account when sizing the cartridge media filter and selecting features (often vendor websites offer assistance with this)?

INF-1 Infiltration Trench Checklist

☐ Has the infiltration trench been located away from steep slopes (>25%)?

☐ Is the infiltration trench set back from structures and leach fields?

☐ Is there at least 10 feet or vertical separation between the bottom of the infiltration trench and the shallow groundwater table?

☐ Is the depth to bedrock adequate to provide proper infiltration?

☐ Has the site been checked to ensure that no preexisting contamination is present?

☐ Does the site have low sediment loading rates to prevent infiltration trench clogging?

☐ Has a soil assessment report been completed, which determines the suitability of the site for an infiltration trench, recommends a design infiltration rate, identifies the high depth to groundwater table surface elevation, and examines how the stormwater runoff will move in the soil?

☐ Has a geotechnical investigation and report been provided if needed?

☐ Has the infiltration trench been located at a site that does not receive run off from sites that store or use chemicals or hazardous waste outside?

☐ Has the infiltration trench been set back from existing septic system drain fields and drinking water wells?

☐ Has pretreatment been provided with a vegetated swale, filter strip, sand filter or proprietary device?

☐ Is the trench at least 2 feet wide and 3 to 5 feet deep?

☐ Is the longitudinal slope of the trench 3% or less?

☐ Is the top layer of the media filter gravel/choking stone/geotextile fabric if flow is sheet flow and 12 inches of surface soil if flow enters through an underground pipe?

☐ Is middle layer of media filter 3-5 feet of washed 1.5 to 3 in. gravel with void space of 30 to 40%?

☐ Is bottom layer of media filter 6" of clean, washed sand?

☐ Have one or more observation wells been installed?

- ☐ Do observation wells consist of recommended slotted 4-6 inch diameter PVC well screen capped with lockable, above-ground lid?
- ☐ Has the infiltration trench been sized to capture and infiltrate the SUSMP defined water quality design volume?
- ☐ Has the infiltration trench been designed to infiltrate all runoff within 72 hours?
- ☐ Has the maximum depth of runoff, ponding depth/trench depth and infiltrating surface area been calculated using recommended design equations (see sizing methodology section/worksheet)?
- ☐ Is the bottom of the infiltration bed native soil, over-excavated to at least one foot in depth and replaced uniformly (with 2-4 inches of coarse sand amendments) without compaction?
- ☐ Has all vertical piping been classified correctly (see drainage section in manual)?
- ☐ Has an observation well been incorporated into the design to ensure that the 72 hour maximum drawdown time is met?
- ☐ Has an overflow route been provided to safely convey flows that overtop the facility or in the case that the facility becomes clogged?
- ☐ Has the overflow channel been designed to safely convey flows from peak design storm to a downstream conveyance system or acceptable discharge point?
- ☐ Has the infiltration trench been kept free of vegetation, and is all existing vegetation surrounding the trench been planted away from trench to avoid drip lines overhanging the facility?
- ☐ Is there safe maintenance access provided to the site for both wet and dry conditions?
- ☐ Has an access road along the length of the trench been provided if there is no existing road or parking lot that can be used for maintenance access?
- ☐ Has access to “operate a backhoe at ‘arms length’” been provided?
- ☐ Was the entire area draining to the facility stabilized before construction began?
- ☐ Have you ensured that the infiltration trench is not hydraulically connected to the storm water conveyance system?

- ☐ If heavy construction material was used to compact subgrade (not recommended), has the infiltrative capacity of the soil been restored via tilling or aerating prior to placing the infiltration bed?
- ☐ Were the exposed subgrade soils inspected by a civil engineer prior to construction to confirm suitable soil conditions for the infiltration facility?

INF-2 Drywell Checklist

- ☐ Has the drywell been located away from steep slopes (>25%)?
- ☐ Is the drywell set back from structures and leach fields?
- ☐ Is there at least 10 feet or vertical separation between the bottom of the drywell and the shallow groundwater table?
- ☐ Is the depth to bedrock adequate to provide proper infiltration?
- ☐ Has the site been checked to ensure that no preexisting contamination is present?
- ☐ Does the site have low sediment loading rates to prevent drywell from clogging?
- ☐ Has pretreatment been provided for all non-rooftop runoff flowing to the drywell?
- ☐ Has a geotechnical investigation and report been provided to ensure site meets specifications for an infiltration facility (including soil infiltration rate, groundwater separation, and no steep slopes)?
- ☐ Has a soil assessment report been completed, which determines the suitability of the site for an drywell, recommends a design infiltration rate, identifies the high depth to groundwater table surface elevation, and examines how the stormwater runoff will move in the soil?
- ☐ Has the drywell been located at a site that does not receive run off from sites that store or use chemicals or hazardous waste outside?
- ☐ Has the drywell been set back from existing septic system drain fields and drinking water wells?
- ☐ Has pretreatment been provided to prevent sediment and other large particulates?
- ☐ Is the surface area of the drywell large enough to infiltrate the storage volume in 72 hours based on maximum allowable depth?
- ☐ Is the top layer of the media filter gravel/choking stone/geotextile fabric if flow is sheet flow and 12 inches of surface soil if flow enters through an underground pipe (pipe should be fitted with a screen)?
- ☐ Is middle layer of media filter 3-5 feet of washed 1.5 to 3 in. gravel with void space of 30 to 40%?
- ☐ Is bottom layer of media filter 6” of clean, washed sand?

- ☐ Have one or more observation wells been installed?
- ☐ Do observation wells consist of recommended slotted 4-6 inch diameter PVC well screen capped with lockable, above-ground lid?
- ☐ Has the drywell been sized to capture and infiltrate the SUSMP defined water quality design volume?
- ☐ Has the drywell been designed to infiltrate all runoff within 72 hours?
- ☐ Has a long term percolation rate of 10% of the measured percolation rate been used in design (due to occlusion and particulate accumulation)?
- ☐ Has the maximum depth of runoff, ponding depth/trench depth and infiltrating surface area been calculated using recommended design equations (see sizing methodology section/worksheet)?
- ☐ Is the bottom of the infiltration bed native soil, over-excavated to at least one foot in depth and replaced uniformly (with 2-4 inches of coarse sand amendments) without compaction?
- ☐ Has all vertical piping been classified correctly (see drainage section in manual)?
- ☐ Has an observation well been incorporated to ensure that the 72 hour maximum drawdown time is met?
- ☐ Has an overflow route been provided to safely convey flows that overtop the facility or in the case that the facility becomes clogged?
- ☐ Has the overflow channel been designed to safely convey flows from peak design storm to a downstream conveyance system or acceptable discharge point?
- ☐ Has the drywell been kept free of vegetation, and is all existing vegetation surrounding the trench been planted away from trench to avoid drip lines overhanging the facility?
- ☐ Is there safe maintenance access provided to the site for both wet and dry conditions?
- ☐ Has maintenance access been provided?
- ☐ Was the entire area draining to the facility stabilized before construction began?
- ☐ Have you ensured that the infiltration trench is not hydraulically connected to the storm water system?

☐ If heavy construction material was used to compact subgrade (not recommended), has the infiltrative capacity of the soil been restored via tilling or aerating prior to placing the infiltration bed?

☐ Were the exposed subgrade soils inspected by a civil engineer prior to construction to confirm suitable soil conditions for the infiltration facility?

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INF-3 Proprietary Infiltration BMPs Checklist

- ☐ Has the infiltration facility been located away from steep slopes (>25%)?
- ☐ Is the infiltration facility set back from structures and leach fields?
- ☐ Is there at least 10 feet or vertical separation between the bottom of the infiltration facility and the shallow groundwater table?
- ☐ Is the depth to bedrock adequate to provide proper infiltration?
- ☐ Has the site been checked to ensure that no preexisting contamination is present?
- ☐ Does the site have low sediment loading rates to prevent infiltration facility clogging?
- ☐ Has pretreatment been provided to prevent premature failure (If infiltration facility fails, complete construction is required)?
- ☐ Has infiltration facility been designed to receive runoff only from sections of the site that have been stabilized?
- ☐ If infiltration facility fails, complete construction is required
- ☐ Has a geotechnical investigation and report been provided to ensure site meets specifications for an infiltration facility (including soil infiltration rate, groundwater separation, and no steep slopes)?
- ☐ Has a soil assessment report been completed, which determines the suitability of the site for an infiltration trench, recommends a design infiltration rate, identifies the high depth to groundwater table surface elevation, and examines how the stormwater runoff will move in the soil?
- ☐ Has the infiltration trench been located at a site that does not receive run off from sites that store or use chemicals or hazardous waste outside?
- ☐ Has the infiltration BMP been sized to capture and treat the water quality design volume?
- ☐ Has a long term percolation rate of 10% of the measured percolation rate been used in design (due to occlusion and particulate accumulation)?
- ☐ Have the recommended sizing guidelines set by the vendor been referenced and used for selection and use of infiltration facility?

INF-4 Permeable Pavement Checklist

- ☐ Has the permeable pavement been located away from steep slopes (>25%)?
- ☐ Is the permeable pavement set back from structures and leach fields?
- ☐ Is there at least 10 feet or vertical separation between the bottom of the permeable pavement and the shallow groundwater table?
- ☐ Is the depth to bedrock adequate to provide proper infiltration?
- ☐ Has the site been checked to ensure that no preexisting contamination is present?
- ☐ Does the site have low sediment loading rates to prevent infiltration trench clogging?
- ☐ Has the permeable pavement been designed to receive runoff only from sections of the site that have been stabilized?
- ☐ Has a geotechnical investigation and report been provided to ensure site meets specifications for an infiltration facility (including soil infiltration rate, groundwater separation, and no steep slopes)?
- ☐ Has a soil assessment report been completed, which determines the suitability of the site for an infiltration trench, recommends a design infiltration rate, identifies the high depth to groundwater table surface elevation, and examines how the stormwater runoff will move in the soil?
- ☐ Has the permeable pavement been located at a site that does not receive run off from sites that store or use chemicals or hazardous waste outside?
- ☐ Has the run off been assessed for necessity of pretreatment?
- ☐ If pretreatment is required, has it been provided to treat run on before it reaches permeable pavement?
- ☐ Has the infiltration BMP been sized to capture and treat the water quality design volume?
- ☐ Have the infiltration capabilities of the site been assessed (i.e. full, partial, or no infiltration allowed)?
- ☐ If no infiltration is allowed, has an underdrain been prohibited?

- ☐ If permeable pavement is located on a site with a slope greater than 2%, has the area been terraced to prevent lateral flow through subsurface?
- ☐ Has the permeable pavement been designed to infiltrate flows through four different layers (incl. top wearing layer, stone reservoir, and transition layers) of material (or through a similar system)?
- ☐ Has the depth of each layer (and void space), along with the hydrology, hydraulics, and structural requirements of the site been determined and approved by a licensed civil engineer?
- ☐ If proprietary permeable pavement is used (i.e. concrete or other pavers), have the design requirements and installation steps been obtained from the vendor and referenced in the selection and construction of the permeable pavement?
- ☐ Has the permeable pavement been designed to drain in less than 72 hours and allowed to dry out periodically?
- ☐ Has a long term percolation rate of 10% of the measured percolation rate been used in design (due to occlusion and particulate accumulation)?
- ☐ Has an overflow mechanism been included in the pavement design?
- ☐ If the overflow mechanism employed is perimeter control, have controls such as a perimeter vegetated swale, perimeter Bioretention, storm drain inlets, or other acceptable control been implemented?
- ☐ If the overflow mechanism employed are overflow pipes, have the pipes been connected to the underdrain, are they located away from vehicular traffic, and is the top of the pipe fitted with a screen?
- ☐ Has the pavement been laid close to level with bottom of base layers level to ensure uniform infiltration?
- ☐ Are site materials stored away from permeable pavement?
- ☐ Has landscaping and stabilization of adjacent areas been completed before installation of pavement?

GS-1 Hydrodynamic Separation Device Checklist

- ☐ Has the vendor been contacted for the latest model and design guidance prior to selection of device?
- ☐ Has the device been sized to capture and treat the water quality design flow rate?
- ☐ Has the vendor been contacted for sizing and installation guidance?
- ☐ Has periodic maintenance been scheduled and budgeted for?

GS-2 Catch Basin Insert Checklist

- ☐ Has the vendor been contacted for the latest model and design guidance prior to selection of device?
- ☐ Has the insert been sized to capture and treat the water quality design flow rate?
- ☐ Has the vendor been contacted for sizing and installation guidance?
- ☐ Has periodic maintenance been scheduled and budgeted for?

APPENDIX H : STORMWATER CONTROL MEASURE ACCESS AND MAINTENANCE AGREEMENTS

(Long Form)

Recorded at the request of:

City of ____

After recording, return to:

City of ____

City Clerk

Stormwater Treatment Device Access and Maintenance Agreement

OWNER:

PROPERTY ADDRESS:_______________________________________

APN:

THIS AGREEMENT is made and entered into in_________________, California, this___day of_______________, by and between_______________ ___________________, hereinafter referred to as "Owner" and the CITY OF____ _________________, a municipal corporation, located in the County of Ventura, State of California hereinafter referred to as "CITY";

WHEREAS, the Owner owns real property ("Property") in the City of ________, County of Ventura, State of California, more specifically described in Exhibit "A" and depicted in Exhibit "B", each of which exhibits is attached hereto and incorporated herein by this reference;

WHEREAS, at the time of initial approval of development project known as____ ___________________________________within the Property described herein, the City required the project to employ on-site control measures to minimize pollutants in urban runoff;

WHEREAS, the Owner has chosen to install a _________________________ ____, hereinafter referred to as "Device", as the on-site control measure to minimize pollutants in urban runoff;

WHEREAS, said Device has been installed in accordance with plans and specifications accepted by the City;

WHEREAS, said Device, with installation on private property and draining only private property, is a private facility with all maintenance or replacement, therefore, the sole responsibility of the Owner in accordance with the terms of this Agreement;

WHEREAS, the Owner is aware that periodic and continuous maintenance, including, but not necessarily limited to, filter material replacement and sediment removal, is required to assure peak performance of Device and that, furthermore, such maintenance activity will require compliance with all Local, State, or Federal laws and regulations, including those pertaining to confined space and waste disposal methods, in effect at the time such maintenance occurs;

NOW THEREFORE, it is mutually stipulated and agreed as follows:

1) Owner hereby provides the City of City's designee complete access, of any duration, to the Device and its immediate vicinity at any time, upon reasonable notice, or in the event of emergency, as determined by City's Director of Public Works no advance notice, for the purpose of inspection, sampling, testing of the Device, and in case of emergency, to undertake all necessary repairs or other preventative measures at owner's expense as provided in paragraph 3 below. City shall make every effort at all times to minimize or avoid interference with Owner's use of the Property.

2) Owner shall use its best efforts diligently to maintain the Device in a manner assuring peak performance at all times. All reasonable precautions shall be exercised by Owner and Owner's representative or contractor in the removal and extraction of material(s) from the Device and the ultimate disposal of the material(s) in a manner consistent with all relevant laws and regulations in effect at the time. As may be requested from time to time by the City, the Owner shall provide the City with documentation identifying the material(s) removed, the quantity, and disposal destination.

3) In the event Owner, or its successors or assigns, fails to accomplish the necessary maintenance contemplated by this Agreement, within five (5) days of being given written notice by the City, the City is hereby authorized to cause any maintenance necessary to be done and charge the entire cost and expense to the Owner or Owner's successors or assigns, including administrative costs, attorneys fees and interest thereon at the maximum rate authorized by the Civil Code from the date of the notice of expense until paid in full.

4) The City may require the owner to post security in form and for a time period satisfactory to the city of guarantee of the performance of the obligations stated herein. Should the Owner fail to perform the obligations under the Agreement, the City may, in the case of a cash bond, act for the Owner using the proceeds from it, or in the case of a surety bond, require the sureties to perform the obligations of the Agreement. As an additional remedy, the Director may withdraw any previous stormwater related approval with respect to the

property on which a Device has been installed until such time as Owner repays to City it's reasonable costs incurred in accordance with paragraph 3 above.

5) This agreement shall be recorded in the Office of the Recorder of Ventura County, California, at the expense of the Owner and shall constitute notice to all successors and assigns of the title to said Property of the obligation herein set forth, and also a lien in such amount as will fully reimburse the City, including interest as herein above set forth, subject to foreclosure in event of default in payment.

6) In event of legal action occasioned by any default or action of the Owner, or its successors or assigns, then the Owner and its successors or assigns agree(s) to pay all costs incurred by the City in enforcing the terms of this Agreement, including reasonable attorney's fees and costs, and that the same shall become a part of the lien against said Property.

7) It is the intent of the parties hereto that burdens and benefits herein undertaken shall constitute covenants that run with said Property and constitute a lien there against.

8) The obligations herein undertaken shall be binding upon the heirs, successors, executors, administrators and assigns of the parties hereto. The term "Owner" shall include not only the present Owner, but also its heirs, successors, executors, administrators, and assigns. Owner shall notify any successor to title of all or part of the Property about the existence of this Agreement. Owner shall provide such notice prior to such successor obtaining an interest in all or part of the Property. Owner shall provide a copy of such notice to the City at the same time such notice is provided to the successor.

9) Time is of the essence in the performance of this Agreement.

10) Any notice to a party required or called for in this Agreement shall be served in person, or by deposit in the U.S. Mail, first class postage prepaid, to the address set forth below. Notice(s) shall be deemed effective upon receipt, or seventy-two (72) hours after deposit in the U.S. Mail, whichever is earlier. A party may change a notice address only by providing written notice thereof to the other party.

IF TO CITY:	IF TO OWNER:
______________________________	______________________________
______________________________	______________________________
______________________________	______________________________

IN WITNESS THEREOF, the parties hereto have affixed their signatures as of the date first written above.

APPROVED AS TO FORM:

____

City Attorney

OWNER:

____

Owner

Name: ____________________________

Title: ____________________________

CITY OF__________________:

____

Name:_______________________

Title:_______________________

OWNER:

____

Name:______________________________

Title:______________________________

ATTEST:

____

City Clerk Date

Notaries on Following Page

RB-AR35085

EXHIBIT A

(Legal Description)

EXHIBIT B

(Map/illustration)

(Short Form)

Recorded at the request of and mail to:

____

____

____

Covenant and Agreement Regarding

Stormwater Treatment Device Maintenance

The undersigned hereby certify that we are the owners of hereinafter legally described real property located in the City of _________________________, County of Ventura, State of California.

Legal Description: ____

____

as recorded in Book ____________________, Page ________, Records of Ventura County,

which property is located and known as **(Address):** _____________________________

____.

And in consideration of the City of ____________ allowing_________________________

____

on said property, we do hereby covenant and agree to and with said City to maintain according to the Maintenance Plan (Attachment 1), all structural stormwater treatment devices including the following:

____

____.

This Covenant and Agreement shall run all of the above described land and shall be binding upon ourselves, and future owners, encumbrances, their successors, heirs, or assignees and shall continue in effect until released by the authority of the City upon submittal of request, applicable fees, and evidence that this Covenant and Agreement is no longer required by law.

NOTARIES ON FOLLOWING PAGE

APPENDIX I : STORMWATER CONTROL MEASURE MAINTENANCE PLAN GUIDELINES AND CHECKLISTS

Included in this appendix are a series of checklists that can be used by both inspectors and maintenance personnel to ensure that observed deficiencies in BMPs are maintained appropriately. The BMP Inspection/Maintenance Checklists are presented in the following order:

1) Bioretention/Planter Box

25) Vegetated Swale Filter

26) Vegetated Filter Strip

27) Sand Filter

28) Infiltration BMPs

29) Permeable Pavement

30) Constructed Treatment Wetland

31) Wet Retention Basin

32) Dry Extended Detention Basin

33) Proprietary Devices

I.1 Bioretention/Planter Box Inspection and Maintenance Checklist

Date: ______________________ Work Order # ___________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: _____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Appearance	Untidy			
Trash and Debris Accumulation	Trash, plant litter and dead leaves accumulated on surface.			
Vegetation	Unhealthy plants and appearance.			
Irrigation	Functioning incorrectly (if applicable).			
Inlet	Inlet pipe blocked or impeded.			
Splash Blocks	Blocks or pads correctly positioned to prevent erosion.			
Overflow	Overflow pipe blocked or broken.			
Filter media	Infiltration design rate is met (e.g., drains 36-48 hours after moderate - large storm event).			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.2 Vegetated Swale Filter Inspection and Maintenance Checklist

Date: ________________________ Work Order # __________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ______________________ Inspector(s): __________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Appearance	Untidy			
Trash and Debris Accumulation	Trash and debris accumulated in the swale.			
Vegetation	When the grass becomes excessively tall (greater than 10-inches); when nuisance weeds and other vegetation start to take over.			
Excessive Shading	Vegetation growth is poor because sunlight does not reach swale. Evaluate vegetation suitability.			
Poor Vegetation Coverage	When vegetation is sparse or bare or eroded patches occur in more than 10% of the swale bottom. Evaluate vegetation suitability.			
Sediment Accumulation	Sediment depth exceeds 2 inches or covers more than 10% of design area.			
Standing Water	When water stands in the swale between storms and does not drain freely.			
Flow spreader or Check Dams	Flow spreader or check dams uneven or clogged so that flows are not uniformly distributed through entire swale width.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1, or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Constant Baseflow	When small quantities of water continually flow through the swale, even when it has been dry for weeks and an eroded, muddy channel has formed in the swale bottom.			
Inlet/Outlet	Inlet/outlet areas clogged with sediment and/or debris.			
Erosion/ Scouring	Eroded or scoured swale bottom due to flow channelization, or higher flows. Eroded or rilled side slopes.			
	Eroded or undercut inlet/outlet structures			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.3 Vegetated Filter Strip Inspection and Maintenance Checklist

Date: ____________________ Work Order # _______________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ___________________ Inspector(s): ________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1 or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Appearance	Untidy			
Trash and Debris Accumulation	Trash and debris accumulated on the filter strip.			
Vegetation	When the grass becomes excessively tall (greater than 10-inches); when nuisance weeds and other vegetation starts to take over.			
Excessive Shading	Grass growth is poor because sunlight does not reach swale. Evaluate grass species suitability.			
Poor Vegetation Coverage	When grass is sparse or bare or eroded patches occur in more than 10% of the swale bottom. Evaluate grass species suitability.			
Erosion/Scouring	Eroded or scoured areas due to flow channelization, or higher flows.			
Sediment Accumulation on Grass	Sediment depth exceeds 2 inches.			
Flow spreader	Flow spreader uneven or clogged so that flows are not uniformly distributed through entire filter width.			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.4 Sand Filter Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: _____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Trash & Debris	Any trash and debris which exceed 5 cubic feet per 1,000 square feet of filter bed area (one standard garbage can). In general, there shall be no visual evidence of dumping. If less than threshold all trash and debris will be removed as part of next scheduled maintenance.			
Inlet erosion	Visible evident of erosion occurring near flow spreader outlets.			
Slow drain time	Standing water long after storm has passed (after 24 to 48 hours) and/or flow through the overflow pipes occurs frequently.			
Concentrated Flow	Flow spreader uneven or clogged so that flows are not uniformly distributed across the sand filter.			
Appearance of poisonous, noxious or nuisance vegetation	Excessive grass and weed growth. Noxious weeds, woody vegetation establishing, Turf growing over rock filter			
Standing Water	Standing water long after storm has passed (after 24 to 48 hours), and/or flow through the overflow pipes occurs frequently.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Tear in Filter Fabric	When there is a visible tear or rip in the filter fabric allowing water to bypass the fabric.			
Pipe Settlement	If piping has visibly settled more than 1 inch.			
Filter Media	Drawdown of water through the media takes longer than 1 hour and/or overflow occurs frequently.			
Short Circuiting	Flows do not properly enter filter cartridges.			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.5 Infiltration BMP Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Appearance, vegetative health	Mowing and trimming vegetation is needed to prevent establishment of woody vegetation, and for aesthetic and vector reasons.			
Vegetation	Poisonous or nuisance vegetation or noxious weeds.			
	Excessive loss of turf or ground cover (if applicable).			
Trash & Debris	Trash and debris > 5 cf/1,000 sf (one standard size garbage can).			
Contaminants and Pollution	Any evidence of oil, gasoline, contaminants or other pollutants.			
Erosion	Undercut or eroded areas at inlet or outlet structures.			
Sediment and Debris	Accumulation of sediment, debris, and oil/grease on surface, inflow, outlet or overflow structures.			
Sediment and Debris	Accumulation of sediment and debris, in sediment forebay and pretreatment devices.			
Water drainage rate	Standing water, or by visual inspection of wells (if available), indicates design drain times are not being achieved (i.e., within 72 hours).			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Media clogging surface layer	Lift surface layer (and filter fabric if installed) and check for media clogging with sediment (function may be able to be restored by replacing surface aggregate/filter cloth).			
Media clogging	Lift surface layer (and filter fabric if installed) and check for media clogging with sediment (partial or complete clogging which may require full replacement).			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.6 Permeable Pavement Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Sediment Accumulation	Sediment is visible			
Missing gravel/sand fill	There are noticeable gaps in between pavers			
Weeds/mosses filling voids	Vegetation is growing in/on permeable pavement			
Trash and Debris Accumulation	Trash and debris accumulated on the permeable pavement.			
Dead or dying vegetation in adjacent landscaping	Vegetation is dead or dying leaving bare soil prone to erosion			
Surface clog	Clogging is evidenced by ponding on the surface			
Overflow clog	Excessive build up of water accompanied by observation of low flow in observation well (connected to underdrain system) If a surface overflow system is used, observation of an obvious clog			
Visual contaminants and pollution	Any visual evidence of oil, gasoline, contaminants or other pollutants.			
Erosion	Tributary area Exhibits signs of erosion Noticeably not completely stabilized			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Deterioration/ Roughening	Integrity of pavement is compromised (i.e., cracks, depressions, crumbling, etc.)			
Subsurface Clog	Clogging is evidenced by ponding on the surface and is not remedied by addressing surface clogging.			
†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.				

I.7 Constructed Treatment Wetland Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: _____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Trash & Debris	Any trash and debris which exceed 5 cubic feet per 1,000 sf of basin area (one standard garbage can). In general, there shall be no visual evidence of dumping. If less than threshold all trash and debris will be removed as part of next scheduled maintenance. If trash and debris is observed blocking or partially blocking an outlet structure or inhibiting flows between cells, it shall be removed quickly			
Sediment Accumulation	Sediment accumulation in basin bottom that exceeds the depth of sediment zone plus 6 inches in the sediment forebay. If sediment is blocking an inlet or outlet, it shall be removed.			
Erosion	Erosion of basin's side slopes and/or scouring of basin bottom.			
Oil Sheen on Water	Prevalent and visible oil sheen.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Noxious Pests	Visual observations or receipt of complaints of numbers of pests that would not be naturally occurring and could pose a threat to human or aquatic health.			
Water Level	First cell empty, doesn't hold water.			
Aesthetics	Minor vegetation removal and thinning. Mowing berms and surroundings			
Noxious Weeds	Any evidence of noxious weeds.			
Tree Growth	Tree growth does not allow maintenance access or interferes with maintenance activity (i.e., slope mowing, silt removal, vactoring, or equipment movements). If trees are not interfering, do not remove. Dead, diseased, or dying trees shall be removed.			
Settling of Berm	If settlement is apparent. Settling can be an indication of more severe problems with the berm or outlet works. A geotechnical engineer shall be consulted to determine the source of the settlement if the dike/berm is serving as a dam.			
Piping through Berm	Discernable water flow through basin berm. Ongoing erosion with potential for erosion to continue. A licensed geotechnical engineer shall be called in to inspect and evaluate condition and recommend repair of condition.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Tree and Large Shrub Growth on Downstream Slope of Embankments	Tree and large shrub growth on downstream slopes of embankments may prevent inspection and provide habitat for burrowing rodents.			
Erosion on Spillway	Rock is missing and soil is exposed at top of spillway or outside slope.			
Gate/Fence Damage	Damage to gate/fence, including missing locks and hinges			
†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.				

I.8 Wet Retention Basin Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ______________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Trash & Debris	Any trash and debris which exceed 5 cubic feet per 1,000 sf of basin area (one standard garbage can) or if trash and debris is excessively clogging the outlet structure. If less than threshold all trash and debris will be removed as part of next scheduled maintenance.			
Sediment Accumulation	Sediment accumulation in basin bottom that exceeds the depth of the design sediment zone plus 6 inches, usually in the first cell.			
Erosion	Erosion of basin's side slopes and/or scouring of basin bottom.			
Oil Sheen on Water	Prevalent and visible oil sheen.			
Noxious Pests	Visual observations or receipt of complaints of numbers of pests that would not be naturally occurring and could pose a threat to human or aquatic health.			
Water Level	First cell empty, doesn't hold water.			
Algae Mats	Algae mats over more than 20% of the water surface.			
Aesthetics	Minor vegetation removal and thinning. Mowing berms and surroundings			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Noxious Weeds	Any evidence of noxious weeds.			
Tree Growth	Tree growth does not allow maintenance access or interferes with maintenance activity (i.e., slope mowing, silt removal, vactoring, or equipment movements). If trees are not interfering, do not remove. Dead, diseased, or dying trees shall be removed.			
Settling of Berm	If settlement is apparent. Settling can be an indication of more severe problems with the berm or outlet works. A geotechnical engineer shall be consulted to determine the source of the settlement if the dike/berm is serving as a dam.			
Piping through Berm	Discernable water flow through basin berm. Ongoing erosion with potential for erosion to continue. A licensed geotechnical engineer shall be called in to inspect and evaluate condition and recommend repair of condition.			
Tree and Large Shrub Growth on Downstream Slope of Embankments	Tree and large shrub growth on downstream slopes of embankments may prevent inspection and provide habitat for burrowing rodents.			
Erosion on Spillway	Rock is missing and soil is exposed at top of spillway or outside slope.			
Gate/Fence Damage	Damage to gate/fence, including missing locks and hinges			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.9 Dry Extended Detention Basin Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ______________________ Inspector(s): ____________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1 or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
General				
Appearance	Untidy, un-mown (if applicable)			
Vegetation	Access problems or hazards; dead or dying trees			
	Poisonous or nuisance vegetation or noxious weeds			
Insects	Insects such as wasps and hornets interfere with maintenance activities.			
Rodent Holes	Any evidence of rodent holes if facility is acting as a dam or berm, or any evidence of water piping through dam or berm via rodent holes			
Trash and Debris	Trash and debris > 5 cf/1,000 sf (one standard size garbage can).			
Pollutants	Any evidence of oil, gasoline, contaminants or other pollutants			
Inlet/Outlet Pipe	Inlet/Outlet pipe clogged with sediment and/or debris. Basin not draining.			
Erosion	Erosion of the basin's side slopes and/or scouring of the basin bottom that exceeds 2-inches, or where continued erosion is prevalent.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1 or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Piping	Evidence of or visible water flow through basin berm.			
Settlement of Basin Dike/Berm	Any part of these components that has settled 4-inches or lower than the design elevation, or inspector determines dike/berm is unsound.			
Overflow Spillway	Rock is missing and/or soil is exposed at top of spillway or outside slope.			
Sediment Accumulation in Basin Bottom	Sediment accumulations in basin bottom that exceeds the depth of sediment zone plus 6-inches.			
Tree or shrub growth	Trees > 4 ft in height with potential blockage of inlet, outlet or spillway; or potential future bank stability problems			
Debris Barriers (e.g., Trash Racks)				
Trash and Debris	Trash or debris that is plugging more than 20% of the openings in the barrier.			
Damaged/ Missing Bars	Bars are bent out of shape more than 3 inches.			
	Bars are missing or entire barrier missing.			
	Bars are loose and rust is causing 50% deterioration to any part of barrier.			
Inlet/Outlet Pipe	Debris barrier missing or not attached to pipe.			
Fencing				
Missing or broken parts	Any defect in the fence that permits easy entry to a facility.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0, 1 or 2)†	Date Maintenance Performed	Comments or Action(s) Taken to Resolve Issue
Erosion	Erosion more than 4 inches high and 12-18 inches wide, creating an opening under the fence.			
Damaged Parts	Damage to gate/fence, posts out of plumb, or rails bent more than 6 inches.			
Deteriorating Paint or Protective Coating	Part or parts that have a rusting or scaling condition that has affected structural adequacy.			
Gates				
Damaged or missing member	Missing gate or locking devices, broken or missing hinges, out of plum more than 6 inches and more than 1 foot out of design alignment, or missing stretcher bar, stretcher bands, and ties.			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

I.10 Proprietary Device Inspection and Maintenance Checklist

Date: ______________________ Work Order # ________________

Type of Inspection: □ post-storm □ annual □ routine □ post-wet season □ pre-wet season

Facility: ____________________ Inspector(s): _________________

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Refer to the manufacturer's instructions for maintenance/inspection requirements, below are generic guidelines to supplement manufacturer's recommendations.				
Underground Vault				
Sediment Accumulation on Media	Sediment depth exceeds 0.25-inches.			
Sediment Accumulation in Vault	Sediment depth exceeds 6-inches in first chamber.			
Trash/Debris Accumulation	Trash and debris accumulated on compost filter bed.			
Sediment in Drain Pipes or Cleanouts	When drain pipes, clean-outs, become full with sediment and/or debris.			
Damaged Pipes	Any part of the pipes that are crushed or damaged due to corrosion and/or settlement.			
Access Cover Damaged/Not Working	Cover cannot be opened; one person cannot open the cover using normal lifting pressure, corrosion/deformation of cover.			
Vault Structure Includes Cracks in Wall, Bottom, Damage to	Cracks wider than 1/2-inch or evidence of soil particles entering the structure through the cracks, or maintenance/inspection personnel determine that the vault is not structurally sound.			

Defect	Conditions When Maintenance Is Needed	Inspection Result (0,1, or 2) †	Date Maintenance Performed	Comments or Action(s) taken to resolve issue
Frame and/or Top Slab	Cracks wider than 1/2-inch at the joint of any inlet/outlet pipe or evidence of soil particles entering through the cracks.			
Baffles	Baffles corroding, cracking warping, and/or showing signs of failure as determined by maintenance/inspection person.			
Access Ladder Damaged	Ladder is corroded or deteriorated, not functioning properly, not securely attached to structure wall, missing rungs, cracks, or misaligned.			
Below Ground Cartridge Type				
Filter Media	Drawdown of water through the media takes longer than 1 hour and/or overflow occurs frequently.			
Short Circuiting	Flows do not properly enter filter cartridges.			

†Maintenance: Enter 0 if satisfactory, 1 if maintenance is needed and include WO#. Enter 2 if maintenance was performed same day.

WATERSHED:	**SUBWATERSHED:**	**UNIQUE SITE ID:**

DATE:	**ASSESSED BY:**	**CAMERA ID:**	**PICTURES:**
GPS ID:	**LMK ID:**	**LAT:**	**LONG:**

SITE DESCRIPTION

Name:____

Address:____

Ownership: ☐ Public ☐ Private ☐ Unknown

If Public, Government Jurisdiction: ☐ Local ☐ State ☐ DOT ☐ Other:____________________

Corresponding USSR/USA Field Sheet? ☐ Yes ☐ No If yes, Unique Site ID:______________

Proposed Retrofit Location:

Storage

☐ Existing Pond ☐ Above Roadway Culvert
☐ Below Outfall ☐ In Conveyance System
☐ In Road ROW ☐ Near Large Parking Lot
☐ Other:________________________

On-Site

☐ Hotspot Operation ☐ Individual Rooftop
☐ Small Parking Lot ☐ Small Impervious Area
☐ Individual Street ☐ Landscape / Hardscape
☐ Underground ☐ Other:____________

DRAINAGE AREA TO PROPOSED RETROFIT

Drainage Area ≈ ______________

Imperviousness ≈ ______________%

Impervious Area ≈ ______________

Notes:

Drainage Area Land Use:

☐ Residential
- ☐ SFH (< 1 ac lots)
- ☐ SFH (> 1 ac lots)
- ☐ Townhouses
- ☐ Multi-Family

☐ Commercial

☐ Institutional
☐ Industrial
☐ Transport-Related
☐ Park
☐ Undeveloped
☐ Other:__________

EXISTING STORMWATER MANAGEMENT

Existing Stormwater Practice: ☐ Yes ☐ No ☐ Possible

If Yes, Describe:

Describe Existing Site Conditions, Including Existing Site Drainage and Conveyance:

Existing Head Available and Points Where Measured:

PROPOSED RETROFIT

Purpose of Retrofit:
☐ Water Quality ☐ Recharge ☐ Channel Protection ☐ Flood Control
☐ Demonstration / Education ☐ Repair ☐ Other:________________________________

Retrofit Volume Computations - Target Storage:	**Retrofit Volume Computations - Available Storage:**

Proposed Treatment Option:
☐ Extended Detention ☐ Wet Pond ☐ Created Wetland ☐ Bioretention
☐ Filtering Practice ☐ Infiltration ☐ Swale ☐ Other:______________________

Describe Elements of Proposed Retrofit, Including Surface Area, Maximum Depth of Treatment, and Conveyance:

SITE CONSTRAINTS

Adjacent Land Use:
☐ Residential ☐ Commercial ☐ Institutional
☐ Industrial ☐ Transport-Related ☐ Park
☐ Undeveloped ☐ Other:____________________
Possible Conflicts Due to Adjacent Land Use? ☐ Yes ☐ No
If Yes, Describe:

Access:
☐ No Constraints
Constrained due to
☐ Slope ☐ Space
☐ Utilities ☐ Tree Impacts
☐ Structures ☐ Property Ownership
☐ Other:____________________

Conflicts with Existing Utilities:
☐ None
☐ Unknown

Yes	**Possible**	
☐	☐	Sewer
☐	☐	Water
☐	☐	Gas
☐	☐	Cable
☐	☐	Electric
☐	☐	Electric to Streetlights
☐		Overhead Wires
☐	☐	Other:______________

Potential Permitting Factors:

Dam Safety Permits Necessary	☐ Probable	☐ Not Probable
Impacts to Wetlands	☐ Probable	☐ Not Probable
Impacts to a Stream	☐ Probable	☐ Not Probable
Floodplain Fill	☐ Probable	☐ Not Probable
Impacts to Forests	☐ Probable	☐ Not Probable
Impacts to Specimen Trees	☐ Probable	☐ Not Probable

How many?______________
Approx. DBH______________

Other factors:____
____

Soils:

Soil auger test holes:	☐ Yes	☐ No
Evidence of poor infiltration (clays, fines):	☐ Yes	☐ No
Evidence of shallow bedrock:	☐ Yes	☐ No
Evidence of high water table (gleying, saturation):	☐ Yes	☐ No

SKETCH

DESIGN OR DELIVERY NOTES

FOLLOW-UP NEEDED TO COMPLETE FIELD CONCEPT

- ☐ Confirm property ownership
- ☐ Confirm drainage area
- ☐ Confirm drainage area impervious cover
- ☐ Confirm volume computations
- ☐ Complete concept sketch
- ☐ Obtain existing stormwater practice as-builts
- ☐ Obtain site as-builts
- ☐ Obtain detailed topography
- ☐ Obtain utility mapping
- ☐ Confirm storm drain invert elevations
- ☐ Confirm soil types
- ☐ Other:____

INITIAL FEASIBILITY AND CONSTRUCTION CONSIDERATIONS

SITE CANDIDATE FOR FURTHER INVESTIGATION: ☐ YES ☐ NO ☐ MAYBE
IS SITE CANDIDATE FOR EARLY ACTION PROJECT(S): ☐ YES ☐ NO ☐ MAYBE
IF NO, SITE CANDIDATE FOR OTHER RESTORATION PROJECT(S): ☐ YES ☐ NO ☐ MAYBE
IF YES, TYPE(S):____

RB-AR35114





Managing Wet Weather with Green Infrastructure

Municipal Handbook

Green Streets

RB-AR35115

Managing Wet Weather with Green Infrastructure

Municipal Handbook

Green Streets

prepared by

Robb Lukes
Christopher Kloss
Low Impact Development Center

The Municipal Handbook is a series of documents
to help local officials implement green infrastructure in their communities.

December 2008

EPA-833-F-08-009

Front Cover Photos
Top: rain garden; permeable pavers; rain barrel;
planter; tree boxes.
Large photo: green alley in Chicago

Green Streets

Introduction

By design and function, urban areas are covered with impervious surfaces: roofs, roads, sidewalks, and parking lots. Although all contribute to stormwater runoff, the effects and necessary mitigation of the various types of surfaces can vary significantly. Of these, roads and travel surfaces present perhaps the largest urban pollution sources and also one of the greatest opportunities for green infrastructure use.

The Federal Highway Administration (FHA) estimates that more than 20% of U.S. roads are in urban areas.[1] Urban roads, along with sidewalks and parking lots, are estimated to constitute almost two-thirds of the total impervious cover and contribute a similar ratio of runoff.[2] While a significant source of runoff, roads are also a part of the infrastructure system, conveying stormwater along gutters to inlets and the buried pipe network. Effective road drainage, translated as moving stormwater into the conveyance system quickly, has been a design priority while opportunities for enhanced environmental management have been overlooked especially in the urban environment.

Table 1. Examples of Stormwater Pollutants Typical of Roads.[3, 4]

Pollutant	Source	Effects
Trash	---	Physical damage to aquatic animals and fish, release of poisonous substances
Sediment/solids	Construction, unpaved areas	Increased turbidity, increased transport of soil bound pollutants, negative effects on aquatic organisms reproduction and function
Metals • Copper • Zinc • Lead • Arsenic	 • Vehicle brake pads • Vehicle tires, motor oil • Vehicle emissions and engines • Vehicle emissions, brake linings, automotive fluids	Toxic to aquatic organisms and can accumulate in sediments and fish tissues
Organics associated with petroleum (e.g., PAHs)	Vehicle emissions, automotive fluids, gas stations	Toxic to aquatic organisms
Nutrients	Vehicle emissions, atmospheric deposition	Promotes eutrophication and depleted dissolved oxygen concentrations

The altered flow regime from traditional roadways, increased runoff volume, more frequent runoff events, and high runoff peak flows, are damaging to the environment and a risk to property downstream. These erosive flows in receiving streams will cause down cutting and channel shifting in some places and excessive sedimentation in others. The unnatural flow regime destroys stream habitat and disrupts aquatic systems.

Compounding the deliberate rapid conveyance of stormwater, roads also are prime collection sites for pollutants. Because roads are a component of the stormwater conveyance system, are impacted by atmospheric deposition, and exposed to vehicles, they collect a wide suite of pollutants and deliver them into the conveyance system and ultimately receiving streams (See Table 1). The metals, combustion by-products, and automotive fluids from vehicles can present a toxic mix that combines with the ubiquitous nutrients, trash, and suspended solids.

> **Green Streets** achieve multiple benefits, such as improved water quality and more livable communities, through the integration of stormwater treatment techniques which use natural processes and landscaping.

While other impervious surfaces can be replaced, for example using green roofs to decrease the amount of impervious roof surface, for the most part, impervious roads will, for some time to come, constitute a significant percentage of urban imperviousness because of their current widespread existence. Reducing road widths and other strategies to limit the amount of impervious surface are critical, but truly addressing road runoff requires mitigating its effects.

Roads present many opportunities for green infrastructure application. One principle of green infrastructure involves reducing and treating stormwater close to its source. Urban transportation right-of-ways integrated with green techniques are often called "green streets". Green streets provide a source control for a main contributor of stormwater runoff and pollutant load. In addition, green infrastructure approaches complement street facility upgrades, street aesthetic improvements, and urban tree canopy efforts that also make use of the right-of-way and allow it to achieve multiple goals and benefits. Using the right-of-way for treatment also links green with gray infrastructure by making use of the engineered conveyance of roads and providing connections to conveyance systems when needed.

Green streets are beneficial for new road construction and retrofits. They can provide substantial economic benefits when used in transportation applications. Billions of dollars are spent annually on road construction and rehabilitation, with a large percentage focused on rehabilitation especially in urban areas. Coordinating green infrastructure installation with broader transportation improvements can significantly reduce the marginal cost of stormwater management by including it within larger infrastructure improvements. Also, and not unimportantly, right-of-way installations allow for easy public maintenance. A large municipal concern regarding green infrastructure use is maintenance; using roads and right-of-ways as locations for green infrastructure not only addresses a significant pollutant source, but also alleviates access and maintenance concerns by using public space.

In urban areas, roads present many opportunities for coordinated green infrastructure use. Some municipalities are capitalizing on the benefits gained by introducing green infrastructure in transportation applications. This paper will evaluate programs and policies that have been used to successfully integrate green infrastructure into roads and right-of-ways.

Green Street Designs

Green streets can incorporate a wide variety of design elements including street trees, permeable pavements, bioretention, and swales. Although the design and appearance of green streets will vary, the functional goals are the same: provide source control of stormwater, limit its transport and pollutant conveyance to the collection system, restore predevelopment hydrology to the extent possible, and provide environmentally enhanced roads. Successful application of green techniques will encourage soil and vegetation contact and infiltration and retention of stormwater.

Alternative Street Designs (Street Widths)

A green street design begins before any BMPs are considered. When building a new street or streets, the layout and street network must be planned to respect the existing hydrologic functions of the land (preserve wetlands, buffers, high-permeability soils, etc.) and to minimize the impervious area. If retrofitting or redeveloping a street, opportunities to eliminate unnecessary impervious area should be explored.

Implementation Hurdles

Many urban and suburban streets, sized to meet code requirements for emergency service vehicles and provide a free flow of traffic, are oversized for their typical everyday functions. The Uniform Fire Code requires that streets have a *minimum 20 feet of unobstructed width;* a street with parking on both sides would require a width of at least 34 feet. In addition to stormwater concerns, wide streets have many detrimental implications on neighborhood livability, traffic conditions, and pedestrian safety.[5]

Oregon State Code Granting Authority for Street Standards to Local Government

ORS 92.044 - Local governments shall *supersede and prevail over any specifications and standards for roads and streets set forth in a uniform fire code adopted by the State Fire Marshal, a municipal fire department or a county firefighting agency*.... Local governments shall consider the needs of the fire department or fire-fighting agency when adopting the final specifications and standards.

The Transportation Growth and Management Program of Oregon, through a Stakeholder Design Team, developed a guide for reducing street widths titled the *Neighborhood Street Design Guidelines.*[6] The document provides a helpful framework for cities to conduct an inclusive review of street design profiles with the goal of reducing widths. Solutions for accommodating emergency vehicles while minimizing street widths are described in the document. They include alternative street parking configurations, vehicle pullout space, connected street networks, prohibiting parking near intersections, and smaller block lengths.

Figure 1. The street-side swale and adjacent porous concrete sidewalk are located in the High Point neighborhood of Seattle, WA
(Source: Abby Hall, US EPA).

In 1997, Oregon, which has adopted the *Uniform Fire Code,* specifically granted local government the authority to establish alternative street design standards but requires them to consult with fire departments before standards are adopted. Table 2 provides examples of alternative street widths allowed in U.S. jurisdictions.[7]

Swales

Swales are vegetated open channels designed to accept sheet flow runoff and convey it in broad shallow flow. The intent of swales is to reduce stormwater volume through infiltration, improve water quality through vegetative and soil filtration, and reduce flow velocity by increasing channel roughness. In the simple roadside grassed form, they have been a common historical component of road design. Additional benefit can be attained through more complex forms of swales, such as those with amended soils, bioretention soils, gravel storage areas, underdrains, weirs, and thick diverse vegetation.

Implementation Hurdles

There is a common misconception of open channel drainage being at the bottom of a street development hierarchy in which curb and gutter are at the top. Seattle's Street Edge Alternative Project and other natural drainage swale pilot projects have demonstrated that urban swales not only mitigate stormwater impacts, but they can also enhance the urban environment.[8]

Table 2. Examples of Alternative Street Widths

Jurisdiction	Street Width	Parking Condition
Phoenix, AZ	28'	parking both sides
Santa Rosa, CA	30' 26'-28' 20' 20'	parking both sides, <1000ADT parking one side no parking neck downs @ intersection
Orlando, FL	28' 22'	parking both sides, res. Lots<55' wide parking both sides, res. Lots>55' wide
Birmingham, MI	26' 20'	parking both sides parking one side
Howard County, MD	24'	parking unregulated
Kirkland, WA	12' 20' 24' 28'	alley parking one side parking both sides – low density only parking both sides
Madison, WI	27' 28'	parking both sides, <3DU/AC parking both sides, 3-10 DU/AC

ADT: Average Daily Traffic DU/AC: dwelling units per acre

Bioretention Curb Extensions and Sidewalk Planters

Bioretention is a versatile green street strategy. Bioretention features can be tree boxes taking runoff from the street, indistinguishable from conventional tree boxes. Bioretention features can also be attractive attention grabbing planter boxes or curb extensions. Many natural processes occur within bioretention cells: infiltration and storage reduces runoff volumes and attenuates peak flows; biological and chemical reactions occur in the mulch, soil matrix, and root zone; and stormwater is filtered through vegetation and soil.

Figure 2. This bioretention area takes runoff from the street through a trench drain in the sidewalk as well as runoff from the sidewalk through curb cuts *(Source: Abby Hall, US EPA).*

Implementation Hurdles

A few municipal DOT programs have instituted green street requirements in roadway projects, but as of yet, specifications for street bioretention have not yet been incorporated into municipal DOT specifications. Many cities do have street bioretention pilot projects; two of the well documented programs are noted in the table. Several concerns and considerations have prevented standard implementation of bioretention by DOTs.

Table 3. Municipalities with Swale Specifications and Standard Details

Municipality	Document	Section Title	Section #
City of Austin[9]	Standard Specifications and Standard Details	Grass-Lined Swale and Grass-Lined Swale with Stone Center	627S
City of Seattle[10]	2008 Standard Specifications for Municipal Construction	Natural Drainage Systems	7-21

Table 4. Municipalities with Bioretention Pilot Projects in the Right-of-Way

Municipality	Bioretention Type	Document
Maplewood, MN	Rain gardens	*Implementing Rainwater in Urban Stormwater Management* [11]
Portland, OR	• Curb extensions • Planters • Rain gardens	*2006 Stormwater Management Facility Monitoring Report* [12]

The diversity of shapes, sizes, and layouts bioretention can take is a significant obstacle to their incorporation with DOT specifications and standards. Street configurations, topography, soil conditions, and space availability are some of the factors that will influence the design of the bioretention facility. These variables make documentation of each new bioretention project all the more important. By building a menu of templates from local bioretention projects, future projects with similar conditions will be easier to implement and cost less to design. The documentation should include copies of the details and specifications for the materials used. A section on construction and operation issues, costs, lessons learned, and recommendations for similar designs should also be included in project documentation. Portland's Bureau of Environmental Services has proven adept at documenting each of its Green Streets projects and making them accessible online.[13]

Utilities are a chief constraint to implementing bioretention as a retrofit in urban areas. The Prince George's County, MD Bioretention Design Specifications and Criteria manual recommends applying the same clearance criteria recommended for storm drainage pipes.[14] Municipal design standards should specify the appropriate clearance from bioretention or allowable traversing.

Prince George's County, MD - 2.12.1.16 Utility Clearance

Utility clearances that apply to storm drainage pipe and structure placement also apply to bioretention. Standard utility clearances for storm drainage pipes have been established at 1' vertical and 5' horizontal. However, bioretention systems are shallow, non-structural IMP's consisting of mostly plant and soil components, (often) with a flexible underdrain discharge pipe. For this reason, other utilities may traverse a bioretention facility without adverse impact. Conduits and other utility lines may cross through the facility but construction and maintenance operations must include safeguard provisions. In some instances, bioretention could be utilized where utility conflicts would make structural BMP applications impractical.

Plants are another common concern of municipal staff, whether it is maintenance, salt tolerance, or plant height with regard to safety and security. Cities actively implementing LID practices in public spaces maintain lists of plants which fit the vegetated stormwater management practice niche. These are plants that flourish in the regional climate conditions, are adapted to periodic flooding, are low maintenance, and, if in cold climates, salt tolerant. Most often these plants are natives, but sometimes an approved non-native will best fit necessary criteria. A municipal plant list should be periodically updated based on maintenance experience, and vegetation health surveys.

Permeable Pavement

Permeable pavement comes in four forms: permeable concrete, permeable asphalt, permeable interlocking concrete pavers, and grid pavers. Permeable concrete and asphalt are similar to their impervious counterparts but are open graded or have reduced fines and typically have a special binder added. Methods for pouring, setting, and curing these permeable pavements also differ from the impervious versions. The concrete and grid pavers are modular systems. Concrete pavers are installed with gaps between them that allow water to pass through to the base. Grid pavers are typically a durable plastic matrix that can be filled with gravel or vegetation. All of the permeable pavement systems have an aggregate base in common which provides structural support, runoff storage, and pollutant removal through filtering and adsorption. Aside from a rougher unfinished surface, permeable concrete and asphalt look very similar to their impervious versions. Permeable concrete and asphalt and certain permeable concrete pavers are ADA compliant.

Implementation Hurdles

Figure 3. Pervious pavers used in the roadway of a neighborhood development in Wilsonville, OR *(Source: Abby Hall, US EPA).*

Of all the green streets practices, municipal DOTs have been arguably most cautious about implementing permeable pavements, though it should be noted that some DOTs have, for decades, specified open-graded asphalt for low use roadways because of lower cost; to minimize vehicle hydroplaning; and to reduce road noise. The reticence to implement on a large-scale, however, is understandable given the lack of predictability and experience behind impervious pavements. However, improved technology, new and ongoing research, and a growing number of pilot projects are dispelling common myths about permeable pavements.

The greatest concern among DOT staff seems to be a perceived lack of long-term performance and maintenance data. Universities and DOTs began experimenting with permeable pavements in parking lots, maintenance yards, and pedestrian areas as early as twenty years ago in the U.S., even earlier in Europe. There is now a wealth of data on permeable pavements successfully used for these purposes in nearly every climate region of the country. In recent years, the cities of Portland, OR, Seattle, WA, and Waterford, CT and several private developments have constructed permeable pavement pilots within the roadway with positive results.

The two typical maintenance activities are periodic sweeping and vacuuming. The City of Olympia, WA has experimented with several methods of clearing debris from permeable concrete sidewalks. Each of the methods was evaluated on the ease of use, debris removal, and the performance pace. The cost analysis by Olympia, WA found that the maintenance cost for pervious pavement was still lower than the traditional pavement when the cost of stormwater management was considered.

> Permeable pavement concerns in the roadway often raise concerns of safety, maintenance, and durability. Municipalities can replace impervious surfaces in other non-critical areas such as sidewalks, alleys, and municipal parking lots. These types of applications help municipalities build experience and a market for the technology.

Table 5. Municipalities with Permeable Pavement Specifications and Standard Details

Municipality	Document	Section Title	Section #
Portland	2007 Standard Construction Specifications	Unit Pavers (includes permeable pavers)	00760
Olympia	WSDOT Specification	Pervious Concrete Sidewalks	8-30

Freeze/thaw and snow plows are the major concerns for permeable pavements in cold climate communities. However, these concerns have proven to be generally unwarranted when appropriate design and maintenance practices are employed. A well designed permeable pavement structure will always drain and never freeze solid. The air voids in the pavement allow plenty of space for moisture to freeze and ice crystals to expand. Also, rapid drainage through the pavement eliminates the occurrence of freezing puddles and black ice. Cold climate municipalities will need to make adjustments to snow plowing and deicing programs for permeable pavement areas. Snow plow blades must be raised enough to prevent scraping the surface of permeable pavements, particularly paver systems. Also, sand should not be applied.

Table 6. A Study in Olympia, WA Comparison of the cost of permeable concrete sidewalks to the cost of traditional impervious sidewalks[15]

Traditional Concrete Sidewalk		Permeable Concrete Sidewalk	
Construction Cost	Maintenance Cost	Construction Cost	Maintenance Cost
$5,003,000*	$156,000	$2,615,000*	$147,000
Total = $5,159,000 $101.16 per square yard		Total = $2,762,000 $54.16 per square yard	

*The cost of stormwater management (stormwater pond) for the added impervious surface is factored into the significantly higher cost of constructing the traditional concrete sidewalk. Maintenance of the stormwater pond is also factored into the traditional concrete sidewalk maintenance cost.

Sidewalk trees and tree boxes

Figure 4. Trees planted at the same time but with different soil volumes, Washington DC
(Source: Casey Trees)

From reducing the urban heat island effect and reducing stormwater runoff to improving the urban aesthetic and improving air quality, much is expected of street trees. Street trees are even good for the economy. Customers spend 12% more in shops on streets lined with trees than on those without trees.[16] However, most often street trees are given very little space to grow in often inhospitable environments. The soil around street trees often becomes compacted during the construction of paved surfaces and minimized as underground utilities encroach on root space. If tree roots are surrounded by compacted soils or are deprived of air and water by impervious streets and sidewalks, their growth will be stunted, their health will decline, and their expected life span will be cut short. By providing adequate soil volume and a good soil mixture, the benefits obtained from a street tree multiply. To obtain a healthy soil volume, trees can simply be provided larger tree boxes, or structural soils, root paths, or "silva cells" can be used under sidewalks or other paved areas to expand root zones. These allow tree roots the space they need to grow to full size. This increases the health of the tree and provides the benefits of a mature sized tree, such as shade and air quality benefits, sooner than a tree with confined root space.

Table 7. Healthy Tree Volume and Permeable Pavement Specifications and Standard Details

Jurisdictions	Minimum Soil Volume	Section Title	Section #
Prince William County, VA	Large tree 970 cf Medium tree 750 cf Small tree 500 cf	Design Construction Manual (Sec 800)	Table 8-8
Alexandria, VA	300 cf	Landscape Guidelines	II.B. (2)

Implementation Hurdles

Providing an adequate root volume for trees comes down to a trade off between space in the right-of-way and added construction costs. The least expensive way to obtain the volume needed for roots to grow to full size is providing adequate space unhindered by utilities or other encroachments. However, it is often hard to reserve space dedicated just to street trees in an urban right-of-way with so many other uses competing for the room they need. As a result, some creative solutions, though they cost more to install, have become useful alternatives in crowded subsurface space. Structural soils, root paths, and "silva cells" leave void space for roots and still allow sidewalks to be constructed near trees.

Root Paths can be used to increase tree root volume by connecting a small tree root volume with a larger subsurface volume nearby. A tunnel-like system extends from the tree underneath a sidewalk and connects to an open space on the other side.

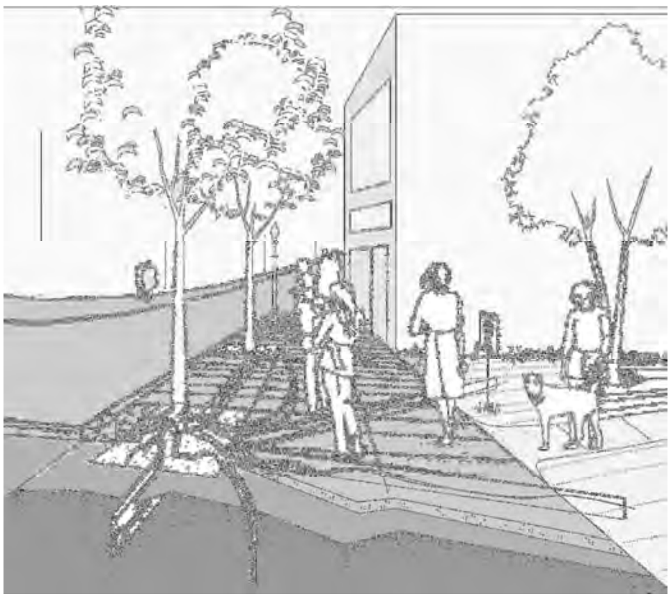

Figure 5. Root Paths direct tree roots under paving and into better soil areas for tree root growth
(Source: Arlington County, VA).

Silva Cells[17] are another option for supporting sidewalks near trees while still providing enough space for roots to grow. These plastic milk crate-like frames fit together and act as a supporting structure for a sidewalk while leaving room for uncompacted soil and roots inside the frame.

Permeable pavement sidewalks are another enhancement to the root space. They provide moisture and air to roots under sidewalks. Soils under permeable pavements can still become compacted. Structural soils[18] are a good companion tree planting practice to permeable pavement. When planting a tree in structural soils an adequate tree root volume is excavated and filled with a mix of stone and soil that still provides void space for healthy roots and allows for sidewalks, plazas or other paved surfaces to be constructed over them.

<u>Case Studies</u>

Portland, OR: Green Street Pilot Projects

Portland, Oregon is a national leader in developing green infrastructure. Portland's innovation in stormwater management was necessitated by the need to satisfy a Combined Sewer Overflow consent decree, Safe Drinking Water Act requirements, impending Total Maximum Daily Load limitations, Superfund cleanup measures and basement flooding. Through the 1990s, over 3 billion gallons of combined sewer overflow discharged to the Willamette River every year.[19] All of these factors plus leadership and local desires to create green solutions and industries compelled the city to implement green infrastructure as a complement to adding capacity to the sewer system with large pipe overflow interceptors. Despite gaps in long-term performance data, Portland took a proactive approach in implementing green infrastructure pilot projects.

Portland's green infrastructure pilot projects have their roots in the city's 2001 Sustainable Infrastructure Committee. The committee, consisting of representatives from Portland's three infrastructure management Bureaus, documented the city's ongoing efforts toward sustainable infrastructure, gathered research on green infrastructure projects from around the country, and identified opportunities for local pilots.[20, 21, 22]

Figure 6. Silva cell structures support the sidewalk while providing root space for street trees
(Source: Deep Root Partners, LP).

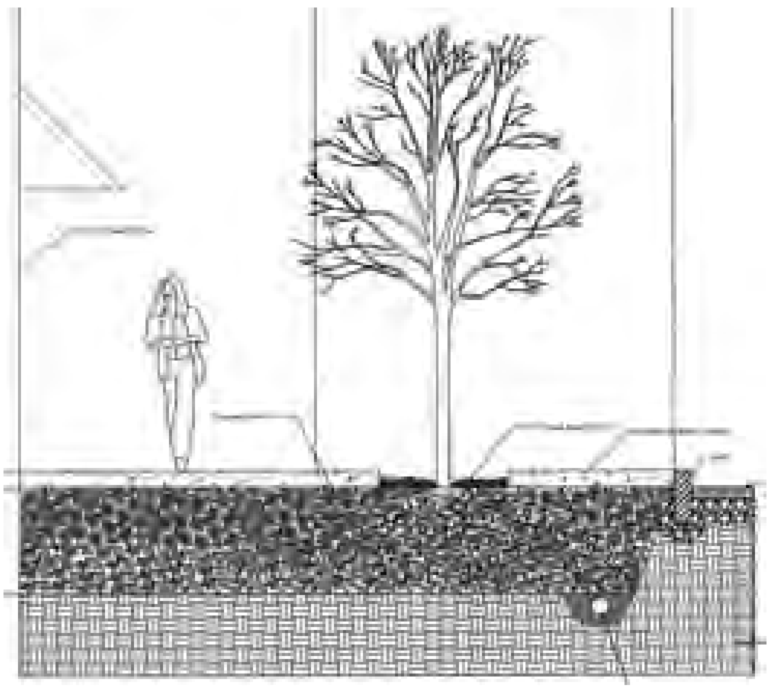

Figure 7. Structural soils provide void space for root growth and load-bearing for sidewalk
(Source: Urban Horticulture Institute, Cornell University).

One of the Bureau of Environmental Services' (BES) earliest green infrastructure retrofit projects within the right-of-way was a set of two stormwater curb extensions on NE Siskiyou Street. Portland had been retrofitting many streets with curb extensions for the purpose of pedestrian safety, but this was the first done for the purpose of treating street runoff. In a simulated 25-year storm event flow test, the curb extensions captured 85% of the runoff volume that would be discharged to the combined sewer system and reduced peak flow by 88%.[23]

Between 2003 and 2007, Portland designed and implemented a variety of Green Street pilots. Funding sources for these projects have come from BES, Portland Department of Transportation, U.S. EPA, and an Innovative Wet Weather Fund. BES combined funds with an EPA grant to create the Innovative Wet Weather Fund. In 2004, nearly $3 million from the Innovative Wet Weather Fund was budgeted for a long list of projects from city green roofs, public-private projects, and a number of pilot projects within the right-of-way.[24] Several pilots have been cost competitive with or less costly than conventional upgrades. The Bureau recognizes that costs will decrease once these projects become more routine. Many of the pilot project costs included one time costs such as the development of outreach materials and standard drawings.

Figure 8: NE Siskiyou Vegetated Curb Extensions
Source: City of Portland – Bureau of Environmental Services

Table 8. Portland, OR - Green Street Pilot Projects

Location	Design	Year Completed	Cost
NE Siskiyou b/w NE 35th Pl. and NE 36th Ave	Stormwater curb extension	2003	$20,000
3 blocks of the Westmoreland Neighborhood	Permeable Pavers in parking lanes and curb to curb	2004	$412,000
SE Ankeny b/w SE 56th and SE 57th Ave.	Stormwater curb extensions	2004	$11,946
NE Fremont b/w NE 131st and 132nd Av	Stormwater curb extension	2005	$20,400
SW 12th Ave b/w SW Montgomery and Mill	Stormwater planters	2005	$34,850
East Holladay Park	Pervious paver parking lot	2005	$165,000
4 blocks of North Gay Avenue b/w N Wygant and N Sumner	Porous concrete in curb lanes and curb to curb; porous asphalt in curb lanes and curb to curb	2005	--
SW Texas	Stormwater wetlands and swales	2007	$2.3 million
Division St. – New Seasons Market	Stormwater planters and swales	--	--
SE Tibbetts and SE 21st Ave.	Stormwater curb extension and planters	--	--

Source: Portland Bureau of Environmental Services, 2008
http://www.portlandonline.com/bes/index.cfm?c=44463&

Each of the pilot projects have been well documented by BES. A consistent format has been used to describe pilot background, features, engineering design, landscaping, project costs, maintenance, monitoring, and, most importantly, lessons learned. These case studies as well as other Green Street documentation can be found on BES's Sustainable Stormwater webpage, http://www.portlandonline.com/BES/index.cfm?c=34598. Due to physical factors (drainage, slope, soil, existing utilities, multiple uses) and development factors (retrofit, redevelopment, and new construction), there will be many variations on Green Streets. As part of the program, a continually updated Green Street Profile Notebook will catalog the successful green street projects. Users can use the Notebook for permitting guidance, to identify green streets facilities appropriate for various factors, but the document is not a technical document with standard details.

The Green Streets Team

The City of Portland, OR is widely acknowledged for long term, forward thinking, and comprehensive transportation and environmental planning. Portland recognized the fact that 66% of the City's total runoff is collected from streets and the right-of-way.[25] The city also saw the potential for transportation corridors to meet multiple objectives, including:

- Comprehensively address numerous City goals for neighborhood livability, sustainable development, increased green spaces, stormwater management, and groundwater protection;
- Integrate infrastructure functions by creating "linear parks" along streets that provide both pedestrian/bike areas and stormwater management;
- Avoid the key impacts of unmanaged stormwater whereby surface waterbodies are degraded, and water quality suffers;
- Manage stormwater with investments citizens can support, participate in, and see;
- Manage stormwater as a resource, rather than a waste;
- Protect pipe infrastructure investments (extend the life of pipe infrastructure, limit the additional demand on the combined sewer system as development occurs);
- Protect wellhead areas by managing stormwater on the surface; and
- Provide increased neighborhood amenities and value.

In a two phased process from 2005 to 2007, the Green Streets Team, a cross agency and interdisciplinary team, developed a comprehensive green streets policy and a way forward for the green streets agenda. Phase 1 identified challenges and issues and began a process for addressing them. Barriers to the public initiation of green street projects included a code and standards that would disallow or discourage green street strategies, long term performance unknowns, and maintenance responsibilities. To address these barriers, the Green Streets Team organized into subgroups focusing on outreach, technical guidance, infrastructure, maintenance, and resources.

Phase 2 of the Green Streets project synthesized the opportunities and solutions identified in Phase 1 into a citywide Green Streets Program. The first priority for this phase was the drafting of a binding citywide policy. The resolution was adopted by the Portland City Council in March 2007.

Prior to the start of the Portland effort, 90% of implemented green street projects were issued by private permits rather than city initiated projects.

Six Approaches to Implementing Green Streets	
Pathway	**Implementation**
City-initiated street improvement projects	City designs, manages, maintains
City-initiated stormwater retrofits	City designs, manages, maintains
Neighborhood-initiated LIDs	
Developer-initiated subdivisions with public streets	Developer designs and builds via City permit and review process, then turns over new right of way to the City after warranty period
Developer-initiated subdivisions with private streets	Developer designs and builds via City permit and review process, and turns over to home-owner association
Developer-related initiated frontage improvements on existing public streets	Developer designs and builds new sidewalks and curbs via City permit and review process, usually because the City required it via a building permit or via a land division

Source: Portland Green Streets, Phase 1

Portland City Council Approved Green Streets Policy

Goal: City of Portland will promote and incorporate the use of green street facilities in public and private development.

City elected officials and staff will:

1. Infrastructure Projects in the Right of Way:
   a. Incorporate green street facilities into all City of Portland funded development, redevelopment or enhancement projects as required by the City's September 2004 (or updated) Stormwater Management Manual. Maintain these facilities according to the May 2006 (or updated) Green Streets Maintenance Policy.

      If a green street facility (infiltrating or flow through) is not incorporated into the Infrastructure Project, or only partial management is achieved, then an off site project or off site management fee will be required.

   b. Any City of Portland funded development, redevelopment or enhancement project, that does not trigger the Stormwater Manual but requires a street opening permit or occurs in the right of way, shall pay into a "% for Green" Street fund. The amount shall be 1% of the construction costs for the project.
      Exceptions: Emergency maintenance and repair projects, repair and replacement of sidewalks and driveways, pedestrian and trail replacement, tree planting, utility pole installation, street light poles, traffic, signal poles, traffic control signs, fire hydrants, where this use of funds would violate contracted or legal restrictions.
2. Project Planning and Design:
   a. Foster communication and coordination among City Bureaus to encourage consideration of watershed health and improved water quality through use of green street facilities as part of planning and design of Bureau projects.
   b. Coordinate Bureau work programs and projects to implement Green Streets as an integrated aspect of City infrastructure.
   c. Plan for large-scale use of Green Streets as a means of better connecting neighborhoods, better use of the right of way, and enhancing neighborhood livability.
   d. Strive to develop new and innovative means to cost-effectively construct new green street facilities.
   e. Develop standards and incentives (such as financial and technical resources, or facilitated permit review) for Green Streets projects that can be permitted and implemented by the private sector. These standards and incentives should be designed to encourage incorporation of green street facilities into private development, redevelopment and enhancement projects.
3. Project and Program Funding:
   a. Seek opportunities to leverage the work and associated funding of projects in the same geographic areas across Bureaus to create Green Street opportunities.
   b. Develop a predictable and sustainable means of funding implementation and maintenance of Green Street projects.
4. Outreach:
   a. Educate citizens, businesses, and the development community/industry about Green Streets and how they can serve as urban greenways to enhance, improve, and connect neighborhoods to encourage their support, demand and funding for these projects.
   b. Establish standard maintenance techniques and monitoring protocols for green street facilities across bureaus, and across groups within bureaus.
5. Project Evaluation:
   a. Conduct ongoing monitoring of green street facilities to evaluate facility effectiveness as well as performance in meeting multiple City objectives for:
      - Gallons managed;
      - Projects distributed geographically by watershed and by neighborhood; and

The second priority for Phase 2 was developing communication and planning procedures for incorporating multi-bureaus plans into the scheduled Portland DOT Capital Improvement Program (CIP). Three timeframes for green street project planning were recommended. In the short term, the CIP Planning Group, backed by the citywide policy directive, will shift to a focus on "identifying and evaluating opportunities to partner." For example, coordinating Water Bureau and BES pipe replacement projects with DOT maintenance, repair, and improvement projects. The mid-term approach is more proactive and involves forecasting potential green street projects using existing bureau data and GIS tools. As for the long term, green street objectives will be incorporated into the citywide systems plan which guides city bureaus for the next 20 years.

The Green Street Team methodology propelled Portland's early green street pilot projects into a comprehensive, citywide multi-bureau program. The program built on previous efforts by the Sustainable Infrastructure Committee as well as other efforts such as the 2005 Portland Watershed Management Plan, established a City Council mandated policy, and institutionalized green street development. The outcome of this approach is multi-agency buy-in and responsibility for the effort. For instance, because of their knowledge of plant maintenance, Portland Parks and Recreation is responsible for the maintenance of some DOT installations.

Chicago, IL: Green Alleys Program

The City of Chicago, Illinois has an alley system that is perhaps the largest in the world. These 13,000 publicly owned alleys result in 1,900 miles, or 3,500 acres, of impermeable surfaces in addition to the street network. Because the alley system was not originally paved, there are no sewer connections as part of the original design. Over time the alleys were paved and flooding in garages and basements began to occur as a result of unmanaged stormwater runoff. Since the city already spends $50 million each year to clean and upgrade 4,400 miles of sewer lines and 340,000 related structures, the preferred solution to the flooded alleys is one that doesn't put more stress on an already overburdened and expensive sewer system.[26]

In 2003, the Chicago Department of Transportation (CDOT) used permeable pavers and French drain pilot applications to remedy localized flooding problems in alleys in the 48th Ward.[27] These applications proved to be successful and by 2006, CDOT launched its Green Alley Program with the release of the Chicago Green Alley Handbook (Handbook).[28]

The Chicago Green Alley Program is unique because it marries green infrastructure practices in the public right-of-way with green infrastructure efforts on private property. The user-friendly Handbook, which describes both facets of the program including the design techniques and their benefits, is an award winning document. The American Society of Landscape Architects awarded the creators of the Handbook the 2007 Communications Honor Award for the clear graphics and simple, yet effective, message.[29] The Handbook explains to the residents why green infrastructure is important, how to be good stewards of the Green Alley in their neighborhood, and what sorts of "green" practices they can implement on their property to reduce waste, save water, and help manage stormwater wisely.

While the initial impetus behind the Green Alley Program was stormwater management, Chicago decided to use this opportunity to address other environmental concerns as well as reducing the urban heat island effect, recycling, energy conservation, and light pollution.

Green Infrastructure in the Right-of-Way

Chicago's Green Alley Program uses the following five techniques in the public right-of-way to "green" the alley:

1. Changing the grade of the alley to drain to the street rather than pond water in the alley or drain toward garages or private property.

2. Using permeable pavement that allows water to percolate into the ground rather than pond on the surface.

3. Using light colored paving material that reflects sunlight rather than adsorbing it, reducing urban heat island effect.

4. Incorporating recycled materials into the pavement mix to reduce the need for virgin materials and reduce the amount of waste going into the landfill.

5. Using energy efficient light fixtures that focus light downward, reducing light pollution.

Figure 9: Permeable Asphalt Installation Using Ground Tire Rubber.
Source: Chicago Department of Transportation, Sustainable Development Initiatives; Streetscape and Urban Design Program, CDOT Division of Project Development.

Four design approaches were created using these techniques. Based on the local conditions, the most appropriate approach is selected. In areas where soils are well-draining, permeable pavement is used. In areas where buildings come right up to the edge of pavement and infiltrated water could threaten foundations, impermeable pavement strips are used on the outside with a permeable pavement strip down the middle. In areas where soils do not provide much infiltration capacity, the alley is regraded to drain properly and impermeable pavement made with recycled materials is used. Another approach utilizes an infiltration trench down the middle of the alley. Light colored (high albedo) pavement, recycled materials, and energy efficient, glare reducing lights are a part of each design approach.

Green Infrastructure on Private Property
The Handbook also describes actions that property owners can take to "green" their own piece of Chicago. The Handbook describes the costs, benefits, and utility of the following practices:

- Recycling;
- Composting;
- Planting a tree;
- Using native landscape vegetation;
- Constructing a rain garden;
- Installing a rain barrel;
- Using permeable pavement for patios;
- Installing energy efficient lighting; and
- Utilizing natural detention.

By bringing this wide range of "green" practices to the attention of homeowners, the positive impacts of the Green Alley Program spread beyond the boundaries of the right-of-way, increasing awareness and providing practical resources to help community members be a part of the solution.

Chicago Green Alley Cost Considerations
When the program began in 2006, repaving the alleys with impermeable pavement ranged in cost from $120,000 to $150,000, whereas a total Green Alley reconstruction was more along the lines of $200,000 to $250,000.[30] While less expensive conventional rehabilitation options may seem more attractive, they don't provide a solution to the localized flooding issues or the combined sewer system overflow problems. Sewer system connections could be established to solve the localized flooding problem, but it would add to the already overburdened sewer system and increase the cost of the reconstruction to that of the impermeable alley option. Consequently, the higher priced Green Alley option proved to be the best investment as it has multiple benefits in addition to solving localized flooding and reducing flow into the combined sewer system. The additional benefits of the Green Alley Program include not only urban heat

island effect reduction, material recycling, energy conservation, and light pollution reduction, but also the creation of a new market.

In 2006, when the Green Alley Program began, the city paid about $145 per cubic yard of permeable concrete. Just one year later, the cost of permeable concrete had dropped to only $45 per cubic yard. Compared with the cost of ordinary concrete, $50 per cubic yard, permeable concrete may have seemed like an infeasible option in the past to customers wanting to purchase concrete.[31] After the city's initial investment in the local permeable concrete market, the product cost has come down making permeable concrete a more affordable option for other consumers besides the city. This has resulted in an increased application of permeable concrete throughout the region.

Figure 10: Permeable Pavers and Permeable Concrete Chicago Alleys
(Source: Abby Hall, US EPA)

The success of the Chicago Green Alley Program is evident. Not only are the alleys been "greened" as a result of the program, the surrounding properties and even the surrounding neighborhoods are experiencing the positive impacts of the program's implementation.

Conclusions and Recommendations

Incorporating green streets as a feature of urban stormwater management requires matching road function with environmental performance. Enhancing roads with green elements can improve their primary function as a transportation corridor while simultaneously mitigating their negative environmental impacts. In theory and practice many municipalities are not far removed from dedicated green streets programs. Street tree and other greenscaping programs are often identified and promoted along urban transportation corridors. Adapting them to become fully functional green streets requires minor design modifications and an evaluation of how to maximize the benefits of environmental systems.

Portland's green streets program demonstrates how common road and right-of-way elements (e.g., traffic calming curb extensions, tree boxes) can be modified and optimized to provide stormwater management in addition to other benefits. The curb cuts and design variations to allow runoff to enter the vegetated areas are subtle changes with a significant impact and demonstrate how stormwater can be managed successfully at the source. One of the biggest successes of the program was reassessing common design features and realizing that environmental performance can be improved by integrating stormwater management.

Where Portland used vegetation, Chicago's Green Alley Program similarly demonstrates that hardscape elements can be an integral part of a greening program. By incorporating permeable pavements that simulate natural infiltration, Chicago enhances the necessary transportation function of alleys while enhancing infrastructure and environmental management. Portland also contrasts the "soft" and "hard" elements of green streets by using both permeable pavements and vegetated elements. The green options available demonstrate the flexibility of green infrastructure to satisfy road function and environmental objectives and highlight why transportation corridors are well suited for green infrastructure.

Elements necessary for a successful green streets program:

- **Pilot projects are critical.** The most successful municipal green street programs to date all began with well documented and monitored pilot projects. These projects have often been at least partially grant funded and receive the participation of locally active watershed groups working with the city infrastructure programs. The pilot projects are necessary to demonstrate that green streets can work in the local environment, can be relied upon, and fit with existing infrastructure. Pilot projects will help to dispel myths and resolve concerns.
- **Leadership in sustainability from the top.** The cities with the strongest green streets programs are those with mayors and city councils that have fully bought into sustainable infrastructure. Council passed green policies and mayoral sustainability mandates or mission statements are needed to institutionalize green street approaches and bring it beyond the token green project.
- **Buy-in from all municipal infrastructure departments.** By their nature, green streets cross many municipal programs. Green street practices impact stormwater management, street design, underground utilities, public lighting, green space planning, public work maintenance, and budgeting. When developing green streets, all of the relevant agencies must be represented. Also, coordination between the agencies on project planning is important for keeping green infrastructure construction costs low. Superior green street design at less cost occurs when sewer and water line replacement projects can be done in tandem with street redevelopment. These types of coordination efforts must happen at the long-term planning stage.
- **Documentation.** Green street projects need to be documented on two levels, the design and construction level and on a citywide tracking level. Due to the different street types and siting conditions, green street designs will take on many variations. By documenting the costs, construction, and design, the costs of similar future projects can be minimized and construction or design problems can be avoided or addressed. Tracking green street practices across the city is crucial for managing maintenance and quantifying aggregate benefits.
- **Public outreach.** Traditional pollution prevention outreach goes hand in hand with green street programs. Properly disposing of litter, yard waste, and hazardous chemicals and appropriately applying yard chemicals will help prolong the life of green street practices. An information campaign should also give the public an understanding of how green infrastructure works and the benefits and trade offs. In many cases, remedial maintenance of green street practices will be performed by neighboring property owners; they need to know how to maintain the practices to keep them performing optimally.

As public spaces, roads are prime candidates for green infrastructure improvements. In addition to enabling legislation, and technical guidance, developing a green streets program requires an institutional re-evaluation of how right-of-ways are most effectively managed. This process typically includes:

- Assessing the necessary function of the road and selecting the minimum required street width to reduce impervious cover;
- Enhancing streetscaping elements to manage stormwater and exploring opportunities to integrate stormwater management into roadway design; and
- Integrating transportation and environmental planning to capitalize on economic benefits.

The use of green streets offers the capability of transforming a significant stormwater and pollutant source into an innovative treatment system. Green streets optimize the performance of public space easing maintenance concerns and allowing municipalities to coordinate the progression and implementation of stormwater control efforts. In addition, green streets optimize the performance of both the transportation and water infrastructure. Effectively incorporating green techniques into the transportation network provides significant opportunity to decrease infrastructure demands and pollutant transport.

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RB-AR35133

United States Environmental Protection Agency
Office of Water (4203)
EPA 833-F00-005
January 2000 (revised December 2005)
Fact Sheet 2.3

Stormwater Phase II Final Rule

Public Education and Outreach Minimum Control Measure

This fact sheet profiles the Public Education and Outreach minimum control measure, one of six measures an operator of a Phase II-regulated small municipal separate storm sewer system (MS4) is required to include in its stormwater management program to meet the conditions of its National Pollutant Discharge Elimination System (NPDES) stormwater permit. This fact sheet outlines the Phase II Final Rule requirements and offers some general guidance on how to satisfy them. It is important to keep in mind that the regulated small MS4 operator has a great deal of flexibility in choosing exactly how to satisfy the minimum control measure requirements.

Why Is Public Education and Outreach Necessary?

An informed and knowledgeable community is crucial to the success of a stormwater management program since it helps to ensure the following:

- ***Greater support*** for the program as the public gains a greater understanding of the reasons why it is necessary and important. Public support is particularly beneficial when operators of small MS4s attempt to institute new funding initiatives for the program or seek volunteers to help implement the program; and

- ***Greater compliance*** with the program as the public becomes aware of the personal responsibilities expected of them and others in the community, including the individual actions they can take to protect or improve the quality of area waters**.**

What Is Required?

To satisfy this minimum control measure, the operator of a regulated small MS4 needs to:

- ❑ Implement a public education program to distribute educational materials to the community, or conduct equivalent outreach activities about the impacts of stormwater discharges on local waterbodies and the steps that can be taken to reduce stormwater pollution; and

- ❑ Determine the appropriate best management practices (BMPs) and measurable goals for this minimum control measure. Some program implementation approaches, BMPs (i.e., the program actions/activities), and measurable goals are suggested below.

What Are Some Guidelines for Developing and Implementing This Measure?

Three main action areas are important for successful implementation of a public education and outreach program:

❶ *Forming Partnerships*

Operators of regulated small MS4s are encouraged to utilize partnerships with other governmental entities to fulfill this minimum control measure's requirements. It is generally more cost-effective to use an existing program, or to develop a new regional or state-wide education program, than to have numerous operators developing their own local programs. Operators also are encouraged to seek assistance from non-governmental organizations (e.g., environmental, civic, and industrial organizations), since many already have educational materials and perform outreach activities.

❷ *Using Educational Materials and Strategies*

Operators of regulated small MS4s may use stormwater educational information provided by their State, Tribe, EPA Region, or environmental, public interest, or trade organizations instead of developing their own materials. Operators should strive to make their materials and activities relevant to local situations and issues, and incorporate a variety of strategies to ensure maximum coverage. Some examples include:

- ***Brochures or fact sheets*** for general public and specific audiences;
- ***Recreational guides*** to educate groups such as golfers, hikers, paddlers, climbers, fishermen, and campers;
- ***Alternative information sources,*** such as web sites, bumper stickers, refrigerator magnets, posters for bus and subway stops, and restaurant placemats;
- ***A library of educational materials*** for community and school groups;
- ***Volunteer citizen educators*** to staff a ***public education task force;***
- ***Event participation*** with educational displays at home shows and community festivals;
- ***Educational programs*** for school-age children;
- ***Storm drain stenciling*** of storm drains with messages such as "Do Not Dump - Drains Directly to Lake;"
- ***Stormwater hotlines*** for information and for citizen reporting of polluters;
- ***Economic incentives*** to citizens and businesses (e.g., rebates to homeowners purchasing mulching lawnmowers or biodegradable lawn products);and
- ***Tributary signage*** to increase public awareness of local water resources.

❸ *Reaching Diverse Audiences*

The public education program should use a mix of appropriate local strategies to address the viewpoints and concerns of a variety of audiences and communities, including minority and disadvantaged communities, as well as children. Printing posters and brochures in more than one language or posting large warning signs (e.g., cautioning against fishing or swimming) near storm sewer outfalls are methods that can be used to reach audiences less likely to read standard materials. Directing materials or outreach programs toward specific groups of commercial, industrial, and institutional entities likely to have significant stormwater impacts is also recommended. For example, information could be provided to restaurants on the effects of grease clogging storm drains and to auto garages on the effects of dumping used oil into storm drains.

What Are Appropriate Measurable Goals?

Measurable goals, which are required for each minimum control measure, are intended to gauge permit compliance and program effectiveness. The measurable goals, as well as the BMPs, should reflect the needs and characteristics of the operator and the area served by its small MS4. Furthermore, they should be chosen using an integrated approach that fully addresses the requirements and intent of the minimum control measure. Finally, they should allow the MS4 to make improvements to its program over each 5-year permit term by providing data on program successes and shortfalls.

EPA has developed a Measurable Goals Guidance for Phase II MS4s that is designed to help program managers comply with the requirement to develop measurable goals. The guidance presents an approach for MS4 operators to develop measurable goals as part of their stormwater management plan. For example, an MS4 could develop a stormwater public education campaign for radio and television. The goal of the campaign might be to increase the number of dog owners who pick up after their pets. To measure the program's progress towards this goal, the program manager might perform a stormwater public awareness survey at the beginning, during, and at the end of the permit term to gauge any change is pet owner behavior over time. As another example, an MS4 might want to encourage "do-it-yourselfers" to recycle used motor oil by establishing and advertising a municipal drop-off center. The MS4 could measure progress toward this goal by tracking the amount of motor oil collected and correlating those data to the timing of public service announcements and other advertisements to see if their message is being received.

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For Additional Information

Contacts

☞ U.S. EPA Office of Wastewater Management
http://www.epa.gov/npdes/stormwater
Phone: 202-564-9545

☞ Your NPDES Permitting Authority. Most States and Territories are authorized to administer the NPDES Program, except the following, for which EPA is the permitting authority:

Alaska	Guam
District of Columbia	Johnston Atoll
Idaho	Midway and Wake Islands
Massachusetts	Northern Mariana Islands
New Hampshire	Puerto Rico
New Mexico	Trust Territories
American Samoa	

☞ A list of names and telephone numbers for each EPA Region and State is located at http://www.epa.gov/npdes/stormwater (click on "Contacts").

Reference Documents

☞ EPA's Stormwater Web Site
http://www.epa.gov/npdes/stormwater
- Stormwater Phase II Final Rule Fact Sheet Series
- Stormwater Phase II Final Rule (64 *FR* 68722)
- National Menu of Best Management Practices for Stormwater Phase II
- Measurable Goals Guidance for Phase II Small MS4s
- Stormwater Case Studies
- Stormwater Month Materials
- And many others

☞ Getting In Step
http://www.epa.gov/owow/watershed/outreach/documents/getnstep.pdf

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Tailoring Outreach Programs to Minority and Disadvantaged Communities and Children

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Minimum Measure: Public Education and Outreach on Stormwater Impacts

Subcategory: Promoting the Stormwater Message

Description

Educational materials can be written in both English and other languages to ensure that a program's message reaches all intended audiences

Many residents of ethnically and culturally diverse communities don't speak English. English messages contained in signs, brochures, advertisements, newsletters and other outreach materials are mostly lost on these groups. For example, in areas like southern Florida and southern California, home to large populations of Spanish-speaking immigrants, it is important to engage non-English speaking residents and inform them about the importance of clean water because like any other community, their activities can generate a substantial amount of stormwater pollution. This type of expanded outreach program is not limited to these areas. Census 2000 figures show increasing minority populations in urban centers and suburbs such as Washington, DC (Fernandez, 2001; Cohn and Witt, 2001), and New York (Cohn, 2001), among others.

Communities can also target other groups for outreach activities. Disadvantaged persons may not have the opportunity to learn about or participate in existing programs or activities. Municipal representatives can design and implement education programs in poorer neighborhoods to address the concerns of residents, and they can suggest ways these residents can improve their neighborhood and environment.

Applicability

Municipalities typically know the locations of ethnic and low-income neighborhoods. However, historic boundaries between neighborhoods may not be accurate. It is important for municipalities to survey residents about neighborhood demographics and determine if a specialized campaign is needed in a particular area. A survey can target areas that the municipality deems likely to contain minority and disadvantaged residents. Municipalities can seek assistance from sociology departments at local universities to help with the survey effort, or they can hire a firm specializing in focus groups and polling to conduct the research.

Once minority and disadvantaged groups have been identified, an analysis of the target group should be conducted. This analysis should determine the audience's perception of stormwater issues. Knowing this helps the municipality tailor the outreach program to the appropriate knowledge base and address specific issues of concern. Tailoring the message will help motivate the groups to participate in the program. For

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example, does the audience know what a watershed is? Do they understand the causes of polluted runoff? If not, those terms should be defined in the messages.

To more effectively develop, format and distribute environmental messages, it helps to know how the target audience receives its information. Which newspapers, magazines, or newsletters do they read? To what organizations do they belong? Do they watch cable television or local news? Do they listen to community radio programs? Who are their opinion leaders, and how can they be reached?

Implementation

After gathering information on the target audience, a message should be crafted to engage them and help them achieve the objectives of the program. To be effective, the target audience must understand the message. It should appeal to them on their own terms.

Tailoring Programs for Minorities. Stormwater goals are more likely to be met by reaching the largest audience possible. However, smaller target audiences may need to be identified to ensure the message is understood. These smaller audiences include specific age groups, demographics, and nationalities. If the target audience contains a number of minority groups, the outreach strategy should address each individually. Minority group representatives can help develop the outreach strategy. Their insight can help ensure the message conveyed is the message intended.

In bilingual areas, materials should be developed in both English and the local language. Furthermore, care should be taken to ensure that the translation is accurate and the meaning of the message is not lost or changed. A classic example of a marketing mishap occured when General Motors introduced its Chevy Nova to Latin America. In Spanish "no va" means "it won't go," making the car very unattractive to buyers. Translated into Chinese, Pepsi's catch phrase "Come alive with the Pepsi generation" means "Pepsi brings your ancestors back from the grave." The language of the message should not only be correct but understandable. Scientific jargon should be avoided, and terms associated with the initiative (e.g., stormwater and runoff) should be clearly defined. Graphics should be used to convey the message, rather than text. If text must be used, it should be kept brief, direct, and clear. If the reading level of the audience (especially children) is unknown, the message can be pretested with representatives of the target group to determine its suitability.

Partnering with minority organizations can be the best way to reach a minority audience. Temples, churches, civic organizations, etc. interact with minority communities and understand their perspectives and motivations. They can provide specific information about the target group, and they can serve as an authority through which to channel the message. Organization leaders can be informed about the program's objectives and why it matters to their community. Organizations can announce upcoming events at meetings and services, publish releases in newsletters and notices, and organize presentations. It is important to stress how stormwater pollution prevention affects *them* in particular.

The news media are an important and powerful means of communicating watershed messages to both targeted and broad audiences (See Using the Media fact sheet. When a campaign is initiated, minority-focused newspapers, magazines, and television and radio stations in the area should be contacted. The proper format--whether in English, another language, or both--should be provided. Public service announcements and headlines should be culturally appropriate.

Tailoring Programs for Disadvantaged Communities. The same principles used to target specific audiences can apply to disadvantaged communities. A stormwater pollution message should be specific and tied to community values (such as clean drinking water or clean waters for fishing and recreation). The audience should know what their *direct benefit* will be from getting involved in the issue or modifying their behavior. For example, turning off the water hose when not in use can save them money on their water bill. Messages should be positive. Positive messages tend to be more effective in changing people's habits than negative ones: "Collect your used motor oil" instead of "Don't dump your oil." Other benefits that could be listed include money savings, time savings, convenience, health improvements, and efficiency. The message should focus on making the behavior change requested, the involvement needed, and the support required, user-friendly.

Tailoring Programs for Children. An outreach program can target children in many ways. Perhaps the easiest is through schools and day care centers. Child-targeted materials like posters, flyers and stickers, can be displayed in school libraries and playgrounds. Teachers might be willing to hand-out stormwater materials or organize special events, like stormwater pollution day or stormwater awareness month. Many watershed outreach programs sponsor water festivals that feature games, interactive booths, river and beach cleanups and essay contests. Stormwater

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pollution programs have often partnered with schools on poster, logo and slogan contests, with the winning entries used in outreach materials. Participants can receive certificates, T-shirts, posters and stickers.

Outreach materials for children should be simple and understandable. Graphics such as photos and mascots can help convey the message. Mascots become familiar faces, with distinct personalities, stories, and lives of their own. Child-friendly mascots can be used in comics, displays, and festivals. They can be featured in calendars, in student lessons and activities, such as skits or puppet shows, and on banners and posters. Interactive materials, like workbooks, "laboratory" experiments, puzzles and games, are especially effective because children learn more by doing than by simply "being told." Many stormwater program websites have added an interactive "kids' page" where children can learn about stormwater pollution by solving puzzles, playing games, and performing experiments on the Internet.

Involving children's organizations in specific, hands-on projects can help spread the message. Approach children's groups to help with stream cleanups, wetland plantings, and volunteer monitoring. Most stormwater programs partner with youth groups during storm drain stenciling projects. Such activities can be incorporated into the group's curriculum. For example, by participating in a storm drain stenciling project, Girl Scouts and Boy Scouts can earn environmental badges.

Community Calendar Gets the Message Out. In 1992, San Diego's Chollas Creek Watershed's Environmental Health Coalition (EHC) mailed a bilingual calendar to every business and home in their target watershed area. Winning entries from a school poster contest provided the art for each month. The English and Spanish calendar contained specific information on the different types of non-point source pollution, and offered tips on how residents could reduce their contribution to water pollution in San Diego Bay. Because a large portion of its target audience was ethnically diverse, the EHC expanded its calendar to include dates of interest to these communities. The calendar noted dates such as Kwanzaa, Boun Soang Heua, and the Chicano Moratorium. The EHC also included dates of activities from neighborhood churches, activity centers, and community groups. The center of the calendar featured a pull-out of a watershed painting by a renowned local artist. The calendar was printed on recycled paper using soy-based inks.

The calendar's success spawned similar calendars in two states and in Mexico. Though expensive and time-consuming to produce, the calendar provided education on water pollution prevention over an entire year, and represented a gift from the EHC (through their Chollas Creek Project) to the community.

Effectiveness

Targeting specific groups can be effective when municipalities understand the cultural, language, and special needs of such groups. Municipalities can gauge the effectiveness of their targeted outreach programs by monitoring participation in watershed cleanup and other environmental activities. They can survey residents about changes in their behavior resulting from outreach efforts, (See Attitude Surveys, or Stream Cleanup and Monitoring) and they can examine general environmental conditions (evidence of stormwater pollution, such as trash or motor oil spills) in or downstream from ethnic neighborhoods or low-income areas.

Benefits

Targeting specific audiences, especially if they constitute a large proportion of the population, yield many benefits. If the outreach program is tailored to a specific audience, the participants are more likely to feel that they are an important part of the effort. They can learn specific ways they help create stormwater pollution and how it affects their neighborhood's environment and quality of life. They also learn what they can do to help curb stormwater pollution and improve conditions in their neighborhood.

Limitations

By understanding the cultural issues, language barriers, and specific needs of their ethnic neighborhoods, municipalities can better engage and respond to residents involved in environmental efforts. Research is the key to identifying where target audiences live and how they get their information. The more a municipality knows about their target audience, the better they can use their limited resources to convey their message.

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Cost

The cost of targeting specific groups depends on the particular outreach materials and programs that are developed. Public service announcements and other news releases are generally free of charge, but staff time for preparation can be substantial. Costs for outreach materials vary widely, but municipalities can choose a medium appropriate to the available resources.

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Last updated on May 24, 2006
URL:http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm

ISOHYETAL MAP

RAINFALL RATE CONVERSION FACTORS	
STORM FREQUENCY RATING	RELATIVE ONE HOUR MAXIMUM RAINFALL
1 YEAR	0.428
5	0.659
10	0.762
25	0.898
50	1.000
100	1.108

1939 RUNOFF INSTRUCTIONS – REVISED 1967

R.W.F.

Figure G-41.1A

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County of Los Angeles Low Impact Development Standards Manual

January 2009

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CHAPTER 1: INTRODUCTION

Urbanization has the potential to impact the water resources in the County of Los Angeles. As land is developed, impervious area and surface runoff increase. Less water is percolated into the groundwater basins and runoff may collect and transport pollutants to the downstream receiving waters, including beaches, streams, and the flood control and water conservation systems of the County of Los Angeles. Low-Impact Development (LID) practices are one means to mitigate the impacts of development and urbanization.

WHAT IS LID?

LID is a new approach to managing rainfall and stormwater runoff. LID practices are designed to protect surface and groundwater quality, maintain the integrity of ecosystems, and preserve the physical integrity of receiving waters by controlling rainfall and stormwater runoff at or close to the source.

Use of these techniques helps reduce off-site runoff and ensure adequate groundwater recharge. LID techniques focus mainly on site-specific hydrology since every aspect of site development affects the hydrologic response of the site. Thus, the primary goal of LID methods is to mimic the undeveloped site hydrology using site-design techniques that store, infiltrate, evaporate, and detain runoff.

HOW DOES LID WORK?

The concept of LID is to distribute small, cost-effective landscape features throughout the project site. The source control concept is quite different from conventional regional treatment (pipe and large stormwater management basin design).

LID incorporates multifunctional site design elements or Best Management Practices (BMPs) for stormwater detention and water quality improvements. These multifunctional site design elements include the use of bioretention/filtration landscape areas, disconnected hydrologic flowpaths, reduced impervious surfaces, functional landscaping, and functional grading to maintain hydrologic functions that existed prior to development, such as infiltration, frequency and volume of discharges, and groundwater recharge.

BMPs are placed throughout the site in many small, discrete units and are distributed in a small portion of each lot or site near the source of impacts, virtually eliminating the need for a centralized facility, such as a regional stormwater management basin. By this process, a developed site can be designed as an integral part of the environment, maintaining undeveloped hydrologic functions through the careful use of LID BMPs. BMPs are defined and described in Chapter 5, Low-Impact Development Best Management Practices.

BMPs and the use of LID practices is most efficient and cost-effective when they are designed to capture and treat the most frequently occurring storm events as well as the first flush portion of runoff producing storm events. Numerous studies have shown that small storms, which occur more frequently than relatively large storms in Southern California, typically transport the greatest load of pollutants to local water bodies. The majority of pollutants are typically transported during the first flush portion of a runoff event, which is often considered to be the first 3/4 inch of a storm event.

CHANGE TO IMPROVE QUALITY OF LIFE

Historically, urban development and storm drain system design have consisted of streets, driveways, sidewalks, and structures constructed out of impervious materials that directly convey runoff to curb and gutter systems, the storm drain system, and downstream receiving waters. Until recently, conventional storm drainage and flood control systems have been designed to convey stormwater away from developed areas as quickly as possible without thoroughly addressing stormwater quality and/or groundwater recharge enhancement.

The natural absorption and infiltration abilities of the land are lost when natural vegetated pervious ground cover is converted to impervious surfaces, such as paved highways, streets, rooftops, and parking lots in conventional development. This can result in postdevelopment runoff with greater volume, velocity, and peak-flow rate than undeveloped runoff from the same area. Increased volume, velocity, rate, and duration of runoff can accelerate the erosion or sedimentation of downstream natural channels. Significant declines in the biological integrity and physical habitat of streams and other receiving waters may occur with a conversion from natural to impervious surfaces. Furthermore, ephemeral and intermittent streams, as found in the semiarid regions in Southern California, may be even more sensitive where a small increase of total impervious area can have impacts to stream morphology. Runoff durations can also increase as a result of flood control and other efforts to control peak-flow rates. See Table 1-1 for a listing of the potential impacts to a watershed due to conventional urban/suburban development.

Table 1-1 Degradation of watershed conditions and stream response.

Change in Watershed Condition	Stream Response
Increased pollutant loads	Metals, bacteria, and synthetic organic compounds: some acutely toxic, negative health effects in fish, altered spawning and migration of fish in presence of metals
	Nutrients: excessive aquatic plant growth; excessive diurnal oxygen fluctuations
Increased imperviousness	Increased storm flow volume and frequency
	Channel erosion
	Increased fine sediment and urban water pollutant loads
	Increased fish passage barriers

Increased fine sediment deposition	Reduced intergravel dissolved oxygen levels in streambed
	Loss of macroinvertebrate habitat
Loss of fragmentation of riparian areas	Reduced delivery of woody debris
	Reduced bank stability and loss of bank habitat structure and complexity
	Reduced shading and temperature control

Studies have shown that the collective discharge of untreated runoff from large areas of conventional residential, commercial, industrial, and municipal development often results in significant environmental impacts to local water resources. Until recently, conventional development has used existing storm drain system design methods that do not provide stormwater quality benefits.

Improvements in stormwater management have been made in the County of Los Angeles, but additional stormwater improvements are now required. With the addition of about 2.5 million new residents in the Los Angeles region by 2030, development in Los Angeles will continue to present challenges for stormwater treatment and management. Stormwater quality management techniques must be reconsidered in the design of new development and redevelopment. New and effective management through LID that improve the quantity and quality of stormwater is vital to the long-term economic growth and quality of life in the County of Los Angeles.

BENEFITS THROUGH THE USE OF LID

ENVIRONMENTAL BENEFITS

Pollution Abatement

LID practices can reduce both the volume of runoff and the pollutant loadings discharged into receiving waters. LID practices result in pollutant removal through settling, filtration, adsorption, and biological uptake. Reductions in pollutant loadings to receiving waters can improve habitat for aquatic and terrestrial wildlife and enhance recreational uses.

Protection of Downstream Water Resources

The use of LID practices can help prevent or reduce hydrologic impacts on receiving waters, reduce stream channel degradation from erosion and sedimentation, improve water quality, increase water supply, and enhance the recreational and aesthetic value of our natural resources. LID practices can be used to protect water resources that are downstream in the watershed. Other potential benefits include reduced incidence of illness from contact recreation activities, such as swimming and wading, more robust and safer seafood supplies, and reduced medical treatment costs.

Groundwater Recharge

LID practices can also be used to infiltrate runoff to recharge groundwater. Growing water shortages nationwide increasingly indicate the need for water resource management strategies designed to integrate stormwater, drinking water, and wastewater programs to maximize benefits and minimize costs. Development typically results in increases in the amount of impervious surface and volume of runoff.

Water Quality Improvements/Reduced Treatment Costs

It is almost always less expensive to keep water clean than it is to clean it up. A study of 27 water suppliers, conducted by the Trust for Public Land and the American Water Works Association, found a direct relationship between natural cover in a watershed and water supply treatment costs. In other words, communities with higher percentages of natural cover had lower treatment costs. According to the study approximately 50 to 55 percent of the variation in treatment costs can be explained by the percentage of forest cover in the source area.

Habitat Improvements

Innovative stormwater management techniques like LID or conservation design can be used to improve natural resources and wildlife habitat, maintain or increase land value, or avoid expensive mitigation costs.

LAND VALUE AND QUALITY OF LIFE BENEFITS

Reduced Downstream Flooding and Property Damage

LID practices can be used to reduce downstream impacts through the reduction of peak flows and the total volume of runoff. This can reduce property damage, the initial capital costs, and the operation and maintenance costs of flood control infrastructure. Strategies designed to manage runoff at the site, or as close as possible to its point of generation, can reduce erosion and sediment transport and reduce downstream impacts. As a result, the costs for clean ups and stream bank restoration can be reduced or avoided altogether. The use of LID techniques can also help protect or restore floodplains, which can be used as park space or wildlife habitat.

Real Estate Value/Property Tax Revenue

Various LID projects and smart growth studies have shown that people are willing to pay more for clustered homes than conventionally designed subdivisions. Clustered housing with open space is appreciated at a higher rate than conventionally designed subdivisions. The Environmental Protection Agency's *Economic Benefits of Runoff Controls* describes numerous examples where developers and subsequent homeowners have received premiums for proximity to attractive stormwater management practices. These designs should be visually attractive, safe for the residents, and should be considered an integral part of planning the development.

Aesthetic Value

LID techniques are usually attractive features because landscaping is an integral part of the designs. Designs that enhance a property's aesthetics using trees, shrubs, and flowering plants that complement other landscaping features can be selected. The use of these designs may increase property values or result in faster sale of the property due to the perceived value of the extra landscaping.

Quality of Life/Public Participation

Placing water quality practices on individual lots provides opportunities to involve homeowners in stormwater management and enhances public awareness of water quality issues. An American Lives, Inc., real estate study found that 77.7 percent of potential homeowners rated natural open space as essential or very important in planned communities.

LID GOALS

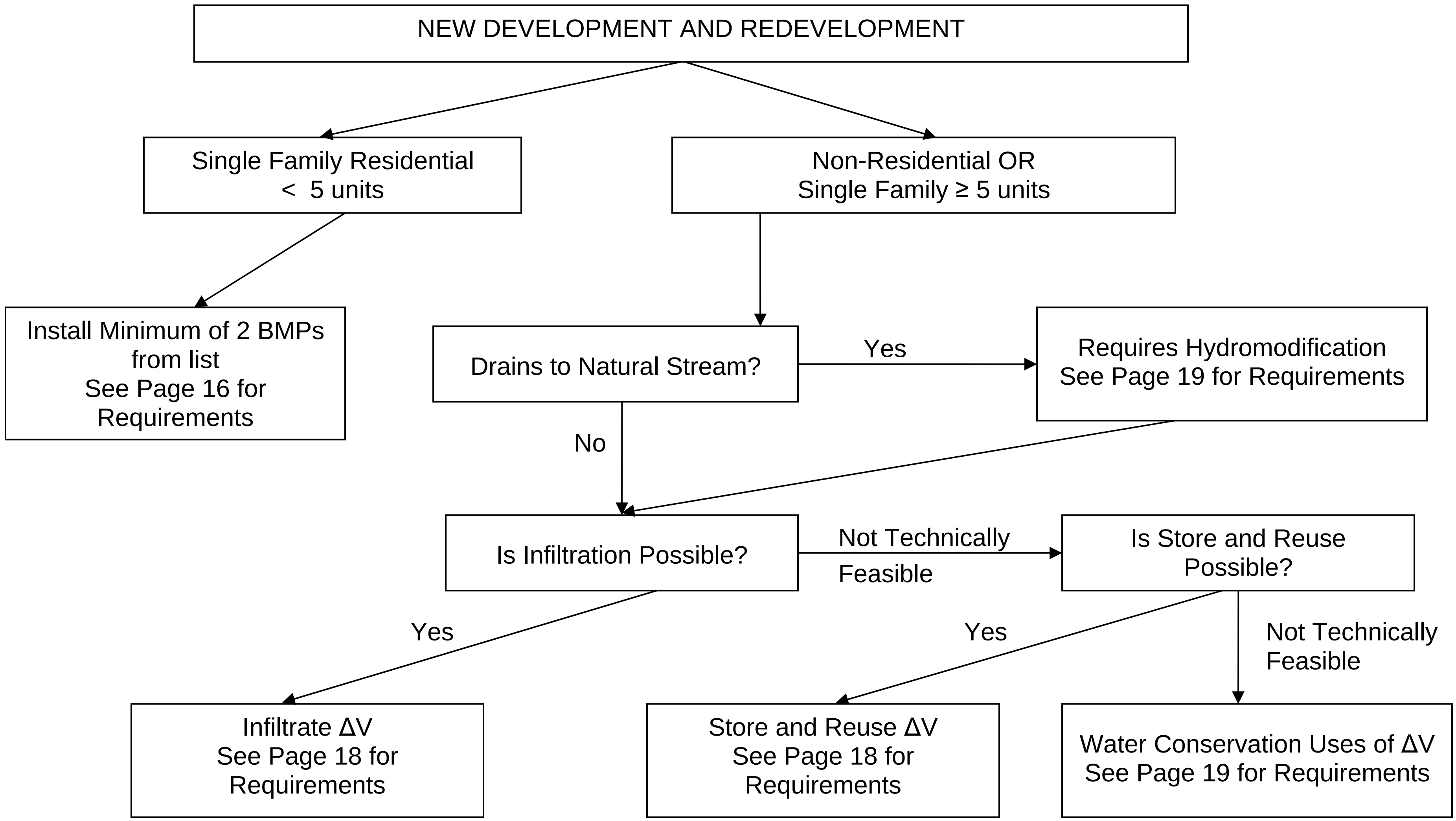
The goals of LID are discussed and demonstrated throughout the manual. The list below highlights some of the main goals and principles of LID:

- Provide an improved technology for water quality improvements of receiving waters and for additional groundwater recharge.
- Introduce new concepts, technologies, and objectives for stormwater management, such as micromanagement and multifunctional landscape features (bioretention areas, swales, and conservation areas), to mimic or replicate hydrologic functions and maintain the ecological/biological integrity of receiving streams.
- Encourage flexibility in regulations that allows innovative engineering and site planning to promote smart growth principles.
- Encourage environmentally sensitive development.
- Encourage public education and participation in environmental protection.

HOW TO USE THIS MANUAL

LID allows the site planner/engineer to use a wide array of simple cost-effective techniques that focus on site-level hydrologic control. This manual describes those techniques and provides examples and descriptions of how they work, and also contains BMP fact sheets. For ease of use and understanding, this document has been divided into 7 chapters. Figure 1-1 summarizes the major components of the LID approach. Compliance with the existing regulations is required by the County of Los Angeles Ordinance 22.52.2210.

LID DESIGN REQUIREMENTS



CHAPTER 2: SITE PLANNING AND SITE DESIGN

INTRODUCTION

A significant element in the implementation of LID, and one that should be incorporated at the earliest possible stage of a project, is the design and layout of the development site. Good LID site design takes advantage of the services provided by the site's natural systems. The natural systems that LID seeks to preserve and even restore are an undeveloped site's hydrologic functions, vegetation, and soils. LID site planning and design practices approach stormwater as a resource that should be conserved.

According to the National Association of Home Builders[1]:

> "LID (LID) strategies strive to allow natural infiltration to occur as close as possible to the original area of rainfall. By engineering terrain, vegetation, and soil features to perform this function, costly conveyance systems can be avoided, and the landscape can retain more of its natural hydrological function. LID practices dovetail with green building practices that incorporate environmental considerations into all phases of the development process. Builders can often use green building and LID to lower actual development costs. Although most effective when implemented on a community-wide basis, using LID practices on a smaller scale, i.e., on a small development, can also have an impact."

HYDROLOGIC FUNCTIONS

Natural hydrologic functions provide the following services in a watershed:

- Rainfall interception: In a vegetated watershed, the surfaces of trees, shrubs, and grasses catch initial light rainfall before it reaches the ground. Interception can delay the start and lower the volume of runoff.

- Shallow surface storage: The shallow pockets present in natural terrain store rainfall and runoff, filtering and allowing infiltration, and delaying the start of runoff.

- Evaporation and transpiration: Evaporation occurs when water changes from a liquid to a vapor and moves into the air. Transpiration occurs when vegetation releases water vapor into the atmosphere. Both processes reduce the volume of runoff, locally return moisture to the atmosphere, and provide local cooling effects. Collectively, this process is called evapotranspiration.

[1] National Association of Home Builders Research Center, *Low Impact Development (LID) Practices for Storm Water Management*, http://toolbase.org/Technology-Inventory/Sitework/low-impact-development, accessed April 7, 2008.

- Infiltration: Infiltration is the movement of surface water down through the soil into groundwater. Such movement filters and reduces the volume of runoff and replenishes groundwater supplies.

- Runoff: Runoff is the flow of water across the land surface that occurs after rainfall interception, surface storage, and infiltration reach capacity.

Hydrologic processes can be adversely impacted by land development through:

- Removing vegetation: The loss of vegetative canopy reduces the amount of rainfall intercepted. The loss of deep root systems allows soils to compress and lose storage and infiltration capacity. The loss of leaf litter and organic matter on the ground removes a number of beneficial physical, chemical, and biological processes that treat runoff.

- Covering porous soils with impervious surfaces: Rainfall that could have been stored or infiltrated is converted directly into runoff, carrying with it the pollution associated with the land use. Rainfall and runoff that could have recharged groundwater reservoirs for later reuse are lost.

- Replacing natural drainage paths with paved pathways, pipes, and channels: While efficiently removing water from a site, hardened conveyances collect the increased runoff with greater speed, causing higher flow rates, the loss of infiltration potential at the site, increased erosion in natural and soft-bottomed channels, and the loss of in-stream and streamside habitat.

VEGETATION

Vegetation provides the following services[2] in a watershed:

- Intercepts rainfall.

- Stores water in plant tissue.

- Filters air and water pollution.

- Provides erosion control.

- Keeps soil pore structure open for storage and infiltration of water.

- Pipes water along roots and into the soil.

- Provides water vapor through transpiration.

- Balances oxygen and carbon dioxide in the atmosphere by photosynthesis.

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[2] American Society of Landscape Architects, et al., *Sustainable Sites Initiative, Preliminary Report on Standards & Guidelines*, November 1, 2007.

- Moderates the climate globally and locally by regulating greenhouse gasses and lowering heat island effects.

- Provides habitat for resident and migratory animals; provides connective habitat in urbanized areas.

Vegetation can be adversely impacted by land development through:

- Disturbance and removal: With the absence of vegetation, a site will lose its capacity to infiltrate, absorb, and filter runoff. Local heat island effects would be created. Soil health would suffer as soils become compacted. Erosion and sedimentation would increase.

- Inadequate space: Confined planting patterns, including cramped root zones, limit healthy plant growth, leading to increased maintenance and premature death of vegetation.

- Introduction of invasive plants: Some plants that are not native to the area can overtake the native or California friendly species, threatening native organisms.

SOILS

Healthy soils provide the following services[3] in a watershed:

- Regulate infiltration, runoff, erosion, sedimentation, and flooding.
- Increased capacity for the storage of water.
- Support growth of vegetation.
- Filter pollutants in runoff.
- Support production of food and raw materials.
- Support the nitrogen cycle.
- Lockup carbon.
- Provide biological habitats.

Soils can be adversely impacted by land development through:

- Compaction: Soil compaction disturbs native soil structure, reduces infiltration rates, and limits root growth and plant survivability. While soil compaction is necessary to provide structurally sound foundations, areas away from foundations are often excessively compacted by vehicle and foot traffic during construction.

[3] Ibid.

- Removal of vegetation: Removal of vegetation can expose soils to erosion and thus cause sedimentation and the modification of natural streams. Disturbance of soil can also release previously locked organic carbons into the atmosphere[4].

- Removal of topsoil: A common practice is the removal of topsoil before or during construction. This practice removes native seeds, removes soil organisms, impedes the reestablishment of healthy soils, and upsets the native soil structure even if the original soil is returned.

- Contamination: The application of pesticides and herbicides can introduce toxic organics and metals into the soil, which can bioaccumulate in higher organisms and possibly get into food sources. Broadly applied pesticides and herbicides could impact unintended species including those found in the soil. Such disruption can adversely affect resistance to pathogens, infiltration, and the filtering of pollutants.

SITE DESIGN PRACTICES[5] FOR LID

The goals of LID are to mimic undeveloped hydrology and control runoff at the source. These goals are accomplished with creative site planning and the incorporation of localized, naturally functioning BMPs into the site's design.

The first step in creating a LID design is site planning. The elements[6] that make up a successful low-impact site plan are:

1. Conserving natural areas, soils, and vegetation.

2. Minimizing disturbances to natural drainage patterns.

3. Minimizing and disconnecting impervious surfaces.

4. Minimizing soil compaction.

5. Directing runoff from impervious areas to pervious areas.

CONSERVING NATURAL AREAS, SOILS, AND VEGETATION

The conservation of natural areas, soils, and vegetation helps to retain numerous functions of predevelopment hydrology, including rainfall interception, infiltration, and evapotranspiration. Maximizing these functions will thereby reduce the amount of runoff that must be treated. Further, minimizing soil disturbance reduces the emission of

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[4] Lal, R., "Soil Carbon Sequestration Impacts on Global Climate Change and Food Security," Science 304: 1623-7 (2004), in *Sustainable Sites Initiative*.
[5] American Society of Landscape Architects, et al., op cit.
[6] County of San Diego, *Low Impact Development Handbook*, December 31, 2007.

greenhouse gasses[7] and conserves natural habitat. For these reasons, site planning, design, and execution, where appropriate, should:

1. Conform to local watershed, conservation, and open space plans.
2. Preserve sensitive environmental areas.
3. Preserve historically undisturbed vegetated areas.
4. Build upon the least porous soils or limit construction activities and disturbances to areas with previously disturbed soils.
5. Protect healthy soils, reuse the top soils already on the site, and import soil only when on-site soils are exhausted.
6. Preserve the maximum surface area of undisturbed grades.
7. Preserve native trees and restrict disturbance of soils beneath tree canopies.
8. Avoid disturbing vegetation and soil on slopes and near surface waters.
9. Leave an undisturbed buffer along both sides of natural streams.
10. Avoid adding materials to the soil that decrease cation exchange capacity (CEC), such as sand, except where required for special water treatment needs.

Examples of conserving natural areas, soils, and vegetation:

- Avoid mass clearing and grading, and grade only those areas where structures are to be built.
- Protect existing streamside areas and habitat.
- Mulch tree and plant beds.
- Incorporate plants to suit existing soil and drainage conditions rather than changing soil and drainage conditions to suit a desired plant list.
- Create multilayered planting schemes that replicate natural sites with both canopy and vegetative ground cover.
- Incorporate compost to increase water retention and soil moisture and reduce the need for fertilizer.
- Use appropriate vegetative plantings and bioremediation techniques to remove or neutralize soil contaminants.

[7] Lal, R., op cit

- Cluster development to preserve porous soils, natural streams, and natural slopes.

MINIMIZING DISTURBANCES TO NATURAL DRAINAGE PATTERNS

Minimizing disturbances to natural drainage patterns preserves the predevelopment timing, rate, and duration of runoff as well as preserving streamside habitats. Preserving the predevelopment drainage characteristics will also minimize the physical impacts on a natural stream. For these reasons, site planning, design, and execution, where appropriate, should:

1. Maintain surface flow patterns of undeveloped sites.

2. Maintain existing water body alignments, sizes, and shapes.

3. Protect seasonal flooding patterns of wetlands.

4. Restore streams and drainage corridors to achieve the same characteristics of timing, flow, and habitat as the original drainage courses in the event that preservation of natural drainage patterns cannot be maintained.

   Examples of minimizing disturbances to natural drainage patterns:

   - Avoid burying, piping, or channelizing streams by carefully planning water crossings and considering alternatives to traditional culverts, even for small crossings.

   - Daylight piped stream systems and restore stream banks and channels to historic, healthy configurations.

   - Avoid the concentration of surface runoff.

   - Avoid large, shallow, and unshaded water features that can increase water temperatures in receiving waters.

   - Create or restore wetlands and riparian areas to absorb, filter, and attenuate runoff.

   - Restore organic matter levels in all root zones to levels consistent with similar soil types in undisturbed regional soils.

   - Minimize manicured lawns and annuals beds as the dominant site elements.

MINIMIZING AND DISCONNECTING IMPERVIOUS SURFACES

Minimizing and disconnecting impervious surfaces increase the chance for rainfall and runoff to infiltrate into the ground, thereby reducing, slowing, and filtering runoff, and increasing groundwater supplies. For these reasons site planning, design, and execution, where appropriate, should:

1. Reduce overall impervious areas by maximizing landscaping and using pervious pavements.

2. Reduce the amount of impervious areas that are hydraulically connected to impervious conveyances, such as driveways, walkways, culverts, swales, streets, or storm drains.

   Examples of minimizing and disconnecting impervious surfaces:

   - Use porous pavements on private property for sidewalks and less traveled surfaces, such as driveways, fire lanes, bike lanes, parking lanes, overflow parking, and parking stalls.
   - Install shared driveways, flared driveways, and residential driveways with center vegetated strips.
   - Provide for shared parking in commercial areas.
   - Direct roof downspouts to vegetated areas, rain gardens, or planter boxes.
   - Isolate paved areas with buffers.
   - Modify curb and gutter and route runoff in vegetated swales.
   - Reduce a building's footprint by building upward rather than outward.
   - Install rain barrels and cisterns below roof downspouts.
   - Install a green roof.

MINIMIZING SOIL COMPACTION

Soil compaction damages soil structure, reduces infiltration rates, limits root growth and plant survivability, and destroys soil organisms. Reduced infiltration creates increased runoff volume. Uncompacted soils support vegetation, support organisms, and store and infiltrate water. For these reasons site planning, design, and execution, where appropriate, should:

1. Restrict grading and compaction to those areas that will support structures.

2. Protect soils, especially porous soils, against compaction and rutting in areas where traffic is unavoidable.

3. Minimize the size of construction easements and material storage areas.

4. Site stockpiles within the development envelope during the construction phase of a project.

5. Prohibit working on wet soils with heavy equipment.

6. Restore compacted open space areas with tilling and soil amendments.

   Examples of minimizing soil compaction:

   - Incorporate a soil noncompaction and restoration plan into the project's construction phase Storm Water Pollution Prevention Plan.

   - Till into compacted soils 3 inches of well-aged organic mulch to a depth of 12 inches after grading.

DIRECTING RUNOFF FROM IMPERVIOUS AREAS TO INFILTRATION AREAS

Runoff across impervious areas will flow faster and carry pollutants accumulating on the impervious surfaces. The prevention of surface infiltration will also create more runoff volume. Directing runoff to infiltration areas will slow the velocity, filter out pollutants, and replenish groundwater. Infiltration has been found to be a reasonable and practical method for reducing pollutant load provided there is suitable pretreatment[8]. For these reasons site planning, design, and execution, where appropriate, should:

1. Grade surfaces to drain toward open space, swales, or bioretention cells with infiltration capability.

2. Grade surfaces to drain through suitable pretreatment trains toward porous pavements with infiltration capability.

3. Use grassed or vegetated swales with infiltration capability to convey runoff rather than using conduit and lined conveyances.

   Examples of directing runoff from impervious areas to infiltration areas:

   - Design streets to drain to grassed or vegetated swales or bioretention cells with infiltration capability.

   - Grade parking areas to drain to grassed or vegetated swales, bioretention cells, and/or pervious pavements with infiltration capability.

   - Grade driveways to drain sideways to adjacent pervious areas with infiltration capability rather than to the street.

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[8] Los Angeles/San Gabriel Rivers Watershed Council, *L. A. Basin Water Augmentation Study*, www.lasgrwc.org/WAS.htm, accessed March 31, 2008.

- Direct roof runoff to vegetated swales, planter boxes, or bioretention cells with infiltration capability.
- Raise stormwater inlets in planting areas to allow water to soak into the soil where it can infiltrate.

CHAPTER 3: DESIGN REQUIREMENTS

All new development and redevelopment under the jurisdiction of the County of Los Angeles is required to meet LID requirements. The goals of LID are to increase groundwater recharge, enhance water quality, and prevent degradation to downstream natural drainage courses.

REQUIREMENTS FOR SMALL SCALE RESIDENTIAL PROJECTS

Residential development and redevelopment of four units or less, or remodels affecting more than 50 percent of the original home footprint are not required to complete hydrologic analysis for the project site, but must include at least two of the following items into the site design:

- Porous pavement

  Install porous pavement that allows rainwater to infiltrate through it. Porous pavement includes, but is not limited to, porous asphalt, porous concrete, ungrouted paving blocks, and gravel. At least 50 percent of the pavement on the lot shall be porous.

- Downspout routing

  Each roof downspout shall be directed to one of the following BMPs. The sum of the capacity of the downspout BMPs shall be at least 200 gallons.

  a. Cistern/rain barrel

     Direct roof downspouts to rain barrels or cisterns. The stored stormwater can then be used for irrigation or other nonpotable uses.

  b. Rain garden/planter box

     Direct roof downspouts to rain gardens or planter boxes that provide retention and treatment of stormwater.

- Disconnect impervious surfaces

  Slope driveways and other impervious surfaces to drain toward pervious surfaces. If possible, runoff should be directed toward vegetated areas or water quality BMPs. Limit the total area not directed toward vegetated areas or water quality BMPs to 10 percent or less of the area of the lot.

- Dry well

  Install a dry well to infiltrate stormwater. The dry well shall be sized to hold at least 200 gallons of stormwater.

- Landscaping and landscape irrigation

  Plant trees near impervious surfaces to intercept rainfall in their leaves. Trees planted adjacent to impervious surfaces can intercept water that otherwise would have become runoff. Two trees shall be planted on each parcel so that they overhang impervious surfaces. Install irrigation systems that minimize water usage and eliminate dry-weather urban runoff.

- Green roof

  Install a green roof to retain and treat stormwater on the rooftop. A green roof shall cover at least 50 percent of the total rooftop area.

REQUIREMENTS FOR LARGE SCALE DEVELOPMENT

All residential developments of five units or greater and all nonresidential developments shall follow the LID Hydrologic Analysis techniques outlined in the Hydrologic Analysis Section of this manual.

LID Requirements

Large scale residential and nonresidential development projects shall prioritize the selection of BMPs to treat stormwater pollutants, reduce stormwater runoff volume, and promote groundwater infiltration and stormwater reuse in an integrated approach to protecting water quality and managing water resources. BMPs shall be implemented in the following order of preference:

1. BMPs that promote infiltration.

2. BMPs that store and beneficially use stormwater runoff.

3. BMPs that utilize the runoff for other water conservation uses including, but not limited to, BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction and integrate multiple uses, and BMPs that percolate runoff through engineered soil and allow it to discharge downstream slowly.

4. If the Director of Public Works determines that compliance with the above (No. 3) LID requirements is technically infeasible, in whole or in part, in response to an applicant's submittal, the Director shall require the applicant to submit a proposal for approval by the Director that incorporates design features demonstrating compliance with the LID requirements to the maximum extent practicable.

The LID goals of increasing groundwater recharge, enhancing water quality, and preventing degradation to downstream natural drainage courses shall be used in the evaluation, approval, and implementation of LID BMPs, as well as any determination of infeasibility.

On-site Infiltration Requirements

The excess volume (ΔV) determined by the hydrologic analysis in Chapter 4 shall be infiltrated throughout the project site whenever possible. This can be accomplished on a lot-by-lot or on a subregional scale provided that equivalent benefit can be demonstrated. The following requirements apply:

- Infiltrate the ΔV from each lot at the lot level, or
- Infiltrate the ΔV from the entire project site including streets and public right of way in subregional facilities. The tributary area of a subregional facility shall generally be limited to 5 acres, but may be exceeded per the Director of Public Works.

Infiltration may not be possible in all development scenarios. Exceptions may include, but are not limited to, the following technical feasibility and implementation parameters:

- Locations where seasonal high groundwater is within 10 feet of the surface.
- Within 100 feet of a groundwater well used for drinking water.
- Brownfield development sites or other locations where pollutant mobilization is a documented concern.
- Locations with potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer.
- Locations with natural, undisturbed soil infiltration rates of less than 0.5 inches per hour that do not support infiltration-based BMPs.
- Locations where infiltration could cause adverse impacts to biological resources.
- Development projects in which the use of infiltration BMPs would conflict with local, State or Federal ordinances or building codes.
- Locations where infiltration would cause health and safety concerns

On-site Storage and Reuse Requirements

When infiltration is not possible, on-site storage and reuse of the ΔV is the next preferred LID BMP option. Storage and reuse of the ΔV may not be possible in all development scenarios. Exceptions may include, but are not limited to, the following technical feasibility and implementation parameters:

- Projects that would not provide sufficient irrigation or (where permitted) domestic grey water demand for use of stored runoff due to limited landscaping or extensive use of low water use plant palettes in landscaped areas.
- Projects that are required to use reclaimed water for irrigation of landscaping.

- Development projects in which the storage and reuse of stormwater runoff would conflict with local, State or Federal ordinances or building codes.
- Locations where storage facilities would cause potential geotechnical hazards as outlined in a report prepared and stamped by a licensed geotechnical engineer.
- Locations where storage facilities would cause health and safety concerns.

Water Conservation Requirements

When infiltration or storage and reuse of the ΔV is not possible, LID BMPs that incorporate vegetation to promote pollutant removal and runoff volume reduction, integrate multiple uses and/or BMPs that percolate runoff through engineered soil and allow it to discharge downstream slowly shall be implemented. These LID BMPs shall be sized to detain and treat the ΔV.

Infeasibility

Compliance with the LID requirements in this manual in whole or in part may not be feasible in all development scenarios. In these situations, the applicant shall demonstrate the infeasibility of compliance with the LID requirements and submit a proposal for approval by the Director that incorporates design features demonstrating compliance with the LID requirements to the maximum extent practicable.

Water Quality Treatment Requirements

The runoff from the water quality design storm event associated with the developed site hydrology described in Chapter 4 must be treated before discharge in compliance with the National Pollutant Discharge Elimination System Municipal Stormwater Permit for the County of Los Angeles.

Hydromodification Requirements

California Drainage Law is a complicated and complex area with respect to the rights of upper and lower landowners. Therefore, it is in everyone’s best interest to require developments to analyze all the factors that may contribute to changed drainage characteristics, which may contribute to downstream drainage impacts (increased flooding and erosion). Below is an outline of the procedure required to analyze drainage impacts on off-site property.

1. All projects are required to conduct hydrology and hydraulic analysis for SUSMP, LID, 2-, 5-, 10-, 25-, and 50-year storm events per the Los Angeles County Department of Public Works Hydraulic and Hydrology manuals.
2. HEC-RAS is required as the standard for analyzing changes in flow velocity, flow volume, and depth/width of flow for all natural drainage courses.

3. Sediment transport analysis using HEC-RAS, SAMS, and HEC-6 is required to determine long-term impacts of streambed accretion and degradation for major drainage courses with Capital Storm flow rates (Q) greater than 5,000 cubic feet per second.

4. All projects are required to fully mitigate off-site drainage impacts caused by hydromodification and changes in water quality, flow velocity, flow volume, and depth/width of flow under all 7 hydrologic scenarios above.

5. If not fully mitigated, the developer is required to obtain Drainage Acceptance letters from impacted downstream property owners. If Drainage Acceptance letters cannot be obtained and mitigation is not feasible, the developer must recommend to Regional Planning that a Statement of Overriding Consideration be included in the California Environmental Quality Act document to disclose that there will be significant unmitigated downstream drainage impacts.

Hydromodification Exemptions

All projects that comply with one or more of the following conditions are exempt from conducting a full analysis for hydromodification impacts. Applicants must still demonstrate that the project mitigates for hydromodification impacts to the satisfaction of the Director of Public Works.

- Projects that disturb less than one acre.
- Less than 10,000 square feet of new impervious area.
- Projects that do not increase impervious area or decrease the infiltration capacity of pervious areas compared to preproject conditions.
- Projects that are replacement, maintenance, or repair of an existing permitted flood control facility.
- Projects within a watershed or subwatershed where a geomorphically-based watershed study has been prepared that establishes that the potential for hydromodification impacts is not present based on appropriate assessment and evaluation of relevant factors, including: runoff characteristics, soil conditions, watershed size and conditions, channel conditions, and proposed levels of development within the watershed.
- Projects that discharge directly or via a storm drain into concrete or significantly hardened channels, which in turn discharge into a sump area under tidal influence, or other receiving water that is not susceptible to hydromodification impacts.
- Projects that have hydrologic control measures that include sufficient subregional, regional, in-stream control measures, or a combination thereof such that hydromodification will not occur.

CHAPTER 4: LID HYDROLOGIC ANALYSIS

INTRODUCTION

Southern California has a relatively dry climate with long periods of very little rainfall often followed by intense storm events. The County of Los Angeles Department of Public Works uses the Modified Rational Method of hydrologic analysis. A detailed discussion of the methodology is included in the Los Angeles County Department of Public Works Hydrology Manual. The most recent version is available online at http://www.ladpw.org/wrd/publication/index.cfm.

LID GOALS

The primary benefits expected from implementation of LID are: (1) increased groundwater recharge, (2) enhanced water quality, and (3) stability of downstream natural reaches.

The main benefits of LID can be achieved with relatively simple analysis using tools that are currently available and consistent with approved methods, such as Los Angeles County's Tc calculator available online at http://www.ladpw.org/wrd/publication/Engineering/hydrology/tc_calculator_files.zip.

METHODOLOGY

<u>LID Hydrologic Analysis Steps</u>

Step 1: Determine hydrologic parameters

Determine drainage area of proposed development site (for sites larger than 40 acres use multiple subareas). Calculate slope and length of flow path and identify soil type.

Step 2 Identify design storm

There are several options for an LID design storm. This accounts for regional differences in rainfall and is consistent with existing SUSMP design criteria.

A. The 85th percentile 24-hour runoff event determined, as the maximized capture stormwater volume for the area, from the formula recommended in Urban Runoff Quality Management, WEF Manual of Practice No. 23/SCE Manual of Practice No. 87, (1998), or

B. The volume of annual runoff, based on unit basin storage water quality volume, to achieve 80 percent or more volume treatment by the method recommended in California Stormwater Best Management Practices Handbook – Industrial/Commercial, (1993), or

C. The volume of runoff produced from a 0.75-inch storm event prior to its discharge to a stormwater conveyance system, or

D. The volume of runoff produced from a historical record based reference 24-hour rainfall criterion for treatment 0.75 inch average for the County of Los Angeles area) that achieves approximately the same reduction in pollutant loads achieved by the 85th percentile 24-hour runoff event.

Step 3: Calculate undeveloped runoff volume

Using an approved hydrologic analysis tool consistent with the Los Angeles County Department of Public Works Hydrology Manual, determine the volume associated with the selected design storm assuming clear flows and undeveloped site conditions (0 percent impervious surfaces).

Step 4: Calculate developed runoff volume

Using the same design storm, determine the runoff volume associated with the proposed development. The impervious values shall be consistent with the hydrology manual recommendations based on land-use type.

Step 5: Calculate the excess volume (ΔV)

Subtract the undeveloped runoff volume from the developed runoff volume. This quantity is required to be infiltrated wherever possible at the site level and the BMPs used to accomplish this requirement shall be distributed throughout the project site.

Step 6: Determine water quality treatment volume or flow rate

The entire volume identified in Step 4 must be treated or infiltrated or one of the following flow rate based events can be used to determine the flow rate of runoff that must be treated:

A. The flow of runoff produced from a rain event equal to at least 0.2 inches per hour intensity; or

B. The flow of runoff produced from a rain event equal to at least 2 times the 85th percentile hourly rainfall intensity for the County of Los Angeles; or

C. The flow of runoff produced from a rain event that will result in treatment of the same portion of runoff as treated using volumetric standards above.

CHAPTER 5: LOW-IMPACT DEVELOPMENT BEST MANAGEMENT PRACTICES

BIORETENTION

POLLUTANT REMOVAL

Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

Bioretention areas are vegetated shallow depressions that provide storage, infiltration, and evapotranspiration. Bioretention areas also remove pollutants by filtering stormwater through plants adapted to the local climate, soil moisture conditions, and an engineered soil mix. In bioretention areas, pore spaces, microbes, and organic material in the engineered soils help retain water in the form of soil moisture and promote the adsorption of pollutants (such as dissolved metals and petroleum hydrocarbons) into the soil matrix. Plants utilize soil moisture and promote the drying of the soil through transpiration. If no underdrain is provided, outflow of the device's stored water into the underlying soils occurs over a period of days. For areas with low permeability, native soils, or steep slopes, bioretention areas can be designed with an underdrain system that routes the treated runoff to a more suitable infiltration area, a cistern for later reuse, or to the storm drain system. In this situation, treatment is achieved mainly through filtration and adsorption in the vegetation and engineered soils.

ADVANTAGES	LIMITATIONS
• Provides shade and windbreaks, and improves aesthetics • Enhances water quality through treatment and gradual infiltration	• Not appropriate for industrial sites or locations where spills may occur • Not suitable for areas where water table is within 10 feet of ground and surface stratum unstable • Not recommended where tree removal would be required • May pose vector control problem

GENERAL CONSTRAINTS AND SITE CONCERNS

Implementation of bioretention for stormwater management is ideal for median strips, parking lot islands, and downstream of swales. Moreover, the runoff in these areas can be designed to either divert directly into the bioretention area or convey into the bioretention area by a curb and gutter collection system. The best location for bioretention areas is upland from inlets that receive sheet flow from graded areas and at areas that will be excavated. In order to maximize treatment effectiveness, the site must be graded in such a way that minimizes erosive conditions as sheet flow is conveyed to the treatment area. Locations where a bioretention area can be readily incorporated into the site plan without further environmental damage are preferred. Furthermore, to effectively minimize sediment loading in the treatment area, bioretention should only be used in stabilized drainage areas. Design considerations include:

- Native soil infiltration rate - Underdrain is required in low permeability soils.
- Vertical relief and proximity to storm drain - Site must have adequate relief between land surface and storm drain to permit vertical percolation through the soil media if collected and conveyed in underdrain to storm drain system.
- Depth to groundwater - Shallow groundwater table may not permit complete drawdown between storms.
- Availability of pervious area - Bioretention areas typically occupy between 2 to 10 percent of the drainage area.

MULTIUSE OPPORTUNITIES

Bioretention areas can be applied in various settings, including:

- Individual lots for rooftop, driveway, and other on-lot impervious surface infiltration.
- Shared facilities located in common areas for individual lots.
- Areas within loop roads or cul-de-sacs.
- Landscaped parking lot islands.

- Within parkways and other right of ways along roads.
- Common landscaped areas in apartment complexes or other multifamily housing designs.
- In parks and along open space edges.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

CISTERNS/RAIN BARRELS

POLLUTANT REMOVAL

Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

Cisterns and rain barrels are containers, which capture stormwater runoff as it comes down through the roof gutter system. Rain barrels are placed outside of a building at roof downspouts to store rooftop runoff for later reuse in lawn and garden watering. Cisterns also collect rooftop runoff, but store the water in significantly larger volumes in manufactured tanks or built underground storage areas. Both cisterns and rain barrels can be implemented without the use of pumping devices, instead relying on gravity flow. The collection of this stormwater reduces the amount of stormwater runoff and assists in the reduction of potential pollutants entering the stormwater conveyance system. Reducing the water used from the municipal water system can reduce a site's water bill.

ADVANTAGES	LIMITATIONS
• Low installation cost • Requires little space for installation • Reduces amount of stormwater runoff • Conserves water usage • Reduction in the discharge of pollutants due to reduction of overall off-site flow volume	• Limited amount of stormwater runoff can be captured • Restricted to structure runoff

GENERAL CONSTRAINTS AND SITE CONCERNS

The following rain barrel and cistern technical and operational features should be considered:

- Screens on gutters and downspouts to remove sediment and particles as the water enters the barrel or cistern.
- Removable child-resistant covers and mosquito screening on water entry holes.
- The option of draining the system completely for maintenance.
- Drain spigots that have garden hose threading, suitable for connection to a drip irrigation system.
- Aesthetic features that are compatible with the lot's landscaping plan or landscaping that provides visual screening.
- Private stormwater maintenance agreements met between the property owner and any potential second and third parties.
- Adequate storage capacity.
- Should be located for easy maintenance or replacement.

DESIGN SPECIFICATIONS

The required capacity of a cistern and rain barrel is a function of the rooftop surface area that drains to it, the inches of rainfall required to fill the vessel, and water losses due mainly to evaporation. Cisterns should be designed to prevent mosquito access.

OPERATIONS AND MAINTENANCE

Maintenance requirements for rain barrels are minimal and consist only of regular inspection of the unit as a whole and any of its constituent parts and accessories. All components should be inspected at least twice a year and repaired or replaced as needed. Cisterns, along with all their components and accessories, should undergo regular inspection at least twice a year. Replacement or repair of the unit as a whole and any of its constituent parts and accessories should be completed as necessary.

During the wet season, cisterns and rain barrels should be inspected periodically for mosquitos.

Note: For more information, please visit the American Rain Catchment Systems Association website at www.arcsa.org.

DRY PONDS

POLLUTANT REMOVAL	
Sediment	Medium
Nutrients	Low
Trash	High
Metals	Medium
Bacteria	Medium
Oil and Grease	Medium
Organics	Medium

DESCRIPTION

Dry extended detention (ED) basins are basins whose outlets have been designed to detain the runoff from a water quality design storm for 36 to 48 hours to allow sediment particles and associated pollutants to settle and be removed. Dry ED basins do not have a permanent pool; they are designed to drain completely between storm events. They can also be used to provide hydromodification and/or flood control by modifying the outlet control structure design and including additional detention storage. The slopes, bottom, and forebay of ED basins are typically vegetated.

Dry ED basins can be located either online or offline. For offline basins, a flow diversion structure is used to divert the design storm volume to the basin from the storm drain. For online basins, all storm drain flows are routed through the basin; storm events exceeding the water quality design capacity will pass through the basin and will discharge over a primary overflow untreated or, during extreme events, over an emergency spillway. In both types of basins, influent flows enter a sediment forebay. Here coarse solids are first removed prior to flowing into the main cell of the basin where finer sediment and associated pollutants settle as stormwater is detained and slowly released through a controlled outlet structure. Dry-weather flows and very low storm flows are often infiltrated within the basin.

ADVANTAGES	LIMITATIONS
• Inexpensive and easy to construct and operate due to simplicity • Provide significant removal of sediments and associated toxics • Provides erosion control • Provides flood control	• Only moderate pollutant removal • Ponded water may cause vector control problem

GENERAL CONSTRAINTS AND SITE CONCERNS

- Surface space availability - typically 0.5 to 2 percent of the total tributary development area required.
- Depth to groundwater - bottom of basin should be higher than the water table.
- Steep slopes - basins placed on slopes greater than 15 percent or within 200 feet from the top of a hazardous slope or landslide area require a geotechnical investigation.
- Compatibility with flood control - basins must not interfere with flood control functions of existing conveyance and detention structures.
- Dry ED basins shall never be placed within a blue-line stream.

MULTIUSE OPPORTUNITIES

A dry ED basin can sometimes be retrofitted into an existing flood control basin or integrated into the design of a park or playfield. Perforated risers, multiple orifice plate outlets, or similar multistage outlets are required for flood control retrofit applications to ensure adequate detention time for small storms while still providing peak-flow attenuation for the flood design storm. Recreational multiuse facilities must be inspected after every storm and may require a greater maintenance frequency than dedicated water quality basins to ensure aesthetics and public safety are not compromised. Any planned multiuse facility must obtain special approval by the County of Los Angeles Department of Public Works.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

DRY WELLS

POLLUTANT REMOVAL	
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

Commonly known as sumps, french drains, drain fields, and shallow injection wells; dry wells simply use gravity to infiltrate stormwater into the subsurface. A dry well is constructed by digging a hole in the ground and filling it with an open graded aggregate or plastic infill devices. Stormwater runoff is diverted to the dry well for infiltration into the ground, allowing it to be stored in the voids. While it may seem harmless and cost-effective at first glance to use these dry wells to infiltrate stormwater into the ground, in reality, the impact to groundwater quality from these devices varies and is highly dependent upon many factors.

ADVANTAGES	LIMITATIONS
• Requires minimal space to install • Low installation costs • Reduces amount of runoff • Provides groundwater recharge • Can serve small impervious areas like rooftops • Helps to disconnect impervious surfaces	• Offers little pretreatment, which may cause clogging • Risk of groundwater contamination in very coarse soils may require groundwater monitoring • Dry wells service a limited drainage area, typically only rooftop runoff • Loss of infiltrative capacity and high maintenance cost in fine soils • Low removal of dissolved pollutants in very coarse soils • Not recommended for use with commercial rooftops unless adequacy of pretreatment is assured

GENERAL CONSTRAINTS AND SITE CONCERNS

Constraints for dry wells are similar to those associated with many infiltration BMPs:

- Soils must be permeable.
- Dry wells should not be installed where hazardous or toxic materials are used, handled, stored, or where a spill of such materials would drain into the dry well.
- Must have a minimum of 10 feet between the bottom of the dry well and the seasonal high-0water table.
- Dry wells must be located at least 10 feet away, on the down slope side of the structure, from building foundations to prevent seepage.
- Not suitable on fill sites or steep slopes.
- Generally, dry wells that are deeper than their widest surface dimension are classified as Class V Injection Wells and are regulated by the Environmental Protection Agency. These wells must comply with the requirements of the Federal Underground Injection Control Program.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

ENGINEERED WETLANDS

POLLUTANT REMOVAL

Sediment	High
Nutrients	Medium
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

Constructed wetlands are constructed pools that retain water throughout the year. They are shallower than wet ponds, but have a greater vegetative cover. It is important to note that natural wetlands are not recommended for stormwater treatment as natural wetlands should be conserved.

Constructed wetlands are developed for the purpose of stormwater management. Additionally, constructed wetlands provide habitat and are aesthetically pleasing, making them widely accepted in communities. Treatment occurs through sedimentation and biological uptake. Many different designs for constructed wetlands exist, however, one of the most often used includes an initial detention pond for settling and increased storage capacity.

ADVANTAGES	LIMITATIONS
• Provides wildlife habitat • Provides removal of wide range of constituents • Provides erosion control • Provides flood control	• Safety concerns when constructed where there is public access • Not suitable for steep, unstable slopes • May have vector control problems • May need base flow to maintain water level • Requires fairly large open space • May require State Division of Safety of Dams approval depending on size

GENERAL CONSTRAINTS AND SITE CONCERNS

- Availability of base flows - stormwater wetlands require a regular source of water to support wetland biota.
- Slope stability - stormwater wetlands are not permitted near steep slope hazard areas.
- Surface space availability - large footprint required.
- Compatibility with flood control - basins must not interfere with flood control functions of existing conveyance and detention structures.

MULTIUSE OPPORTUNITIES

Provided adequate surcharge storage, a stormwater wetland may be combined with a flood control basin to provide both water quality control and peak-flow control. Wetlands can also be designed with wildlife viewing areas and walking trails around the perimeter to provide passive recreation. Any planned multiuse facility must obtain special approval by the County of Los Angeles Department of Public Works.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

GREEN ROOFS

POLLUTANT REMOVAL	
Sediment	High
Nutrients	Medium
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

A green roof is a heavy weight roof system of waterproofing material with a thick soil/vegetation protective cover. The green roof can be used in place of a traditional roof to limit impervious site area. The green roof captures and then evapotranspirates 50 to 100 percent of precipitation depending on the season. Green roofs attempt to mimic predeveloped hydrology, thereby reducing postdeveloped peak-runoff rates to near predeveloped rates. They help mitigate runoff temperatures by keeping roofs cool and retaining most of the runoff in warm seasons. Green roofs should not be used on slopes greater than 10 percent. A drain system and overflow to an approved conveyance and destination/disposal method will be required.

There are two types of green roofs: extensive and intensive systems. Intensive green roofs have larger depths of soil and require more maintenance and irrigation. Extensive green roofs feature very thin planting mediums and require little maintenance.

ADVANTAGES	LIMITATIONS
• Requires no additional space • Reduces overall volume of stormwater • Reduces pollutant discharge due to microbial processes and plant uptake	• Requires drought-tolerant vegetation • Increased roof loading • Requires maintenance to the same extent as any landscaped area • Need to be watered regularly in first year after construction until vegetation is established

GENERAL CONSTRAINTS AND SITE CONCERNS

Green roofs can be installed during initial construction or placed on buildings as part of a retrofit. The amount of stormwater that a green roof mitigates is directly proportional to the area it covers, the depth and type of the growing medium, slope, and the type of plants selected. The larger the green roof area, the more stormwater mitigated. Green roofs are appropriate for industrial and commercial facilities and large residential buildings such as condominiums or apartment complexes. Green roofs can also prove useful for small residential buildings under some circumstances. For instance, green roofs are commonly used on single-family residential structures in Germany and other European countries. Single-family residential structures, like all buildings with green roofs, must be able to support the loading from a saturated roof. Furthermore, the green roofs should be easily accessible; and residents should understand the maintenance requirements necessary to keep the roof functional.

A building must be able to support the loading of green roof materials under fully saturated conditions. These materials include a waterproofing layer, a soil or substrate layer, and a plant layer. Plants selected need to be suited for local climatic conditions and can range from sedums, grasses, and wildflowers on extensive roofs to shrubs and small trees on intensive roofs.

DESIGN SPECIFICATIONS

GENERAL SPECIFICATIONS

Proprietary green roof applications must comply with the vendor's guidelines for installation and maintenance. In the case of a conflict between vendor guidelines and County requirements, the stricter shall apply. Good quality waterproofing material must be used on the roof surface. Soil of adequate fertility and drainage capacity at depths of 2 to 6 inches and weight of 10 to 30 pounds per square foot shall be applied for an extensive green roof. For an intensive green roof, a minimum soil depth of 8 inches and weight of 60 pounds per square foot should be used. The building structure must be shown to be adequate to hold the additional weight. Vegetation shall be self-sustaining plants without the need for fertilizers or pesticides. Soil coverage to prevent erosion shall be established immediately upon installation by using mulch, vegetation mats, or other approved protection method. Ninety percent plant coverage shall be achieved within two years. Temporary irrigation to establish plants is recommended. A permanent irrigation system using potable water may be used, but an alternative means of irrigation such as air conditioning condensate or other nonpotable sources is recommended. Alternative sources should be analyzed to determine if the source has chemicals that might harm or kill the vegetation. Maximum roof slope shall be 10 percent, unless the applicant can provide documentation for runoff control on steeper slopes.

STRUCTURAL ROOF SUPPORT

The structural roof support must be sufficient to hold the additional weight of the green roof. For retrofit projects, check with an architect, structural engineer, or roof consultant to determine the condition of the existing building structure and what might be needed to support a green roof. This might include additional decking; roof trusses; joists, columns, and/or foundations. Generally, the building structure must be adequate to hold an additional 10 to 25 pounds per square foot (psf) saturated weight, depending on the vegetation and growth medium that will be used. (This is in addition to snow load requirements.) An existing rock ballast roof may be structurally sufficient to hold a 10 to 12 psf green roof. (Ballast typically weighs 10 to 12 psf.)

For new construction, the project architects and structural engineers shall address the structural requirements of the green roof during the design process. Greater flexibility and options are available for new buildings than for reroofing. The procedures for the remaining components are the same for both reroofing and new construction.

WATERPROOF MEMBRANE

Waterproof membranes are made of various materials, such as modified asphalts (bitumens), synthetic rubber ethylene propylene diene monomer (EPDM), hypolan chlorosulfonated polyethylene (CSPE), and reinforced polyvinyl chloride (PVC). Some of the materials come in sheets or rolls and some are in liquid form. They have different strengths and functional characteristics. Some of these products require root inhibitors and other materials to protect the membrane. Numerous companies manufacture waterproofing materials appropriate for green roofs.

PROTECTION BOARDS OR MATERIALS

These materials protect the waterproof membrane from damage during construction and over the life of the system, usually made of soft fibrous materials.

ROOF BARRIER

Root barriers are made of dense materials that inhibit root penetration. The need for a root barrier depends on the waterproof membrane selected. Modified asphalts usually require a root barrier while synthetic rubber (EPDM) and reinforced PVC generally do not. Check with the manufacturer to determine if a root barrier is required for a particular product. Membranes impregnated with pesticides are not allowed. Manufacturers must provide the County of Los Angeles Department of Public Works with evidence that membranes impregnated with copper will not leach out at concentrations of concern.

DRAINAGE LAYER

There are numerous ways to provide drainage. Products range from manufactured perforated plastic sheets to a thin layer of gravel. Some green roof designs do not require any drainage layer other than the growth medium itself, depending on roof slope and size (e.g., pitched roofs and small flat roofs).

GROWTH MEDIUM

The growth medium is generally 2 to 6 inches thick and well drained. It weighs from 10 to 25 pounds per square foot when saturated. A simple mix of 1/4 topsoil, 1/4 compost, and 1/2 pumice perlite may be sufficient for many applications. Some companies have their own growth medium specifications. Other components could include digested fiber, expanded clay or shale, or coir.

VEGETATION

Green roof vegetation should have the following attributes:

- Drought tolerant, requiring little or no irrigation after establishment.
- A growth pattern that allows the plant to thoroughly cover the soil. At least 90 percent of the overall surface shall be covered.
- Self-sustaining, without the need for fertilizers, pesticides, or herbicides.

  Able to withstand heat, cold, and high winds
- Very low maintenance, needing little or no mowing or trimming.
- Perennial or self-sowing.
- Fire resistant.

A mix of sedum/succulent plant communities is recommended because they possess many of these attributes. Herbs, forbs, grasses, and other low ground covers can also be used to provide additional benefits and aesthetics; however, these plants may need more watering and maintenance to survive and keep their appearance.

Installation: Four methods (or combinations of them) are generally used to install the vegetation; vegetation mats, plugs/potted plants, sprigs, and seeds.

1. Vegetation mats are sod-like, pregerminated mats that achieve immediate full-plant coverage. They provide immediate erosion control, do not need mulch, and minimize weed intrusion. They also need minimal maintenance during the establishment period and little ongoing watering and weeding.

2. Plugs or potted plants may provide more design flexibility than mats. However, they take longer to achieve full coverage, are more prone to erosion, need more watering during establishment, require mulching, and more weeding.

3. Sprigs are hand broadcast. They require more weeding, erosion control, and watering than mats.

4. Seeds can be either hand broadcast or hydraseeded. Like sprigs, they require more weeding, erosion control, and watering than mats.

GRAVEL BALLAST

Gravel ballast is sometimes placed along the perimeter of the roof and at air vents or other vertical elements. The need for ballast depends on operational and structural design issues. It is sometimes used to provide maintenance access, especially to vertical elements requiring periodic maintenance. In many cases very little, if any, ballast is needed. In some situations a header or separation board may be placed between the gravel ballast and adjacent elements (such as soil or drains). If a root barrier is used, it must extend under the gravel ballast and growth medium and up the side of the vertical elements.

DRAIN

As with a conventional roof, a green roof must safely drain runoff from the roof to an approved stormwater destination.

OPERATIONS AND MAINTENANCE

GENERAL REQUIREMENTS

- Soil Substrate/Growth Medium - soil shall be inspected for evidence of erosion from wind or water. If erosion channels are evident, they shall be stabilized with additional soil substrate/growth medium and covered with additional plants.

- Green Roof System Structural Components - Structural components shall be operated and maintained in accordance with manufacturers' requirements. Drain inlets shall be kept unrestricted. Inlet pipe shall be cleared when soil substrate, vegetation, debris, or other materials clog the drain inlet. Sources of sediment and debris shall be identified and corrected. Determine if drain inlet pipe is in good condition and correct as needed.

- Debris and Litter: Debris shall be removed to prevent clogging of inlet drains and interference with plant growth.

- Vegetation: Vegetation shall be maintained to provide 90 percent plant cover. During the establishment period, plants shall be replaced once per month as needed. During the long-term period, dead plants shall generally be replaced as needed. Fallen leaves and debris from deciduous plant foliage shall be removed. Nuisance and prohibited vegetation shall be removed when discovered. Dead vegetation shall be removed and replaced with new plants. Weeding shall be manual with no herbicides or pesticides used. Weeds shall be removed regularly and not allowed to accumulate. Fertilization is not necessary and fertilizers shall not be applied. During drought conditions, mulch or shade cloth may be applied to prevent excess solar damage and water loss. Mowing of grasses shall occur as needed. Clippings shall be removed.

- Irrigation can be accomplished either through hand watering or automatic sprinkler systems. If automatic sprinklers are used, manufacturers' instructions for operations and maintenance shall be followed. During the establishment period (1 to 3 years), water sufficient to assure plant establishment shall be applied. During the long-term period (3 plus years), water sufficient to maintain plant cover shall be applied.

- Spill prevention measures from mechanical systems located on roofs shall be exercised when handling substances that can contaminate stormwater. Releases of pollutants shall be corrected as soon as identified.

- Training and/or written guidance information for operating and maintaining green roofs shall be provided to all property owners and tenants. A copy of the operations and maintenance plan shall be provided to all property owners and tenants.

- Access and safety to the green roof shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Walkways shall be clear of obstructions and maintained to design standards.

- Aesthetics of the green roof shall be maintained as an asset to the property owner and community. Evidence of damage or vandalism shall be repaired and accumulation of trash or debris shall be removed upon discovery.

- Insects shall not be harbored at the green roof. Standing water creating an environment for development of insect larvae shall be eliminated by manual means. Chemical sprays shall not be used.

Note: Please visit www.greenroofs.org for more information on green roofs.

INFILTRATION BASIN

POLLUTANT REMOVAL	
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

An infiltration basin is a shallow surface pond that is designed to infiltrate stormwater through permeable soils. Infiltration basins retain runoff until it gradually infiltrates through the soil and eventually into the groundwater. Vegetation is used to avoid erosion of the basin bottom and slopes. The vegetation provides pollutant removal efficiency and can also help recharge groundwater, thus helping to maintain low flows in stream systems. Pollutant removal takes place through a combination of filtration, adsorption, and biological processes.

Infiltration basins are effective in reducing the pollutants of concern listed above; however, coarser sediments can clog and render the basin ineffective. An evaluation of the soils at the site is required to determine if an infiltration basin is an appropriate BMP to use.

As opposed to infiltration trenches, an infiltration basin creates a visible surface pond because it is not backfilled with rocks or stones. Infiltration basins are generally used for drainage areas between 5 and 50 acres. For drainage areas less than 5 acres, an infiltration trench or other BMP may be more appropriate. For drainage areas greater than 50 acres, maintenance of an infiltration basin would be burdensome and an extended/dry detention basin or wet pond may be more appropriate.

Infiltration basins are generally dry except immediately following storms. A low-flow channel may be necessary if a constant base flow is present.

ADVANTAGES	LIMITATIONS
• Avoids discharge to surface waters • Good pollutant removal capabilities • Controls runoff volume • Provides erosion and flood control • Provides groundwater recharge • Provides more habitat value than other infiltration systems • It replicates pre-development hydrology • Can fulfill an area's landscape requirement	• Dependent upon soil and subsurface conditions • High failure rates due to clogging and high maintenance burden • Sediment forebay or pretreatment required • Not recommended to treat industrial sites or sites where hazardous spills may occur • Minimum soil infiltration rate of 0.5 inches/hour • Soil infiltration rates greater than 2.4 inches/hour require full treatment of water prior to infiltration, due to risk of groundwater contamination • Not appropriate for sites with Hydrologic Soil Types C and D • In coarse soil types there is risk of groundwater contamination • Requires complete stabilization of upstream drainage areas prior to construction • Not suitable for fill areas or steep slopes • Once basin becomes clogged it is difficult to restore function • Accumulation of metals and petroleum hydrocarbons may reach toxic level

GENERAL CONSTRAINTS AND SITE CONCERNS

The use of an infiltration basin may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock may preclude the use of an infiltration basin. Generally, infiltration basins are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill.

As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if the groundwater is used for human consumption or agricultural purposes. The infiltration basin is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the basin. In these areas, other BMPs that do not allow interaction with the groundwater should be considered. In addition, an appropriate erosion-control seed mix needs to be used for the basin.

An infiltration basin needs to be built without driving heavy equipment over the infiltration surface. Any equipment driven on the surface should have extra-wide (low pressure) tires. Prior to any construction, the infiltration area needs to be enclosed with a top to stop entrance by unwanted equipment.

It is important to note that before construction begins, the entire drainage area needs to be stabilized. This can be done by implementing a temporary diversion berm around the perimeter of the construction site to prevent drainage and sediment buildup to this area. After construction is completed, the entire contributing drainage area needs to be stabilized and clean of construction material before runoff can be allowed into the infiltration basin.

It is also important to note that the use of treated wood or galvanized metal anywhere inside the facility is prohibited. The use of galvanized fencing is permitted only in accordance with County fencing requirements.

Evaluation of a particular site to determine if the use of an infiltration basin is appropriate includes:

- Determination of the soil type (ASTM D 3385-88 – Consider NRCS Soil Types A and B only) and consult USDA Soil Survey Tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30 percent clay or more than 40 percent of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.

- Groundwater separation should be at least 10 feet from the basin invert to the measured groundwater elevation and 100 feet away from groundwater wells. There is concern at the State and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.

- Placement should be away from buildings, slopes, and highway pavement (greater than 10 feet) and production wells and bridge structures (greater than 100 feet).

- Sites constructed of fill having a base flow or with a slope greater than 15 percent should not be considered.

- Ensure that adequate head is available to operate flow-splitter structures (to allow the basin to be off-line) without ponding in the splitter structure or creating backwater upstream of the splitter.

- Base flow should not be present in the tributary watershed.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

INFILTRATION TRENCHES

POLLUTANT REMOVAL

Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

An infiltration trench is a long and narrow excavated ditch over porous soils, backfilled with rocks or stones, and lined with filter fabric on the sides and bottom. Stormwater runoff is diverted into the infiltration trench. Since the trench has no outlet, runoff is stored in the void spaces between the stones or gravel. Stormwater infiltrates into the soil where pollutants are removed through a combination of filtration, adsorption, and biological processes.

Infiltration trenches are effective in reducing the pollutants of concern listed above. Pretreatment BMPs such as vegetative swales, buffer strips, or detention basins are typically required to remove coarser sediments that can clog and render the trench ineffective. An evaluation of the soils at the site is required to determine if an infiltration trench is an appropriate BMP to implement.

Infiltration trenches differ from infiltration basins in that the former is used for small drainage areas and stores runoff out of sight within the void spaces of rocks or stones underground. Infiltration basins are for larger drainage areas and runoff is stored within a visible surface pond.

ADVANTAGES	LIMITATIONS
• Avoids discharge to surface waters • Good pollutant removal capabilities • Controls runoff volume • Provides erosion and flood control • Provides groundwater recharge • Little aesthetic impact • Fits in narrow areas and unused areas of a development site • It replicates pre-development hydrology	• Dependent upon soil and subsurface conditions • High failure rates due to clogging and high maintenance burden • Not recommended to treat industrial sites or sites where hazardous spills may occur • Maximum drainage area should be less than 5 acres • Minimum soil infiltration rate of 0.5 inch/hour • Soil infiltration rates greater than 2.4 inches/hour require full treatment of water prior to infiltration due to risk of groundwater contamination • Not appropriate for sites with Hydrologic Soil Types C and D • In coarse soil types there is risk of groundwater contamination • Requires complete stabilization of upstream drainage areas prior to construction • Not suitable for fill areas or steep slopes • Once trench becomes clogged it is difficult to restore function • Accumulation of metals and petroleum hydrocarbons may reach toxic level

GENERAL CONSTRAINTS AND SITE CONCERNS

The use of infiltration trenches may be limited by a number of factors including type of native soil, climate, and location of groundwater table. Site characteristics such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock may preclude the use of infiltration trenches. Generally, infiltration trenches are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill. As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if the groundwater is used for human consumption or agricultural purposes. The infiltration trench is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the trench. In these areas, other BMPs that do not allow interaction with the groundwater should be considered.

It is important to note that before construction begins, the entire drainage area needs to be stabilized. This can be done by implementing a temporary diversion berm around the perimeter of the construction site to prevent drainage and sediment buildup to this area. After construction is completed, the entire contributing drainage area needs to be stabilized and clean of construction material before runoff can be allowed into the infiltration trench.
To determine if the use of infiltration trenches is appropriate, the following factor must be considered:

- Determination of the soil type (ASTM D 3385-88 – Consider NRCS Soil Types A and B only) and consult USDA Soil Survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30 percent clay or more than 40 percent of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.

- Groundwater separation should be at least 10 feet from the basin invert to the measured groundwater elevation and 100 feet away from groundwater wells. There is concern at the State and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.

- Placement should be away from buildings, slopes, and highway pavement (greater than 10 feet) and production wells and bridge structures (greater than 100 feet).

- Sites constructed of fill, having a base flow, or with a slope greater than 15 percent should not be considered.

- Ensure that adequate head is available to operate flow-splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

LANDSCAPE IRRIGATION

DESCRIPTION

The majority of residential water usage is dedicated to landscape irrigation. Irrigation systems are often poorly designed and maintained, resulting in inefficient water usage and urban runoff. Urban runoff from irrigation often carries fertilizers, pesticides, herbicides, and other pollutants used on landscapes. Efficient irrigation design can minimize the amount of water used to irrigate a landscape and eliminate urban runoff from the site. Methods to increase irrigation efficiency include low-flow sprinkler heads, smart controllers that take into account local evapotranspiration rates, sensors that detect unfavorable weather conditions, and low-flow sprinkler heads.

DESIGN SPECIFICATIONS

SMART IRRIGATION CONTROLLERS

A smart irrigation controller is a device that automatically adjusts watering times in response to weather changes. Smart irrigation controllers use sensors and weather information to manage watering times and frequency. In order to comply with the landscape irrigation option for small scale residential projects, the applicant shall install a smart irrigation controller for any area of the lot that is either landscaped or designated for future landscaping.

PLANTER BOXES

POLLUTANT REMOVAL	
Sediment	High
Nutrients	High
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

There are two types of planter boxes: contained planters and infiltration planters. Contained planters are used for planting trees, shrubs, and ground cover to be placed over impervious surface. The planter may be a prefabricated pot of various dimensions or may be constructed in place and have an infinite variety of shapes and sizes. Contained planters are placed on impervious surfaces such as sidewalks, plazas, and rooftops. Drainage is allowed through the bottom of the planter.

Infiltration planters are structural landscaped reservoirs used to collect, filter, and infiltrate stormwater runoff allowing pollutants to settle and filter out as the water percolates through the planter soil and infiltrates into the ground. In addition to providing pollution reduction, flow rates and volumes can also be managed with infiltration planters. Planters can be used to reduce the total impervious area and should be integrated into the overall site design. Numerous design variations of shape, wall treatment, and planting scheme can be used to fit the character of a site. An overflow to an approved conveyance and disposal method will be required.

ADVANTAGES	LIMITATIONS
• Requires very little space • Aesthetically pleasing • Can provide water treatment or infiltration • Wide applicability • Useful for disconnecting downspouts	• Infiltration rate limited to infiltration capacity of underlying soil • A relatively limited volume of stormwater can be mitigated using planter boxes

GENERAL CONSTRAINTS AND SITE CONCERNS

Contained planter boxes are suitable for any location as they are placed over impervious surfaces. Planter boxes are ideal for urban infill environments where space is limited. For infiltration planters, the infiltration rate of the native soil is a key element in determining size.

DESIGN SPECIFICATIONS

DESIGN CONSIDERATIONS

Plants shall be relatively self-sustaining with little need for fertilizers or pesticides. Irrigation is optional, although plant viability must be maintained. Trees are encouraged for stormwater interception. Planter storage depth must be at least 12 inches unless a larger than --required planter square footage is used. Minimum planter width is 30 inches. Planters shall be constructed without slope.

SOIL SUITABILITY

Contained planters are appropriate for all soil types as they are placed over impervious surface. Topsoil shall be used within the top 12 to 18 inches of the facility. Infiltration planters are appropriate for soils with a minimum infiltration rate of 0.5 inch per hour. There shall be no less than 3 feet of undisturbed infiltration medium between the bottom of the facility and any impervious layer (i.e., hardpan, solid rock, high groundwater levels, etc.). Topsoil shall be used within the top 18 inches of the facility.

PLANTER WALLS

Planter walls shall be made of stone, concrete, brick, clay, plastic, wood, or other stable material. Chemically treated wood that can leach out toxic chemicals and contaminate stormwater shall not be used.

SIZING

Individual infiltration planters sized with the simplified approach shall be designed to receive less than 15,000 square feet of impervious area runoff. Planters shall be designed to pond water for less than 36 hours after each storm event.

LANDSCAPING

Contained planters shall be planted to cover at least 50 percent of the planter surface. Tree planting is not required in planters, but is encouraged where practical. Tree planting is also encouraged near planters.

CONSTRUCTION CONSIDERATIONS

Infiltration planter areas should be clearly marked before site work begins to avoid soil disturbance during construction. No vehicular traffic, except that specifically used to construct the facility, should be allowed within 10 feet of planter areas.

OPERATIONS AND MAINTENANCE

INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
ROUTINE MAINTENANCE	• Downspout from rooftop or sheet flow from paving allows unimpeded stormwater flow to the planter. Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery. Damaged pipe shall be repaired upon discovery. • Planter reservoir receives and detains stormwater prior to infiltration. Water should drain from reservoir within 3 to 4 hours of storm event. Sources of clogging shall be identified and corrected. Topsoil may need to be amended with sand or replaced all together. • Overflow pipe safely conveys flow exceeding reservoir capacity to an approved stormwater receiving system. Overflow pipe shall be cleared of sediment and debris when 50 percent of the conveyance capacity is plugged. Damaged pipe shall be repaired or replaced upon discovery. • Spill prevention measures shall be exercised when handling substances that contaminate stormwater. Releases of pollutants shall be corrected as soon as identified. • Training and/or written guidance information for operating and maintaining stormwater planters shall be provided to all property owners and tenants. A copy of the Operations and Maintenance Plan shall be provided to all property owners and tenants.

ROUTINE MAINTENANCE	• Vegetation shall be healthy and dense enough to provide filtering while protecting underlying soils from erosion. Mulch shall be replenished at least annually. Vegetation, large shrubs, or trees that limit access or interfere with planter operation shall be pruned or removed. Fallen leaves and debris from deciduous plant foliage shall be raked and removed. Nuisance or prohibited vegetation shall be removed when discovered. Invasive vegetation contributing up to 25 percent of vegetation of all species shall be removed and replaced. Dead vegetation shall be removed to maintain less than 10 percent of area coverage or when planter function is impaired. Vegetation shall be replaced within a specific timeframe (e.g., 3 months) or immediately, if required, to maintain cover density and control erosion where soils are exposed. • Access to the stormwater planter shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles if applicable. Obstacles preventing maintenance personnel and/or equipment access to the stormwater planter shall be removed. Gravel or ground cover shall be added if erosion occurs (e.g., due to vehicular or pedestrian traffic). • Insects and rodents shall not be harbored in the stormwater planter. Pest control measures shall be taken when insects/rodents are found to be present. If sprays are considered, then a mosquito larvicide such as Bacillus thurendensis or Altoside formulations can be applied only if absolutely necessary, and only by a licensed individual or contractor. Holes in the ground located in and around the stormwater planter shall be filled and compacted.
MAJOR MAINTENANCE	• Splash blocks prevent splashing against adjacent structures and convey water without disrupting media. Any deficiencies in structure such as cracking, rotting, and failure shall be repaired. • Planter shall contain filter media and vegetation. Structural deficiencies in the planter including rot, cracks, and failure shall be repaired. • Filter media consisting of sand, gravel, and topsoil shall allow stormwater to percolate uniformly through the planter. The planter shall be excavated and cleaned; and gravel or soil shall be replaced to correct low infiltration rates. Holes that are not consistent with the design and allow water to flow directly through the planter to the ground shall be plugged. Sediment accumulation shall be hand removed with minimum damage to vegetation using proper erosion control measures. Sediment shall be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation. Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.

POROUS PAVEMENT

POLLUTANT REMOVAL

Sediment	Low
Nutrients	High
Trash	High
Metals	High
Bacteria	Low
Oil and Grease	High
Organics	Low

DESCRIPTION

There are many types of pervious pavement on the market today. Numerous products and design approaches are available including special asphalt paving; manufactured products of concrete, plastic, and gravel; paving stones; and brick. It may be used for walkways, patios, plazas, driveways, parking lots, and some portions of streets subject to compliance with building codes. The material must be installed and maintained to manufacturers' specifications. These materials may not be allowed in certain areas. A professional engineer must design pervious pavement systems that will be supporting vehicular traffic.

ADVANTAGES

- Provide significant reductions in surface runoff and pollutant loading
- Can be designed with an underdrain in situations where infiltration is not feasible
- Reduces pavement ponding

LIMITATIONS

- Only applicable for low traffic volume areas
- To maintain effectiveness, porous pavements require frequent maintenance
- Easily clogged by sediments if not situated properly
- Extended rain can reduce the pavement's load bearing capacity

GENERAL CONSTRAINTS AND SITE CONCERNS

When designing pervious pavement systems, the infiltration rate of the native soil is a key element in determining the depth of base rock for the storage of stormwater or for determining whether an underdrain system is appropriate. Traffic loading and design speed are important considerations in determining which type of pervious pavement is applicable. Pedestrian, Americans with Disabilities Act accessibility, aesthetics, and maintainability are also important considerations depending on pavement use.

Pervious pavements shall not be used on sites with a likelihood of high oil and grease concentrations. These site uses include vehicle wrecking or impound yards, fast food establishments, automotive repair and sales, and parking lots that receive a high number of average daily trips (> 1,000). Runoff from unpaved areas should not be directed toward pervious pavement due to the potential for sediment loads to clog the pavement.

MULTIUSE OPPORTUNITIES

Pervious pavement is highly versatile and can be used in replacement of impermeable asphalt in many situations.

DESIGN SPECIFICATIONS

CONSTRUCTION CONSIDERATIONS

Installation procedures are vital to the success of pervious pavement projects, particularly pervious asphalt and concrete pavement mixes. The subgrade cannot be overly compacted with the inclusion of fine particulates or the void ratio critical to providing storage for large storm events will be lost. Weather conditions at the time of installation can affect the final product. Extremely high or low temperatures should be avoided during construction of pervious asphalt and concrete pavements.

SOIL SUITABILITY

Pervious pavement systems are appropriate for all soil types, but will require underdrain systems for soils that do not infiltrate well (less than 0.5 inch per hour). There shall be no less than 3 feet of undisturbed infiltration medium between the bottom of the base rock and any impervious layer (i.e., hardpan, solid rock, high groundwater levels, etc.), unless an underdrain system is used.

DIMENSIONS AND SLOPES

Minimum/maximum dimensions and other specifications are product specific and shall comply with manufacturers' recommendations. Slopes shall be less than 10 percent in all cases.

SIZING

Porous pavement should be designed to capture at least the water quality design storm event for its tributary area. The remaining storm volume bypasses the BMP and can be routed to another treatment or infiltration BMP or to the conventional stormwater conveyance system.

1. The prediction of the rate of infiltration of water through natural soils is related to soil type, porosity, degree of compaction, moisture content, and field capacity. This complexity governs soil drain times and has made the development of a single comprehensive model to predict drain times in actual porous pavement applications difficult. However, determining drain time is the key element in designing the size of porous pavement systems. The depth of the subbase can be determined by:

$$H_d = E \times t_d / r$$

Where:

H_d = Depth of reservoir layer (in).

t_d = Detention time (hr).

E = Soil infiltration rate (in/hr).

r = Void ratio.

The required porous pavement surface area can then be computed by:

$$A_s = V / (r \times H_d)$$

Where:

A_s = Porous pavement surface area (ft^2).

V = Water quality volume (ft^3).

2. Specifications. The cross-section typically consists of four layers. A description of each layer is presented below.

3. Asphalt Layer. The surface asphalt layer consists of an open-graded asphalt mixture ranging from depths of 2 to 4 inches depending on required bearing strength and pavement design requirements. Porous pavements contain approximately 16 percent voids, compared to 3 to 5 percent for conventional pavements allowing runoff to quickly infiltrate.

4. Top Filter Layer. This layer consists of a 0.5-inch-diameter crushed stone to a depth of 1 to 2 inches. This layer serves to stabilize the porous asphalt layer.

5. Reservoir Layer. The reservoir subbase consists of 1.5 to 3-inches crushed stone. The depth of this layer depends on the desired storage volume, which is a function of the soil infiltration rate, void spaces, and in colder climates the depth of the frost line, but typically ranges from 2 to 4 feet. The reservoir layer should be designed to drain completely in 48 to 72 hours.

6. Bottom Filter Layer. This layer serves to stabilize the reservoir layer and is the interface between the reservoir layer and the filter fabric covering the underlying soil. It consists of a 2-inch-thick layer of 0.5-inch crushed stone.

7. Filter Fabric. It is very important to line the entire trench area, including the sides, with filter fabric prior to placement of the aggregate. The filter fabric serves a very important function by inhibiting soil from migrating into the reservoir layer and reducing storage capacity.

8. Underlying Soil. The underlying soil should have an infiltration capacity of at least 0.1 inch/hour, but preferably greater than 0.50 inch/hour. Soils at the lower end of this range may not be suited for a full infiltration system.

9. Construction Practices (adapted from Schueler, 1992).

   a. All adjacent areas should be stabilized to prevent any sediment from washing onto the pavement surface, leading to premature clogging.

   b. The subgrade shall be prepared as required while limiting undue compaction; permeability must be maintained. Equipment with tracks or over-sized rubber tires shall be used; DO NOT use vehicles with standard rubber tires.

   c. The reservoir base course shall be laid in lifts over the base filter course and lightly compacted. The base courses should be kept free of all dirt and debris during construction.

   d. The asphalt layer shall be laid directly over the top filter course in one lift. The laying temperature should be between 240 and 260 degrees. The ambient temperature should be above 50 degrees.

   e. Compaction should take place when the surface is cool enough to resist a 9-Mg roller (class equivalent of a 10-ton roller). One or 2 passes is all that is required for proper compaction. Any more may reduce porosity.

   f. Transporting of the mix to the site shall be in clean vehicles with smooth dump beds that have been sprayed with a nonpetroleum release agent. The mix should be covered during transport to limit cooling.

   g. After final rolling, no vehicular traffic of any kind should be permitted on the pavement until cooling and hardening has taken place; no sooner than 6 hours, but preferably a day or two.

OPERATIONS AND MAINTENANCE

INSPECTION AND MAINTENANCE ACTIVITIES SUMMARY	
ROUTINE MAINTENANCE	• Regular sweeping shall be implemented for porous asphalt or concrete systems. The surface shall be kept clean and free of leaves, debris, and sediment. The surface shall not be overlaid with an impermeable paving surface • Overflow devices shall be inspected for obstructions or debris, which shall be removed upon discovery. Overflow or emergency spillways shall be capable of transporting high flows of stormwater to an approved stormwater receiving system. • Vegetation and large shrubs/trees that limit access or interfere with porous pavement operation shall be pruned. • Fallen leaves and debris from deciduous plant foliage shall be raked and removed. • Poisonous, nuisance, dead, or odor producing vegetation shall be removed immediately. • Grass shall be mowed to less than 4 inches and grass clippings shall be bagged and removed. • Irrigation shall be provided as needed. • Spill prevention measures shall be exercised when handling substances that can contaminate stormwater. A spill prevention plan shall be implemented at all nonresidential sites and in areas where there is likelihood of spills from hazardous materials. • Access to the pervious pavement shall be safe and efficient. Egress and ingress routes shall be maintained to design standards. Roadways shall be maintained to accommodate size and weight of vehicles if applicable. • Obstacles preventing maintenance personnel and/or equipment access to the porous pavement shall be removed. • Standing water creating an environment for development of insect larvae shall be eliminated. • Holes in the ground located in and around the pervious pavement shall be filled and compacted.
MAJOR MAINTENANCE	• Sources of erosion damage shall be identified and controlled when native soil is exposed near the overflow structure. • Gravel or ground cover shall be added if erosion occurs, e.g., due to vehicular or pedestrian traffic. • Source control measures prevent pollutants from mixing with stormwater. Typical nonstructural control measures include raking and removing leaves, street sweeping, vacuum sweeping, limited and controlled application of pesticides and fertilizers, and other good housekeeping practices.

SAND FILTERS

POLLUTANT REMOVAL

Sediment	High
Nutrients	Low
Trash	High
Metals	High
Bacteria	Medium
Oil and Grease	High
Organics	High

DESCRIPTION

Sand filters consist of a layer of sand in a structural box used to trap pollutants. The water filters through the sand and then flows into the surrounding soils or an underdrain system that conveys the filtered stormwater to a discharge point. Water that has percolated through the sand is collected via a perforated underdrain system before being conveyed to the downstream storm drainage system. As stormwater passes through the sand, pollutants are trapped in the small pore spaces between sand grains or are adsorbed to the sand surface. Over time bacteria can grow in the sand bed and provide some biological treatment. However, continuous dry-weather flows would be necessary to maintain the moisture required by the bacteria. Stormwater sand filters may also be two-chambered, including a pretreatment settling basin and a filter bed filled with sand. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering media (sand) in the second chamber.

ADVANTAGES	LIMITATIONS
• Relatively high pollutant removal • Sufficient capture volume provides significant control of channel erosion and enlargement	• More expensive to construct than many other BMPs • May require more maintenance than some other BMPs depending on the size of the filter bed • High-solid loads will cause filter to clog • Does not work well in large watersheds • Certain designs maintain permanent sources of standing water where mosquito and midge breeding is likely to occur

GENERAL CONSTRAINTS AND SITE CONCERNS

In general, sand filters are preferred over infiltration practices, such as infiltration trenches, when contamination of groundwater with conventional pollutants is of concern. This usually occurs in areas where underlying soils alone cannot treat runoff adequately or groundwater tables are high. In addition, sand filters are the preferred treatment option in regions where evaporation exceeds rainfall since a wet pond would be unlikely to maintain the required permanent pool. Additionally, implementation of sand filters for stormwater management is ideal for relatively small impervious watersheds.

- High loading rates may clog quickly if flows are not adequately pretreated.
- Vertical relief and proximity to storm drain site must have adequate relief between land surface and storm drain to permit vertical percolation through the sand filter and collection and conveyance in underdrain to storm drain system.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

VEGETATED BUFFERS

POLLUTANT REMOVAL

Sediment	High
Nutrients	Low
Trash	Medium
Metals	Medium
Bacteria	Low
Oil and Grease	High
Organics	Medium

DESCRIPTION

Vegetated buffers are vegetated areas designated to treat sheet flow runoff from adjacent impervious surfaces or intensive landscaped areas such as golf courses. Vegetated buffers use biological and chemical processes to filter stormwater runoff by slowing runoff velocities, filtering out sediment and other pollutants, and providing some infiltration into underlying soils. While some assimilation of dissolved constituents may occur, vegetated buffers are generally more effective in trapping sediments and particulate-bound metals, nutrients, and pesticides. Although vegetated buffers are not designed to attenuate peak stormwater flows, their use can be an effective water quality measure, and like many other LID techniques, vegetated buffers can add development aesthetic value and cost significantly less than hardscaped stormwater infrastructure.

A vegetated buffer is commonly operated as a pretreatment BMP located upstream of other BMPs capable of greater pollutant removal rates. If designed properly, vegetated buffers are able to provide relatively high pollutant removal. As a stand-alone BMP, vegetated buffers can only treat low-intensity rainfall events. While providing water quality treatment for small frequent storms, vegetated buffers operating as online facilities must still retain the ability to convey high runoff rates from the roadway when high-intensity storms occur. Vegetated buffers cannot treat high-velocity flows and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels.

ADVANTAGES

- Simple to install (only planting and some earthwork)
- Require minimal maintenance
- Can provide reliable water quality by trapping, filtering, and infiltrating contaminants typically present in runoff
- Can provide open space and recreation opportunities in residential areas
- Can help to accent the natural landscape providing green space adjacent to parking lots and roadways

LIMITATIONS

- Not recommended for arid areas where sustaining growth is difficult
- Not appropriate for hilly or intensively paved areas due to high-velocity runoff
- Not appropriate for industrial sites or locations where spills may occur
- Thick vegetative cover must be maintained to work effectively
- If improperly graded and designed this BMP can render an ineffective practice mainly due to erosion
- Channelization and premature failure may result from poor design, imprecise construction, and lack of maintenance

GENERAL CONSTRAINTS AND SITE CONCERNS

The most important criteria for the selection of this BMP is soil, space, and slope.

- The effectiveness of a vegetated buffer depends heavily on having an evenly distributed sheet flow, the size of the contributing area, and the associated volume runoff to be treated. To prevent the formation of concentrated flows, it is advised to have each vegetated buffer serve a contributing area of 5 acres or less.

- Slopes should be less than 5 percent grade to avoid the formation of gullies and rills that can disrupt sheet flow. Vegetated buffers may have reduced effectiveness on slopes 6 to 15 percent and will not function at all on slopes 15 percent or greater. Limited site slope may cause ponding.

- The maximum length (in the direction of flow toward the buffer) of the tributary area should be 60 feet. The minimum length in direction of flow is 15 feet.

- A water table depth within 3 feet of the surface provides greater removal rate of soluble pollutants (i.e., within root zone).

- The effectiveness of vegetated buffers increases where the climate permits year-round dense vegetation and decreases in arid regions where vegetation in upland areas is scarce.

- Steep terrain and/or large tributary areas may cause concentrated erosive flow. A shallow, evenly distributed flow across entire width of strip is required. The maximum flow path from a contributory impervious surface should not exceed 150 feet. Sheet flow depth should be less than 0.5 inch for the design storm. Depending on the pollutant removal required, residence time should be at least 5 minutes preferably 9 minutes or more.

- A level spreader may be necessary to induce sheet flow over the vegetated buffer and avoid short-circuit caused by channelization of concentrated flows and sheet flow elimination. Level spreader options include porous pavement strip, stabilized turf strips, slotted spreader curbing, rock filled trench, concrete sills, or plastic-lined trench acting as a small detention pond.

- Vegetated buffers should be placed 3 to 4 feet from edge of pavement to accommodate a vegetation free zone.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

VEGETATED SWALES

POLLUTANT REMOVAL

Sediment	Medium
Nutrients	Low
Trash	Low
Metals	Medium
Bacteria	Low
Oil and Grease	Medium
Organics	Medium

DESCRIPTION

Vegetated swales are open, shallow channels with low-lying vegetation covering the side slopes and bottom that collect and slowly convey runoff flow to downstream discharge points. Vegetated swales provide pollutant removal through settling and filtration in the vegetation (usually grasses) lining the channels, provide the opportunity for volume reduction through infiltration and evapotranspiration, and reduce the flow velocity in addition to conveying stormwater runoff. An effective vegetated swale achieves uniform sheet flow over and through a densely vegetated area for a period of several minutes. The vegetation in the swale can vary depending on its location within a development project and is the choice of the designer depending on the functional criteria outlined below. Swales that are integrated within a project may use turf or other more intensive landscaping while swales that are located on the project perimeter, within a park, or close to an open space area may be planted with a more naturalistic plant palette.

ADVANTAGES	LIMITATIONS
• Potentially inexpensive • Significant collateral water quality benefits • Roadside ditches are easily converted to swales	• Can be difficult to avoid channelization • Cannot treat a large drainage area. Large areas may need to be divided and treated with several swales • Impractical in areas with steep topography • Not effective and may even erode when flow velocities are high if the grass cover is not properly maintained • In some places their use is restricted by law; many local municipalities require curb and gutter systems in residential areas • Swales are more susceptible to failure, if not properly maintained, than other treatment BMPs

GENERAL CONSTRAINTS AND SITE CONCERNS

- Steep terrain and/or large tributary areas may cause erosive flows.
- Limited site slope may cause ponding.
- Swales must not interfere with flood control functions of existing conveyance and detention structures.

MULTIUSE OPPORTUNITIES

Swales can easily be converted into roadside vegetated buffers or parking lot landscaping.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

WET PONDS

POLLUTANT REMOVAL

Sediment	High
Nutrients	Medium
Trash	High
Metals	High
Bacteria	High
Oil and Grease	High
Organics	High

DESCRIPTION

Wet ponds are constructed, naturalistic ponds with a permanent or seasonal pool of water (also called a wet pool or dead storage). Aquascape facilities, such as artificial lakes, are a special form of wet pool facility that can incorporate innovative design elements to allow them to function as a stormwater treatment facility in addition to an aesthetic water feature. However, stormwater lakes are generally more appropriate for maintenance by a homeowners' association or an agency other than the Los Angeles County of Los Angeles Department of Public Works. In certain circumstances, a stormwater lake may be a candidate for the County of Los Angeles Department of Public Works maintenance. In such circumstances, special approval is required by the County.

ADVANTAGES

- If properly designed, constructed, and maintained, wet basins can provide substantial aesthetic/recreational value and wildlife and wetlands habitat
- Ponds are often viewed as a public amenity when integrated into a park setting
- Due to the presence of the permanent wet pool, properly designed and maintained wet basins can provide significant water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed

LIMITATIONS

- Some concern about safety when constructed where there is public access
- Mosquito and midge breeding is likely to occur in ponds
- Cannot be placed on steep unstable slopes
- Need for base flow or supplemental water if water level is to be maintained
- Require a relatively large footprint
- Depending on volume and depth, pond designs may require approval from the State Division of Safety of Dams

GENERAL CONSTRAINTS AND SITE CONCERNS

- Availability of base flows - wet ponds require a regular source of water if water level is to be maintained.
- Slope stability – wet ponds are not permitted near steep slope hazard areas.
- Surface space availability - large footprint required.
- Compatibility with flood control - basins must not interfere with flood control functions of existing conveyance and detention structures.

MULTIUSE OPPORTUNITIES

Provided adequate surcharge storage, a wet pond may be combined with a flood control basin to provide both water quality control and peak-flow control. Wet ponds can also be designed with wildlife viewing areas and walking trails around the perimeter to provide passive recreation. Any planned multiuse facility must obtain special approval by the County of Los Angeles Department of Public Works.

Note: Please refer to the *County of Los Angeles Department of Public Works Stormwater Best Management Practice Design and Maintenance Manual* for the most up-to-date information on this BMP.

CHAPTER 6: EXAMPLE DESIGNS

LID EXAMPLE DESIGN NO. 1

DETERMINE REQUIREMENTS

For a single-family residential tract with more than 5 units, the following applies:

- Infiltrate or retain the increase in the volume of the runoff from the water quality storm on the parcel level.
- Treat the entire volume of the runoff from the water quality storm.

DETERMINE HYDROLOGIC PARAMETERS

The total area of the site is 25 acres. Of that, 10 acres is dedicated open space. The total area that must be mitigated for is 15 acres.

A = 15 acres

Soil 97

Assume 42% impervious

Flow path = 1080'

Average Slope = (1600-1580) / 1080 = 1.85%

IDENTIFY DESIGN STORM

Select a water quality storm from the menu of storm events. For this example, assume a 3/4-inch storm over 24 hours.

CALCULATE UNDEVELOPED RUNOFF VOLUME

The rate and volume of runoff can be calculated using the Tc Calculator utility (available at http://ladpw.org/wrd/publication/).

$Q_u = 0.29\ cfs$
$V_u = 4000\ ft^3$

CALCULATE DEVELOPED RUNOFF VOLUME

Using the same design storm and methodology, calculate the runoff rates and volumes that would occur after development.

$Q_d = 1.25\ cfs$
$V_d = 17700\ ft^3$

The developed volume V_d is the total volume that must be treated.

CALCULATE ΔV

$\Delta V = Q_d - Q_u = 17700 - 4000 = 13700\ ft^3$

The increase in runoff volume ΔV is the amount that must be infiltrated on a parcel level.

CHOOSE BMPS

For this example, porous pavement driveways with underlying infiltration trenches have been selected as one method of infiltrating the ΔV.

There are 42 lots and it is assumed that each lot has a 15- x 15-foot driveway.

The depth of the infiltration trench under each driveway can then be calculated.

Assume a 0.4 void ratio for the underlying gravel.

D = 13700 ft^3 / (42 lots * 15’ x 15’ * .4) = 3.63 ft

LID EXAMPLE DESIGN NO. 2

DETERMINE REQUIREMENTS

For a commercial redevelopment project, the following applies:

- Infiltrate or retain the increase in the volume of the runoff from the water quality storm on the parcel level.
- Treat the entire volume of the runoff from the water quality storm.

DETERMINE HYDROLOGIC PARAMETERS

The total area of the site is 5 acres.

A = 5 acres

Soil 20

Assume 95 percent impervious.

Flow path = 680'

Average Slope = (1200-1170) / 680 = 4.4 percent.

Identify Design Storm

Select a water quality storm from the menu of storm events. For this example, assume a 3/4-inch storm over 24 hours.

CALCULATE UNDEVELOPED RUNOFF VOLUME

The rate and volume of runoff can be calculated using the Tc Calculator utility (available at http://ladpw.org/wrd/publication/).

$Q_u = 0.1\ cfs$
$V_u = 1343\ ft^3$

CALCULATE DEVELOPED RUNOFF VOLUME

Using the same design storm and methodology, calculate the runoff rates and volumes that would occur after development.

$Q_d = 0.86\ cfs$
$V_d = 11550\ ft^3$

The developed volume V_d is the total volume that must be treated.

CALCULATE ΔV

$$\Delta V = Q_d - Q_u = 11550 - 1343 = 10200\ ft^3$$

The increase in runoff volume ΔV is the amount that must be infiltrated on a parcel level.

CHOOSE BMPS

For this example, bioretention planters and porous pavement have been selected as the methods of infiltrating the ΔV.

Assuming a 3-foot depth and a 0.4 void ratio for gravel, 8500 ft^2 are necessary to infiltrate the total volume, or roughly 4 percent of the total area of the site.

The wasted space at the ends of parking spaces can be used for bioretention facilities.

$$175\ ft^2 \times 7 + 300\ ft^2 \times 5 = 2725\ ft^2$$

The remaining volume can be infiltrated using porous pavement.

$$8500 - 2725 = 5775\ ft^2$$

RB-AR35213

HYDROMODIFICATION ASSESSMENT AND MANAGEMENT IN CALIFORNIA

Eric D. Stein
Felicia Federico
Derek B. Booth
Brian P. Bledsoe
Chris Bowles
Zan Rubin
G. Mathias Kondolf
Ashmita Sengupta

Southern California Coastal Water Research Project
Technical Report 667 - April 2012

RB-AR35214

Hydromodification Assessment and Management in California

Commissioned and Sponsored by California State Water Resources Control Board Stormwater Program

Eric D. Stein	*Southern California Coastal Water Research Project*
Felicia Federico	*University of California, Los Angeles - La Kretz Center for California Conservation Science*
Derek B. Booth	*University of California, Santa Barbara*
Brian P. Bledsoe	*Colorado State University, Fort Collins*
Chris Bowles	*CBEC, Inc., Eco-engineering*
Zan Rubin	*University of California, Berkeley*
G. Mathias Kondolf	*University of California, Berkeley*
Ashmita Sengupta	*Southern California Coastal Water Research Project*

April 2012

Technical Report 667

Acknowledgements

We would like to thank the California State Water Resources Control Boards for their financial support to develop this document and for their invaluable input in terms of the priority technical and management needs associated with hydromodification. In particular, we thank Greg Gearheart and Eric Berntsen of the State Water Board's Storm Water Program, and Dominic Roques of the Central Coast Regional Water Board, for their input, review and overall guidance throughout the process. Their contributions were essential to helping to focus the document on areas of highest importance for the future of hydromodification management.

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EXECUTIVE SUMMARY

Most jurisdictions in California are now required to address the effects of *hydromodification* through either a municipal stormwater permit or the statewide construction general permit. Hydromodification is generally defined as changes in channel form associated with alterations in flow and sediment due to past or proposed future land-use alteration. Hydromodification management has emerged as a prominent issue because degradation of the physical structure of a channel is often indicative of and associated with broader impacts to many beneficial uses, including water supply, water quality, habitat, and public safety. Conversely, reducing hydromodification and its effects has the potential to protect and restore those same beneficial uses. Although hydromodification has the potential to affect all water body types, this document focuses on assessing and managing effects to streams because they are the most prevalent, widely studied, and arguably most responsive type of receiving water.

Hydromodification by definition results from alteration of watershed processes; therefore, correcting the root causes of hydromodification ought to be most effective if based on integrated watershed-scale solutions. To date, such a watershed approach has not been adopted in California; most hydromodification management plans simply consist of site-based runoff control with narrow, local objectives and little coordination between projects within a watershed. Furthermore, each municipality is required to develop its own approach to meeting hydromodification management requirements rather than drawing from standard or recommended approaches that facilitate regional or watershed-scale integration. Long-term reversal of hydromodification effects, however, will require movement away from reliance on such site-based approaches to more integrated watershed-based strategies.

This document has two goals, and hence two audiences. The first goal is to describe the elements of effective hydromodification assessment, management and monitoring. The audience for this goal is primarily the State and Regional Water Boards, since meeting this goal will require integration of watershed and site-scale activities that are likely beyond the responsibility or control of any individual municipality. Success will require fundamental changes in the regulatory and management approach to hydromodification that will likely advance only iteratively and potentially require one or more NPDES permit cycles to fully implement. The second goal of this document is to provide near-term technical assistance for implementing current and pending hydromodification management requirements. This goal can be achieved by municipalities within the construct of existing programs and therefore the primary audience for this aspect of the document is local jurisdictions. Achieving this goal will facilitate greater consistency and effectiveness between hydromodification management strategies, giving them a stronger basis in current scientific understanding.

Watershed analysis should be the foundation of all hydromodification management plans (Figure ES-1). This analysis should begin with a documentation of watershed characteristics and processes, and past, current, and expected future land uses. The analysis should lead to identification of existing opportunities and constraints that can be used to help prioritize areas of greater concern, areas of restoration potential, infrastructure constraints, and pathways for potential cumulative effects. The combination of watershed and site-based analyses should be used to establish clear objectives to guide management actions. These objectives should articulate desired and reasonable physical and biological conditions for various reaches or portions of the watershed and should prioritize areas for protection, restoration, or management. Strategies to achieve these objectives should be customized based on consideration of current and expected future channel and watershed conditions. A one-size-fits-all approach should be avoided. Even where site-based control measures, such as flow-control basins, are judged appropriate, their location and design standards should be determined in the context of the watershed analysis.

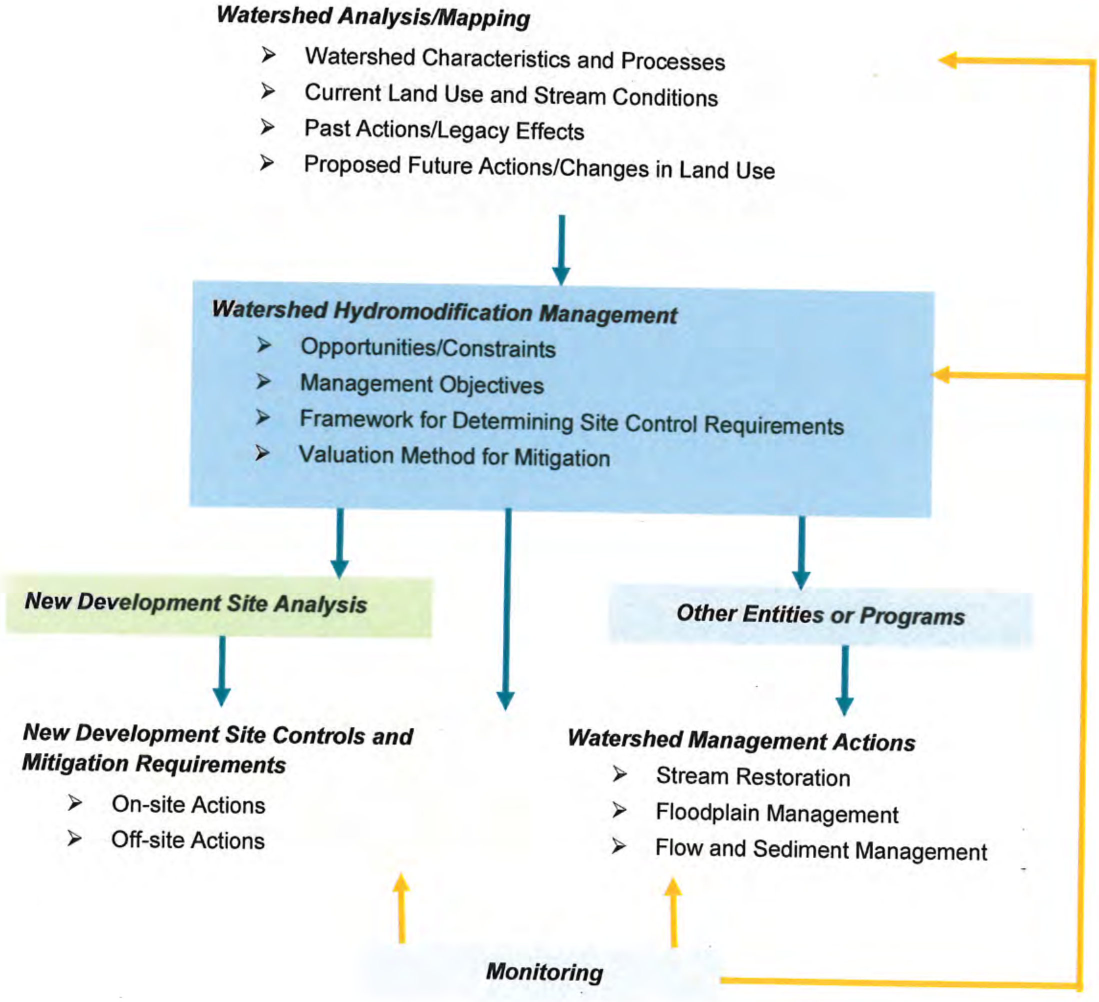

Figure ES-1. Framework for Integrated Hydromodification Management.

An effective management program will likely include combinations of on-site measures (e.g., low-impact development techniques, flow-control basins), in-stream measures (e.g., stream habitat restoration), floodplain and riparian zone actions, and off-site measures. Off-site measures may include compensatory mitigation measures at upstream locations that are designed to help restore and manage flow and sediment yield in the watershed.

Project-specific analysis and design requirements should vary depending on location, discharge point, and size. The range of efforts may include:

- Application of scalable, standardized designs for flow control based on site-specific soil type and drainage design. The assumptions used to develop these scalable designs should be conservative, to account for loss of sediment and uncertainties in the analysis and our understanding of stream impacts.
- Use of an erosion potential metric, based on long-term flow duration analysis and in-stream hydraulic calculations. Guidelines should specify stream reaches where in-stream controls would and would not be allowed to augment on-site flow control.
- Implementation of more detailed hydraulic modeling for projects of significant size or that discharge to reaches of special concern to understand the interaction of sediment supply and flow changes.
- Analysis of the water-balance for projects discharging into streams with sensitive habitat. This may include establishment of requirements for matching metrics such as number of days with flow based on the needs of species present.

Achieving these goals will require that hydromodification management strategies operate across programs beyond those typically regulated by NPDES/MS4 requirements. Successful strategies will need to be developed, coordinated, and implemented through land-use planning, habitat management and restoration, and regulatory programs. Regulatory coordination should include programs administered by the Water Boards, such as non-point source runoff control, Section 401 Water Quality Certifications and Waste Discharge Requirement programs, and traditional stormwater management programs. It should also include other agency programs, such as the Department of Fish and Game Streambed Alteration Program and the Corps of Engineers Section 404 Wetland Regulatory Program. Thus, all levels of the regulatory framework—federal, state, and local—will need to participate in developing and implementing such a program. The integrated watershed-based approach will likely take one or more permit cycles (i.e., at least ten years) to fully implement.

Short- and long-term recommendations for management are summarized in Table ES-1 below.

Table ES-1. Recommendations for implementing watershed-based hydromodification management.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Establish consistent standards for HMPs • Promote use of watershed approaches in HMPs to move away from reliance on project-based management actions • Develop a valuation method to determine appropriate off-site mitigation • Transition to a broader set of monitoring endpoints including flow, geomorphology, and biology	• Implement watershed analysis of opportunities and constraints related to hydromodification • Implement a broader set of tools to improve on-site management actions • Develop institutional capacity to oversee and review modeling and assessment tools • Develop capacity for information/data management and dissemination
Long-term (1+ decades)	• Develop watershed-based regulatory programs and policies for hydromodification management • Integrate hydromodification management needs into other regulatory programs (e.g. TMDL, 401/WDR)	• Develop institution capacity to implement watershed-based hydromodification programs • Incorporate hydromodification and other water quality management into the land use planning process

To successfully accomplish these various recommendations for implementation, both agencies and private-sector practitioners will need to make use of a range of analytical tools. Such tools generally fall into three categories: descriptive tools, mechanistic models, and empirical/statistical models. Models may be used deterministically and/or in a probabilistic manner. These different types of tools can be selected or combined, depending on the specific objective, such as characterizing stream condition, predicting response, establishing criteria / requirements, or evaluating the effectiveness of management actions. Selection of tools should also consider the type of output, intensity of resource requirements (i.e., data, time, cost), and the extent to which uncertainty is explicitly addressed. It is important to note that deterministic modeling without accompanying probabilistic analysis may mask the uncertainties inherent in predicting hydromodification effects. Short-term and long-term recommendations for the application and improvement of tools to support the management framework are shown in Table ES-2.

Although there is sufficient scientific and engineering understanding of hydromodification causes and effects to begin implementing more effective management approaches now, improvements should be informed and adapted based on subsequent monitoring data. To be useful, monitoring programs should be designed to answer questions and test hypotheses that are implicit in the choice of management actions, such that practices that prove effective can be emphasized in the future (and those that prove ineffective can be abandoned). The focus of monitoring efforts, however, needs to be tailored to the time frame of the questions being addressed and the implementing agency (Table ES-3), reflecting the dual goals and audiences of this document.

Table ES-2. Recommendations for the application and improvement of tools in support of the proposed management framework.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Develop quality control and standardization for continuous simulation modeling • Perform additional testing and demonstration of probabilistic modeling for geomorphic response • Pursue development of biologically- and physically-based compliance endpoints	• Work cooperatively with adjacent jurisdictions to implement hydromodification risk mapping at the watershed scale • Implement continuous simulation modeling for project impact analysis
Long-term (1+ decades)	• Improve tools for sediment analysis and develop tools for sediment mitigation design • Develop tools for biological response prediction • Improve tools for geomorphic response prediction	• Expand use of probabilistic and statistical modeling for geomorphic response • Apply biological tools for predicting and evaluating waterbody condition

Table ES–3. Recommendations for hydromodification monitoring.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Define the watershed context for local monitoring (at coarse scale) • Evaluate whether permit requirements are making positive improvements	• Evaluate whether specific projects/ regulations are meeting objectives • Identify the highest priority action(s) to take
Long-term (1+ decades)	• Define watershed context and setting benchmarks for local-scale monitoring (i.e., greater precision, if/as needed) • Demonstrate how permit requirements can improve receiving-water "health," state-wide (and change those requirements, as needed)	• Evaluate and demonstrate whether actions (on-site, instream, and watershed scale) are improving receiving-water conditions • Assess program cost-effectiveness • Identify any critical areas for resource protection

Identifying and, ultimately, achieving the desired conditions in receiving waters requires multiple lines of evidence to characterize condition in an integrative fashion. At their most comprehensive, the chosen metrics should include measures of flow, geomorphic condition, chemistry, and biotic integrity. Biological criteria are key to integrative assessment: in general, biological criteria are more closely related to the designated uses of waterbodies than are physical or chemical measurements. This understanding is reflected in the State's proposed bio-objectives policy, which includes explicit links to hydromodification management.

In summary, transitioning from the current site-based to a more effective watershed-based approach to hydromodification management that addresses both legacy and future impacts will require cooperation between the State and Regional Water Boards and local jurisdictions. Both technical and regulatory/program approaches will need to be updated or revised altogether over the next several permit cycles to realize this long-term goal. Substantial resources will be necessary to realize these goals; therefore, opportunities for joint funding and leveraging of resource should be vigorously pursued from the onset. This cooperative approach should replace the current fragmented efforts among regions and jurisdictions.

1. Overview and Intended Uses of the Document

1.1 Overall Objectives and Intended Audience

Regulation and management of hydromodification is in its infancy in California. As with any new endeavor, initial attempts to meet this need is unproven, inconsistent, and relatively narrow in focus. To improve on existing efforts, the State Water Resources Control Board (SWRCB) has engaged a team of experts to provide technical support to both regulators and permittees for development of Hydromodification Management Plans (HMPs) and their associated permit requirements. This resulting document has two goals and hence two audiences.

The first goal of this document is to provide broad perspectives on what would constitute effective hydromodification assessment, management and monitoring, based on our current best scientific understanding of the topic. The audience for this goal is primarily the State and Regional Water Boards, since meeting this goal will require integration of watershed and site-scale activities that are likely beyond the control or responsibility of any individual municipality. Success will require fundamental changes in the regulatory and management approach to hydromodification that will likely be possible only iteratively and potentially requiring one or more NPDES permit cycles to fully implement. The State and Regional Water Boards will need to provide leadership in implementing these changes, but they will also need to work cooperatively with permittees so that planning, management and monitoring programs can be adapted to operate in a more integrated manner over the broader spatial scales and longer time frames that are necessary to achieve genuine success. Furthermore, hydromodification management plans will need to address preexisting conditions from previous (i.e., legacy) land uses. Clearly, addressing such past effects will require approaches beyond regulation of new development.

This document provides broad perspectives on what would constitute effective hydromodification assessment, management and monitoring, based on our current best scientific understanding of the topic. The document also provides near-term technical assistance for implementing current and pending hydromodification management requirements.

The second goal of this document is to provide near-term technical assistance for implementing current and pending hydromodification management requirements. This goal can be achieved by municipalities within the construct of existing programs, and therefore the primary audience for this aspect of the document is MS4 permittees. Achieving this goal will facilitate greater consistency and effectiveness between HMPs, giving them a stronger basis in current scientific understanding, and will also serve as initial steps toward realizing the broader goal stated above.

1.2 Rationale and Justification

The process of urbanization has the potential to affect stream courses by altering watershed hydrology and geomorphic processes. Development and redevelopment can increase impervious surfaces on formerly undeveloped landscapes and reduce the capacity of remaining pervious surfaces to capture and infiltrate rainfall. The most immediate result is that as a watershed develops, a larger percentage of rainfall becomes surface runoff during any given storm. In addition, runoff reaches the stream channel much more efficiently, so that the peak discharge rates for floods are higher for an equivalent rainfall than they were prior to development. This process has been termed hydromodification. In some instances, direct channel alteration such as construction of dams and channel armoring has also been termed "hydromodification." Such direct alterations are not the focus of this document. Rather, this document focuses on the geomorphic and biological changes associated with changes in land use in the contributing watershed, which in turn alter patterns and rates of runoff and sediment yield. These changes can result in adverse impacts to channel form, stream habitat, surface water quality, and water supply that can alter habitat and threaten infrastructure, homes, and businesses.

The State and Regional Water Boards have recognized the need to manage and control the effects of hydromodification in order to protect beneficial uses in streams and other receiving water bodies. This recognition has led to the inclusion of requirements for development of "hydromodification management plans" (HMPs) in many Phase 1 and some Phase 2 Municipal Stormwater (MS4) permits. Most HMPs require the permitted municipalities to develop programs and policies to assess the potential effects of hydromodification associated with new development and redevelopment, to require the inclusion of management measures to control the impacts of hydromodification, and to develop monitoring programs to assess the effectiveness of HMP implementation at controlling and/or mitigating the impacts of hydromodification.

Development of HMPs is challenging for several reasons. First, there are few accepted approaches for assessing the impacts of hydromodification. Traditional modeling tools are generally untested and may be difficult to apply or inappropriate for use in some California watersheds and streams. Responses of streams to hydromodification are difficult to assess, given inherent climatic variability and the highly stochastic nature of rainfall and the resulting response of streams to runoff events. There are few local examples or case studies from which to draw experiences or conclusions.

As a result of these challenges, individual HMPs to date have utilized a variety of approaches with little coordination or consistency between them. Little information is available on the relative efficacy of any of these approaches. Furthermore, where approaches and tools developed for HMPs in one region of the State (or even from a different region of the country altogether) have been used in subsequent HMPs elsewhere, there has been little or no consideration of the effect of regional climatological or physiographical differences on the transferability of analytical techniques and tools.

1.3 Need for an Expanded Approach

Current site-based hydromodification management approaches are limited in their ability to address the underlying processes that are responsible for most deleterious impacts of hydromodification. Hydromodification effects, by definition, are watershed-dependent processes that are influenced by water and sediment discharge, movement, and storage patterns that may be occurring up- or downstream of a specific project site. Ideally, then, the first step of any hydromodification management plan (HMP) should be a watershed analysis; management of processes at the site or project scale should be done only in the context of such a watershed analysis. Understanding larger-scale processes facilitates prioritization of activities in areas of greatest need and allows for management measures to be located where they have the largest potential benefit, even if that is not on or adjacent to the project site where the current impact is occurring. It also allows for expansion of site based management beyond simple flow control and/or channel stabilization toward strategies that consider flow, sediment, and biological conditions as an integrated set of desired endpoints.

Because watershed boundaries are often not the same as geopolitical boundaries of cities or counties, incorporation of watershed analysis will require leadership from the State and Regional Water Boards. Changes to the current regulatory structure may be necessary to accommodate inter-jurisdictional cooperation and regional information sharing. Similarly, program implementation by both large and small municipalities must include mechanisms that allow site-specific decisions to be informed by watershed-scale analysis.

This document is intended to help address some of these challenges and needs by providing technical recommendations, both to state and regional program developers and to local implementing agencies, for assessment, modeling, development of management strategies, and monitoring. This document can support current HMP development and, at the same time, serve as a first step toward achieving the longer term goals of more integrated, watershed-based hydromodification management.

Current site-based approaches are limited in their ability to address the underlying processes that are responsible for hydromodification impacts.

Effective management of hydromodification will require coordinated approaches across programs at the watershed scale that address all aspects of runoff, sediment generation and storage, instream habitat, and floodplain management.

Adopting this broader approach means that managing the effects of hydromodification cannot be the purview of the stormwater (MS4) program alone. Effective management of hydromodification will require coordinated approaches across programs at the watershed scale that address all aspects of runoff, sediment generation and storage, instream habitat, and floodplain management. Various SWRCB programs have the opportunity and ability to contribute to the goals of comprehensive hydromodification management, including the non-point source control program, water quality certifications, waste discharge requirements, basin planning, SWAMP, and the emerging State Wetland Policy and Freshwater Bio-objectives program. Each of these programs can take advantage of the tools and approaches outlined in this paper to contribute to coordinated management of hydromodification in order to protect beneficial uses and meet basin plan objectives. Furthermore, successful control and mitigation of hydromodification effects will support other programs by improving water quality, enhancing groundwater recharge, and protecting habitat. Therefore, hydromodification management can be a unifying element of many programs and support integrated regional watershed planning.

It is important to note that hydromodification has the potential to affect all water body types; therefore, HMPs should address potential effects to all streams and receiving waters. Because streams are most directly affected by hydromodification, they have been the focus of current regulatory requirements and, therefore, most HMPs. Consequently, this document emphasizes tools and approaches applicable to fluvial systems, which are broadly defined to include wadeable streams, large rivers, headwater streams, intermittent and ephemeral drainages, and alluvial fans (although new specific tools may be necessary for assessment and management of alluvial fans). We recognize, however, that hydromodification can also affect nearshore and coastal environments, including bays, harbors, and estuaries, by altering estuary channel structure, water quality, sand delivery, siltation, and salinity. These effects have been less extensively studied or documented and have received substantially less attention in current hydromodification requirements. Future efforts should more directly address hydromodification effects to all receiving waters, but the information is not presently available to provide equally comprehensive guidance here.

1.4 Scope and Organization

This document is not intended to be prescriptive or to serve as a "cookbook" for development of hydromodification management strategies. Rather, it is a resource to evaluate the utility of existing tools and approaches, and it proposes a framework for integrating multiple approaches for more comprehensive assessment and management. This framework should be used to aid in the development of HMPs that are appropriate for specific regions and settings and take advantage of the best available science. It can also be used to improve consistency in assessment and monitoring approaches so that information collected across regions and programs can be compiled and leveraged to provide more comprehensive assessments of the effectiveness of management actions. Ultimately, such consistency should improve the effectiveness of all programs.

The authors, a team of technical experts, developed the content for this document in consultation with agency staff and regulated entities. The document begins with a brief general discussion of the effects of hydromodification and stream response mechanisms, providing the best available science to support subsequent recommendations. The main body of the document focuses on presenting a proposed new management paradigm where site-based management is nested within an overall watershed assessment that accounts for past, current, and proposed future land use. The body of the document also includes a discussion of existing tools and how they can be used more effectively and appropriately to evaluate potential impacts and guide decisions on selection and design of management practices. The third major section of the document focuses on monitoring that includes evaluation of hydrologic, geomorphic, and biologic conditions with an overriding goal of adaptive management. The document concludes with several technical appendices that offer specific guidance on the appropriate application of tools and models within the existing HMP approaches, and a bibliography of resources.

2. HYDROMODIFICATION SCIENCE

2.1 Introduction

Land-use changes can alter a wide variety of watershed processes, including site water balance, surface and near-surface runoff, groundwater recharge, and sediment delivery and transport. Although alteration to these watershed processes (referred to collectively as hydromodification) can affect many elements of a landscape, the focus of this document is on impacts to stream systems. Furthermore, while this paper will often refer to urbanization, it is recognized that other types of land-use changes (grazing, agricultural, forestry, etc.) can have similar impacts. This section reviews relevant hydrologic processes and summarizes the impact of urbanization on hydrologic, biologic, and geomorphic systems, and it describes our current understanding of the physical mechanisms underlying these impacts. This provides a foundation for establishing assessment tools and predictive models, as well as for developing management and monitoring programs.

Although not addressed by this report, urbanization also has a range of effects on water quality (*Heaney and Huber* 1984, *Brabec et al.* 2002) by increasing pollutant loads (*Owe et al.* 1982), increasing nutrient loads (*Wanielista and Yousef* 1993, *Hubertz and Cahoon* 1999), and diluting dissolved minerals through increased runoff and decreased infiltration and soil contact (*Loucaides et al.* 2007). As a result of both its physical and chemical effects, urbanization also affects the integrity of biota (*Heaney and Huber* 1984) including fishes (*Klein* 1979, *Weaver and Garman* 1994, *Wang et al.* 2000) and invertebrates (*Sonneman et al.* 2001, *Wang and Kanehl* 2003). These impacts are acknowledged and evaluated in the discussion of monitoring Section 4, but the details of their interactions and effects are not otherwise addressed here.

Land-use changes can alter a wide variety of watershed processes, including site water balance, surface and near-surface runoff, groundwater recharge, and sediment delivery and transport. Alteration to these watershed processes are referred to collectively as hydromodification.

2.2 Hydrology Overview

To understand the effects of urbanization, the basic processes of the hydrologic system must be highlighted. A watershed's drainage system consists of all the features of the landscape that water flows over or through (*Booth* 1991). These features include vegetation, soil, underlying bedrock, and stream channels. Urban elements such as roofs, gutters, storm sewers, culverts, pipes, impervious surfaces such as parking lots and roads, and cleared and compacted surfaces fundamentally change the rate and character of hydrologic processes. Generally, the hydrologic changes associated with development and urbanization increases the speed and efficiency with which water enters and moves through the drainage system. In undeveloped watersheds, only a portion of the precipitation that falls ever enters the stream channel. Instead, precipitation may be: 1) evaporated off the ground surface or intercepted by vegetation and evaporated; 2) transpired from the soil; or 3) infiltrated deeply into regional aquifers. For the portion of precipitation that ultimately enters the stream, the rate and processes of delivery vary between watersheds, with important implications for how urbanization will affect runoff.

Flow can be classified as stormflow (or "quickflow") if it enters the stream channel within a day or two of rainfall (*Dunne and Leopold* 1978). Quickflow occurs through 1) infiltration excess (also called "Horton") overland flow, wherever rainfall intensity exceeds the infiltration capacity of the soil and water flows over the ground surface; 2) saturation excess overland flow, where overland flow occurs following filling of all pore space in surface soils; 3) shallow subsurface flow, where water flows relatively quickly through permeable shallow soils (but still more slowly than either Horton or saturation overland flow); and 4) precipitation directly into stream channels. Conversely, water that infiltrates more deeply is classified as delayed flow, because it travels slowly as deep groundwater and emerges into a stream slowly over time.

As a storm progresses, runoff patterns and rates can change, even within the same catchment. For example, surficial soils may become saturated during the course of a storm (or a storm season) as the water table rises, and this can induce a shift in runoff from shallow (or even deep) subsurface flow to the quickflow process of saturation excess overland flow (*Booth* 1991). Even under scenarios in which rainfall intensity exceeds infiltration capacity, Horton overland flow will not be connected to stream channels until surface depressions are filled.

2.3 Impacts of Urbanization

The archetypal model of development involves clearing vegetation; grading, removing, and compacting soils; building roads and stormwater sewers; constructing buildings; and re-landscaping. The specific ways in which these activities alter runoff processes are discussed below. Development may also directly alter stream, such as through channel straightening, levee construction, and flood control reservoirs; however, discussion of the impacts of these alterations is beyond the scope of this document.

2.3.1 Decreased Interception

When rainfall occurs in a watershed, some of the precipitation will be intercepted by vegetation and leaf litter and prevented from entering the stream channel network (Figure 2-1). The percentage of precipitation that can be intercepted varies according to cover type and the character of rainfall (rainfall intensity, storm duration, storm frequency, evaporation conditions) (*Dunne and Leopold* 1978). The effectiveness of interception decreases as a storm progresses because once the surface area of a tree is completely wetted, water will drip off leaves and run down the vegetation as stem flow. Typically, 10-35% of precipitation is intercepted by trees and 5-20% by crops, though these amounts vary widely (*Dunne and Leopold* 1978, *Xiao and McPherson* 2002, *Reid and Lewis* 2009, *Miralles et al.* 2010). In urban environments where vegetative cover is greatly reduced, landscape-scale interception may be lower by an order of magnitude (*Xiao and McPherson* 2002). Precipitation that is not intercepted enters the drainage system. Thus, the mere reduction in interception in urban areas may produce the hydrologic equivalent of a storm that is 10-30% larger.

Figure 2-1. Vegetation reduces runoff by intercepting a portion of the total rainfall and preventing water from entering the drainage system. (Illustration by Jennifer Natali).

The influence of urbanization on climate is complex and varied. For example, urbanization has been shown to increase temperature (*Kalnay and Cai* 2003), increase or decrease wind speeds (*Oke* 1978, *Balling and Brazel* 1987, *Grimmond* 2007), increase pan-evaporation rates (*Balling and Brazel* 1987), and increase shading of the ground surface (*Kalnay and Cai* 2003). In most studies of urban hydrology, the dynamics of evapotranspiration (ET) are typically, explicitly or implicitly, ignored (*Grimmond and Oke* 1999). This exclusion exists because of the widespread assumption that urban ET is negligible compared to rural areas with higher proportions of vegetation-covered soils (*Chandler* 1976, *Oke* 1979). In cases such as urban deforestation in the temperate Eastern United States, it is appropriate to assume a net loss of ET due to urbanization (*Bosch and Hewlett* 1982, *Sun et al.* 2005, *Roy et al.* 2009). However, spatial variability and the site-specific dynamics of climate, vegetation, and land-use should be considered carefully in arid and semi-arid regions where vegetation is limited prior to development. In drier climates (including much of southern California), primary productivity (and ET) may be substantially increased through the irrigation of urban landscaping (*Buyantuyev and Wu* 2008).

2.3.2 Decreased Infiltration

Infiltration in urban areas is decreased due to several factors: impermeable surfaces such as roads, parking lots, and roofs prevent infiltration by blocking water from reaching soils; heavy-equipment construction operations cause soil compaction and degrade soil structures; construction projects may remove surface soils and expose subsurface soils with poorer infiltration capacity; vegetation-clearing and bare-earth construction increase erosion and loss of topsoil (*Pitt et al.* 2008). The effect of impervious surfaces is intuitive, visible, and dramatic (*Booth and Jackson* 1997), but not all impervious areas affect runoff processes equally. For example, if an impervious surface is built over clayey soils with poor infiltration, the overall runoff rates will be less affected than if built over sandy soils with high natural infiltration rates. While the loss of pervious area has received substantial attention within scientific and policy communities, until recent years considerably less attention has been paid to the effects of compaction and the reductions in infiltration capacity of soils (*Pitt et al.* 2008). Commonly, an area of green is assumed to be permeable, but playing fields and even ornamental lawns may have very low infiltration capacities (*Pitt et al.* 2008). A study of urban runoff in Washington found that impervious areas generated only 20% more runoff than what appeared to be green, pervious areas of lawns (*Wigmosta et al.* 1994). Factors such as excavation and lawn-establishment methods appear to be more significant for infiltration than any other factor including grain size of the original sediments (*Hamilton and Waddington* 1999). Tillage may increase infiltration slightly, while compost or peat soil amendments can increase infiltration by 29 to 50 percent (*Kolsti et al.* 1995).

2.3.3 Increased Connectivity and Efficiency of the Drainage System

Rainfall in urban areas moves quickly as overland flow into storm sewers and the stream channel network (Figure 2-2). The delivery of precipitation into urban stream channels is extremely efficient, transforming essentially all precipitation into stormflow and creating nearly instantaneous runoff. Under natural conditions, in contrast, most runoff to streams is via groundwater paths that typically flow at least one or two orders of magnitude slower than surface water. Thus converting subsurface flow into surface stormflow has dramatic consequences. Furthermore, artificial surfaces such as roofs, pavement, and storm sewers are 1) straight, which shortens the travel distance required for delivery into the channel network; and 2) smooth, which decreases friction and allows flow to travel more quickly than in natural channels (*Hollis* 1975). Storm sewer systems increase the density of "channels," which further shortens runoff travel distances (Figure 2-3). In particular, upland regions that may not have had any surface channels prior to urbanization are frequently fitted with storm sewers, which dramatically increase delivery efficiency into the channel network (*Roy et al.* 2009). In sum, urbanization transforms watershed processes and flow paths that were once slow, circuitous, and disconnected into engineered and non-engineered systems that are highly efficient, direct, and connected.

In contrast to the slow measured runoff to natural streams by surface and subsurface pathways, the delivery of precipitation into urban stream channels is extremely efficient, transforming essentially all precipitation into stormflow and creating nearly instantaneous runoff.

2.3.4 Decreased Infiltration into Stream Beds

Concreting of bed and banks, channel narrowing, and channel straightening limit infiltration from a stream into the ground. Concrete channel margins create infiltration barriers, while channel narrowing and straightening limit the surface area accessible for infiltration and also create a less complex channel. Channel complexity such as pools, riffles, steps, and debris dams create hydraulics that slow flow velocities and also divert water into the subsurface (*Lautz et al.* 2005). In arid and semi-arid watersheds where streams may flow only occasionally, infiltration through bed, banks, and floodplain areas may significantly lower peak flows and may sustain aquifers vital to regional water supplies and natural habitats (*Kresan* 1988, *Dahan et al.* 2008). Increasing recognition is being paid in the scientific literature to the infiltration services provided by natural channels and floodplains (*Macheleidt et al.* 2006, *Schubert* 2006).

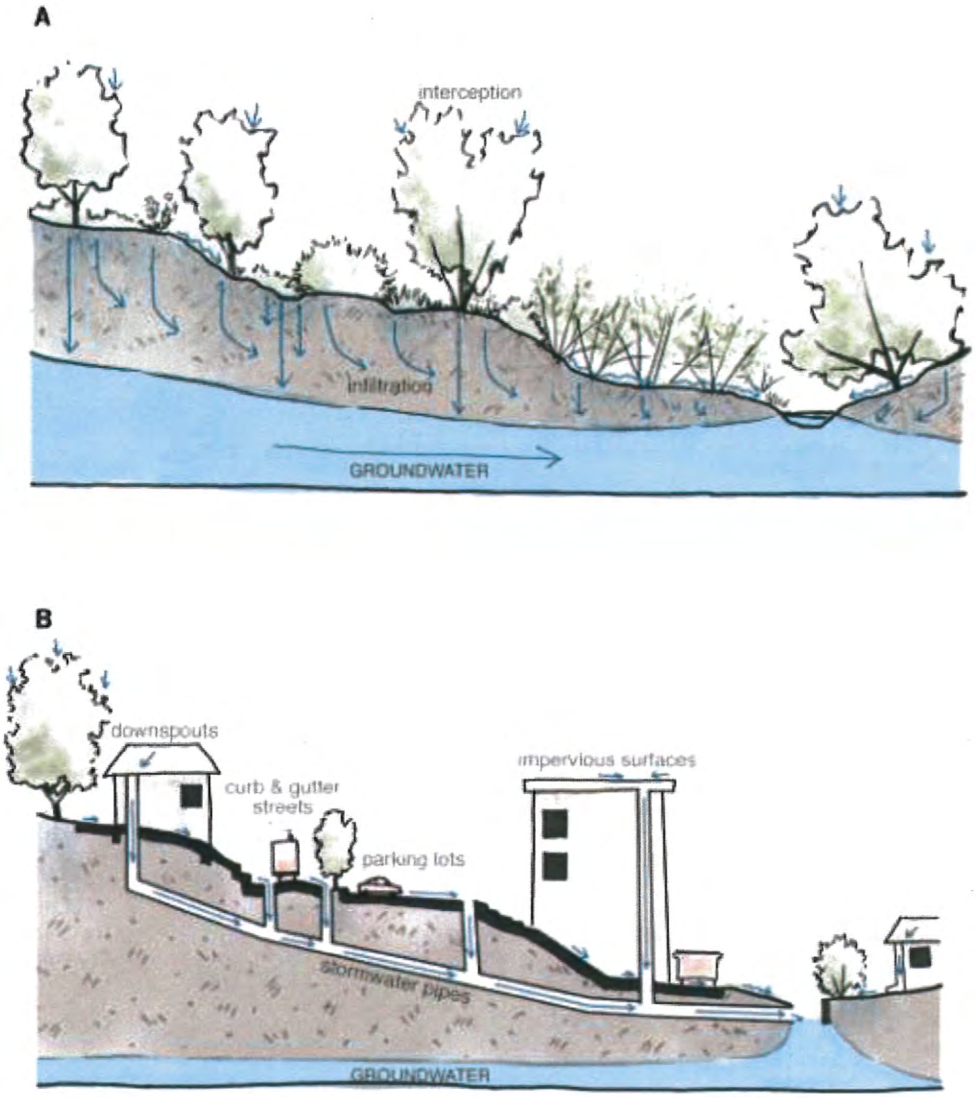

Figure 2-2. Stormwater flowpaths are shortened and quickened through paving, building, soil compaction, and sewer infrastructure. The rapid concentration of streamflow increases storm peaks. Rapid runoff and reduced infiltration prevent groundwater recharge. (Illustration by Jennifer Natali).

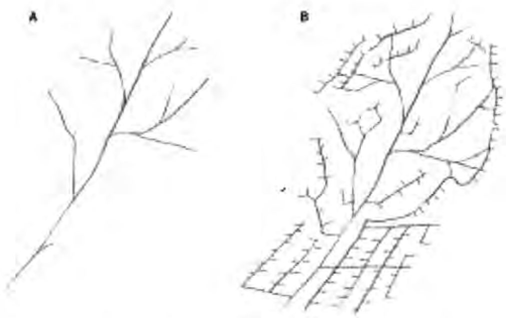

Figure 2-3. Increased surface runoff causes an extension of the channel network. This occurs through increased channel erosion or through constructed networks (to manage increased surface flow). The expanded channel network delivers runoff to downstream reaches much more efficiently. (Illustration by Jennifer Natali).

2.4 Changes in Instream Flow

The instream flow changes resulting from urbanization depend upon site-specific watershed and development characteristics, but typically they include modification of the timing, frequency, magnitude, and duration of both stormflows and baseflow. Urbanization has been shown to increase the magnitude of stormflows, increase the frequency of flood events, decrease the lag time to peak flow, and quicken the flow recession (Figure 2-4; *Hollis* 1975, *Konrad and Booth* 2005, *Walsh et al.* 2005). Because the effects of urbanization manifest differently for different components of the hydrograph, the hydrologic alterations of moderate storms, large storms, and baseflow are discussed individually below.

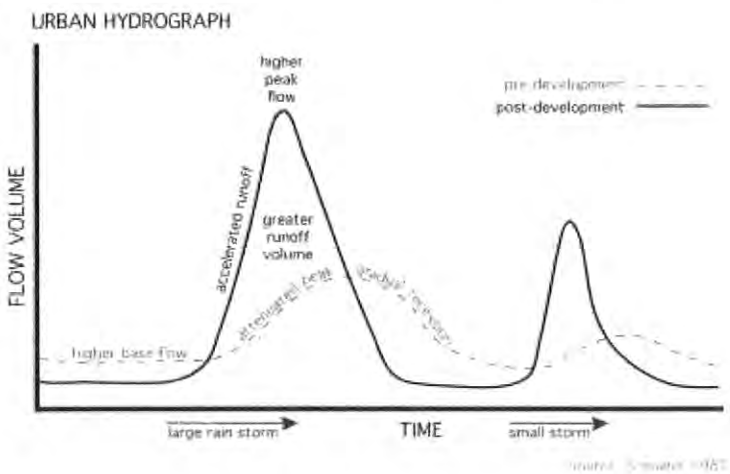

Figure 2-4. Increased runoff efficiency causes higher magnitude peak flows, shorter duration runoff events, decreased baseflow, and dramatic increases in small storms that may have generated little or no runoff under pre-development conditions. (Illustration by Jennifer Natali).

2.4.1 Moderate Stormflow

Urbanization of a watershed can drastically increase the frequency and magnitude of small and moderate flow events (Hawley and Bledsoe 2011). The magnitude of flow amplification increases generally in proportion to the amount of impervious area (*Leopold* 1968, *Hollis* 1975). For example, flows with a return period of one year or longer were shown to be unaffected by paving 5% of the watershed, yet the magnitude of a one-year flow could be more than ten times higher when 20% of a watershed is paved (*Hollis* 1975). In undeveloped watersheds, small storms may not generate any overland flow or streamflow increase at all, because interception, infiltration, soil absorption, and evapotranspiration contain all the precipitation.

Urbanization of a watershed can drastically increase the frequency, duration, and magnitude of small and moderate flow events by factors of 10 or more.

The change to a flashier regime with larger magnitude streamflow generated from small and moderate storms has two primary consequences. First, the stream power and sediment-transport capacity of the stream increase significantly, potentially creating channel erosion and/or stressing instream biota. Second, the season of stormflow is likely to be extended. In undeveloped watersheds, early or late-season storms typically do not generate significant runoff because soils are dry, can effectively absorb most precipitation, and therefore do not generate overland flow or streamflow. Antecedent moisture conditions are less important in urban watersheds where overland flow is generated regardless, and streamflow is generated by even a small storm in a dry watershed. Through magnifying small and moderate storms, urbanization may increase the duration of sediment-transporting and habitat-disturbing flows by factors of 10 or more (*Booth* 1991, *Booth and Jackson* 1997).

2.4.2 Large, Infrequent Storms

In large storms with return intervals of 10 or more years, the influence of urbanization is less pronounced though still present. Whereas a 1-year stormflow may be increased by ten times by paving 20% of the watershed, historical data from humid-region watersheds suggest that the peak magnitude of a 100-year flood would not even be doubled (*Hollis* 1975). The diminishing influence of urbanization on floods of higher recurrence intervals is understood by recognizing that the hydrologic processes of large storms resemble the processes of urban runoff. Essentially, a 100-yr flood is an event that is long in duration, severe in intensity, and likely occurs when soils are already wet. Even in an undeveloped watershed, a storm of this magnitude can typically generate (saturation) overland flow and transport water efficiently into the channel network in a manner more generally comparable to an urban setting.

2.4.3 Baseflow

Urbanization does not affect instream baseflows consistently. Many studies have documented baseflow reductions and/or lowered groundwater levels that have been attributed to decreased infiltration (*Simmons and Reynolds* 1982, *Ferguson and Suckling* 1990) and groundwater extraction (*Postel* 2000). In extreme cases, baseflow in urban watersheds can disappear completely during drought years, dry seasons, or even between storm events during the wet season. The effect of reducing infiltration may be counteracted in urban and suburban landscapes, however, through irrigation of lawns, parks, golf courses, and other water inputs such as septic systems, leaky pipes, and sewage treatment outflow which typically import water from outside the watershed and contribute to both streamflow and groundwater recharge (*Konrad and Booth* 2005, *Walsh et al.* 2005, *Roy et al.* 2009). Indeed, imported water volumes in very dense cities may be an order of magnitude greater than precipitation. Lerner (2002) judged that leakage in water importation and delivery infrastructure typically ranges from 20-50%, and in general this leakage will increase groundwater recharge in urban areas. Similarly, other studies have found municipal irrigation capable of raising groundwater levels and causing surface flooding (*Rushton and Al-Othman* 1994) and changing ephemeral streams into perennial streams (*Rubin and Hecht* 2006, *Roy et al.* 2009). In summary, the magnitude and direction baseflow and groundwater recharge alteration depends on climate, land use, water use, and the infrastructure system of the watershed. There are no simple "rules."

2.5 Changes in Sediment Yield

The role of watershed sediment yield in the behavior of watersheds was first characterized systematically by Wolman (1967) in a three-part conceptual framework of how rivers respond to urban development, in which 1) pre-development quasi-equilibrium conditions are followed by 2) a period of active construction involving grading, vegetation removal, and bare earth exposed to erosion; and 3) the establishment of an urban landscape consisting of pavement, houses, gutters and sewers etc. The construction period is marked by an increase in sediment (typically 2-10 times pre-development rates) produced from bare surfaces and the disturbances associated with construction (*Chin* 2006). The sediment produced during construction is often deposited within stream channels, initiating aggradation and/or channel widening. Following the construction period, sediment production decreases (Figure 2-5) and runoff increases, resulting in increased transport capacity and the potential for severe channel erosion that can result in channel enlargement of commonly 2-3 (and as much as 15) times the original channel cross-section (*Chin* 2006). Changes in post-construction sediment production rates are not well studied, though case studies have found sediment yields in post-construction watersheds to be somewhat higher than rural, undeveloped basins.

The combination of increased runoff and decreased sediment production can result in channel enlargement of commonly 2-3 (and as much as 15) times the original channel cross-section.

Post-construction sediment loads are typically derived from channel enlargement as a result of increased peak flows and the legacy of construction-phase disturbance (*Trimble* 1997, *Nelson and Booth* 2002). The rate of decline in post-construction sediment yields is therefore predominantly controlled by the degree of channel instability caused by the construction phase and the effect of increased peak flows. If the channel margins are armored, densely vegetated, or otherwise erosion resistant, sediment yields may decline quickly following urbanization. If channel instability ensues, elevated sediment yields may persist for decades or more.

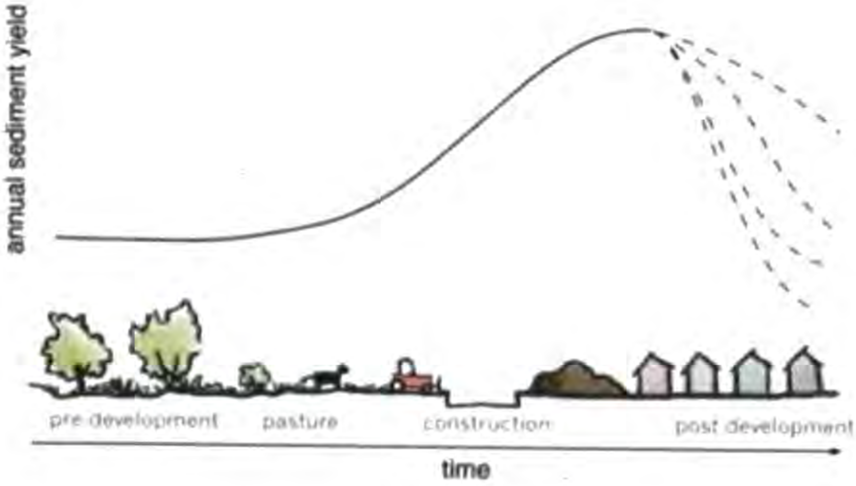

Figure 2-5. Increased sediment yields occur during the land-clearing and construction phases of development. Post-construction sediment yields decrease, though the rate of decrease varies considerably depending on the degree of channel instability caused by the construction phase and by increased runoff. (Illustration by Jennifer Natali).

2.6 Impacts on Channel Form and Stability

Channel form and stability reflect both hydrologic and geomorphic processes. Changes to runoff characteristics and sediment supply can affect all aspects of stream morphology, including planform, cross-sectional geometry, longitudinal profile, bed topography (e.g., pools, riffles), and bed sediment size and mobility. While many factors influence the type and degree of impacts (discussed below), a suite of commonly observed morphological changes due to hydromodification include channel enlargement (incision and widening), decreased bank stability, increased local sediment yield from eroding reaches, overall simplification of stream habitat features such as pools and riffles, changes in bed substrate conditions, loss of connectivity between channel and floodplain (*Segura and Booth* 2010), and changes in sediment delivery to coastal waters (*Jacobson et al.* 2001). Impacts may also propagate upstream as headcuts resulting from reductions in base level due to excess erosion. Likewise, tributaries entering downstream of a developed area may also experience the upstream propagation of headcuts due to base level reductions of the mainstem.

In addition to Jacobson *et al.* (2001), two well-researched literature reviews of morphological impacts (as well impacts to riparian habitat and biota) can be found in: "Impacts of Impervious Cover on Aquatic Systems" by The Center for Watershed Protection (2003) and "Physical Effects of Wet Weather Flows on Aquatic Habitats: Present Knowledge and Research Needs" published by Water Environment Research Foundation (*Roesner and Bledsoe* 2003). Note that these two studies differ significantly in how they synthesize and interpret the reviewed literature, and the CWP publication acknowledges that it does not necessarily apply to streams in the arid west.

2.6.1 Physical Principles Underlying Channel Impacts

A convenient conceptual framework for the physical impacts of hydromodification on stream morphology is "Lane's Balance" (*Lane* 1955; Figure 2-6). This framework encapsulates a fundamental (albeit qualitative) relationship between the hydrologic and geomorphic processes that balance water flow and sediment in a channel. It expresses the condition of sediment transport capacity, as controlled by water discharge and slope, in broad balance with the supplied load and size of bed sediment for a channel in equilibrium. An increase in streamflow or a decrease in sediment supply (for example) will typically initiate a corresponding decrease in slope and/or increase in grain size in order to reestablish equilibrium. That decrease in slope is expressed by channel incision or degradation. In contrast, an increase in sediment supply or decrease in streamflow will typically result in aggradation and a corresponding increase in slope.

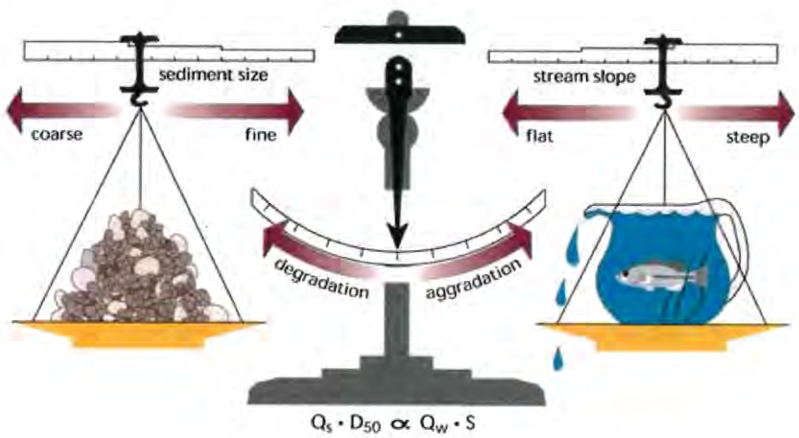

Figure 2-6. Lane's Balance, showing the interrelationship between sediment discharge (Q_s), median bed sediment size (D_{50}), water discharge (Q_w), and channel slope (S).

Slope and grain size are not the only modes of adjustment, as stream channels have many more degrees of freedom in responding to changes in streamflow and sediment supply. For example, Schumm (1969) extended Lane's Balance to include width, depth, sinuosity, and meander wavelength. More quantitatively (and more complexly), adjustments to channel form resulting from hydromodification are controlled by interactions among flow-generated shear stresses (described by hydraulic equations for open channel flow, as a function of channel geometry, roughness, and longitudinal slope), inflowing sediment load, and the shear strength of the bed and bank sediments (a function of their size distribution and cohesiveness).

2.6.2 Natural Variability in Stream Systems

Understanding natural variability in streams is critical to predicting and assessing anthropogenic impacts. A stream may be considered "stable" or "at equilibrium" when its overall planform, cross-section and profile are maintained with no net degradation or aggradation within a range of variance, over extended timeframes (*Mackin* 1948, *Schumm* 1977, *Leopold and Bull* 1979, *Biedenharn et al.* 1997). Such systems can often withstand short-term disturbances without significant change. Even without discrete disturbances, natural streams may be in a state of dynamic equilibrium (*Schumm* 1977), where the channel exhibits stability over the long term even while actively migrating laterally such that erosion of outer banks is accompanied by sediment deposition and bar building on inner banks. Streams may also be fluctuating between aggradation/ degradation/ stability, all within a limited range of conditions. A large-scale event, like a flood or landslide, can cause dramatic changes in channel form, but the channel will often re-established its pre-event planform, geometry and slope over time.

In contrast, a persistent alteration like hydromodification can cause the rate of change to increase. As a result, the channel may begin an evolutionary (or catastrophic) change in morphology, leading to enlargement and instability. A geomorphic threshold is the condition at which there is an abrupt and significant channel adjustment or failure because the channel has evolved to a critical situation. It is the condition at which the proverbial straw breaks the camel's back. Channels that are near a geomorphic threshold can exhibit significant adjustments in response to a relatively small degree of hydromodification. For example, a channel with banks that are near the height and angle for geotechnical failure may widen abruptly due to slight incision.

2.6.3 The Role of Sediment Transport and Flow Frequency in Channel Morphology

Extensive research has been devoted to establishing specific relationships between flow frequency and characteristics of channel morphology. The concept of "effective discharge" was introduced by Wolman and Miller (1960), using a magnitude-frequency analysis to assess the effectiveness of flow events to transport sediment. They concluded that, for the rivers in their analysis, relatively frequent events (occurring on average about 1 times/year) are most effective over the long term in transporting sediment. This concept has formed the basis for a large body of literature (and occasional controversy) over the subsequent five decades relating to the relationships between these flow frequencies and principal channel dimensions (e.g., bankfull stage, width-to-depth ratio), and the application of these relationships to stream design and restoration, as well as prediction and control of hydromodification impacts. Much of the controversy has related to the use of a single event ("dominant discharge" or "bankfull flow") as the basis for such applications, with the implicit assumption that control for that single discharge will result in commensurate channel changes regardless of the distribution of flow frequencies and flow durations over a wider range of discharges.

More recently, the concept of a *range* of moderately frequent, "geomorphically significant" flows that transport the majority of the sediment over the long term (King County 1990, *Bledsoe* 2002, *Roesner and Bledsoe* 2003) was proposed to replace the focus on a single event. The geomorphically significant flow range is considered to be the most influential in determining channel form, as this collective group of flows typically does the most "work" on the channel boundary over engineering time scales. Controlling changes to the frequency of flows within this range is therefore critical to reducing impacts to stream morphology, and is the scientific basis for the "flow-duration" control criteria discussed in the following sections. A flow-duration criterion aims to match the pre-development volumes, durations, and frequencies of this critical range of sediment transporting flows over a period of many decades. Even this concept, however, relies on the implicit assumption that infrequent large events, no matter how dramatic their effects, typically occur "too infrequently" to reset channel morphology and habitat over the timescales of concern in meeting regulatory requirements. These events are typically managed through traditional flood control practices as opposed to hydromodification management.

A flow-duration management approach aims to match the pre-development volumes, durations, and frequencies of this critical range of sediment transporting flows over a period of many decades.

2.6.4 Applicability to California Streams

The traditional concepts of dynamic equilibrium in streams and geomorphically significant flows, discussed above, derive largely from studies on perennial streams in humid areas. An important question is: to what extent do these concepts apply to managing hydromodification impacts to streams within arid and semi-arid areas (such as large portions of California, and particularly the southern and eastern regions)? In such climate regions, precipitation is highly variable, with low annual totals and episodic, large events. Many streams are ephemeral or intermittent and located in a setting of extremely high sediment production associated with erosive geology resulting from high rates of tectonic uplift, sparse vegetative cover and frequent fires (*Graf* 1988, *Stillwater Sciences* 2007). These streams are often characterized by multi-thread sand-bed channels that are inherently unstable and readily respond to changes in flow conditions. In the ephemeral streams described by Bull (1997), for example, the natural behavior is one of alternating periods and locations of aggradation and degradation, varying both temporally and spatially. In such "episodic" streams, the vast majority of sediment may be moved by extreme, highly infrequent events. The importance of understanding the role of episodic events has been emphasized for semi-arid and arid fluvial systems (e.g., *Wolman and Gerson* 1978, *Brunsden and Thornes* 1979, *Yu and Wolman* 1987). The latter authors reviewed concepts of frequency and magnitude in geomorphology research and noted that episodic behavior hinges on frequency of episodic events relative to the time required to return to an "equilibrium" channel form. Episodic behavior is more prevalent where the average long-term disturbance is low but the year-to-year variability is high, a characteristic of arid and semi-arid climates.

Although the morphology of arid and semi-arid streams may be more strongly influenced by extreme events under natural conditions, hydromodification has nevertheless been shown to cause rapid and significant physical changes in such California streams (*Trimble* 1997, *Coleman et al.* 2005, *Hawley and Bledsoe* 2011). Such dramatic responses to the effects of urbanization on relatively frequent flows, often over periods of a decade or less, have profound implications for aquatic life and physical habitat. Despite the flashy streamflow regimes, high sediment supplies, and steep gradients of many streams in the region, the responses of California streams are controlled by the same physical processes as those in other regions that have been studied more extensively. As such, the key controls of stream response can be identified and managed to mitigate the chronic effects of hydromodification between infrequent extreme events. However, it is always advisable to ensure that the application of tools and approaches for prediction and assessment should be based on reference data and empirical models (where applicable) drawn from stream types that are similar in both hydrologic and geomorphic characteristics.

2.6.5 Factors Determining Extent of Impacts

The extent and nature of impacts to stream morphology and habitat from a given change in runoff and sediment supply vary widely, depending on the channel geometry, longitudinal slope, channel material type(s) and size(s), and the type and density of channel vegetation (*Center for Watershed Protection* 2003, *Roesner and Bledsoe* 2003). For example, increased flows within a deep, narrow channel may result in significantly higher shear stresses at the bed; this same increase in a wide, shallow channel may become predominantly overbank flow, with less effect on bed shear stress. Where all other factors are equal, fewer impacts would be expected where flows have access to broad overbank areas (i.e., floodplains) during relatively common floods (*Segura and Booth* 2010), channel materials are more resistant, and stabilizing riparian vegetation is present. Conversely, where erosion and bank instability result in the loss of vegetation reinforcement, a positive feedback response may cause erosion to be accelerated. Furthermore, the relative erosive resistance of bed and bank materials will influence the extent of lateral versus vertical channel adjustments (*Simon and Rinaldi* 2006, *Simon et al.* 2007). For example, if bank resistance is lower than bed resistance, then the channel will tend to widen rather than deepen.

The extent of impacts will also depend on the stream's physiographic context and spatial and temporal patterns of urban development within the watershed (Konrad and Booth 2005). Large-scale studies of hydrologic responses to urbanization (Chin 2006, Poff et al. 2006) also highlighted the regional variation in these responses and reinforced the need to understand local watershed and channel characteristics when managing hydromodification impacts. The presence of road crossings and other infrastructure can provide local grade control and create sediment bottlenecks which often translate to exacerbated erosion in the immediately downstream areas.

The extent and nature of impacts to stream morphology and habitat from a given change in runoff and sediment supply vary widely, depending on the channel geometry, longitudinal slope, channel material type(s) and size(s), and the type and density of channel vegetation, and the spatial and temporal patterns of urban development

An additional consideration relates to the pre-development balance between sediment and streamflow, which is dependent on precipitation patterns, the location of a stream reach within the watershed, the associated sediment behavior of that reach (i.e., production, transport or deposition zone), and local rates of sediment production.

While many of these factors may be quantified for a given time and location, stream systems are enormously complex both spatially and temporally. The existence of physical thresholds and feedback systems can cause an incremental change to result in a disproportionately large response (*Schumm* 1977, 1991). Furthermore, there may be significant temporal lags between the point in time at which land use is altered and when channel impacts are observed (*Trimble* 1995, 1997). In recognition of these effects and the associated uncertainty, predictive models and management tools may present results in terms of probabilities or within the context of a risk-based approach, as discussed further in this document. Such effects also have substantial implications for the design of assessment and monitoring programs.

There may be significant temporal lags between the point in time at which land use is altered and when channel impacts are observed.

2.6.6 Impacts on Other Types of Receiving Waters

Although outside the scope of this document, hydromodification impacts to other water body types are recognizable and should be the subject of additional research and future consideration.

Wetlands, Estuaries, and Coastal Ecosystems. Urbanization can alter water quality, quantity and sediment delivery to wetlands and sensitive coastal ecosystems. Urbanization has led to loss or degradation of wetlands and estuaries as a result of 1) draining and conversion to agriculture (*Dahl*, 1997); 2) upstream alterations to flow and sediment regimes that can change the magnitude, frequency, timing, duration, and rate of change of estuarine salinity, turbidity, freshwater flooding, freshwater baseflow, and groundwater recharge dynamics (*Azous and Horner* 2001); and 3) contaminated runoff from urban areas (*Paul and Meyer* 2001, *J Brown et al.* 2010). Urbanization may also lead to coastal erosion in circumstances where reservoir sediment trapping or post-development decreases in sediment yield reduce the sediment supply to the coast (*Pasternack et al.* 2001, *Syvitski et al.* 2005).

Alluvial Fans. Alluvial fans are dynamic landforms that are under increased development pressure in recent decades, particularly in the expanding cities of the American West. Upstream urbanization, and the resultant flashier flow regime, shortens the time available for infiltration and groundwater recharge in alluvial fans. Furthermore, development on fans themselves results in channel straightening and/or construction of concrete flood conveyance channels that also reduce or eliminate infiltration. The reduction in infiltration amplifies the flood risk further downstream. Additionally, alluvial fans may be more vulnerable than other landscapes to channel instability resulting from hydromodification, because they lack intrinsic geologic controls on channel gradient, and commonly have little vegetation or bank cohesion to provide stability in the purely alluvial deposits (*Chin* 2006).

2.6.7 Influence of Scale

The ability to detect impacts from land-use changes depends upon the spatial and temporal scale at which they are measured. Issues of hydrograph timing and the relative size of the storm system with respect to the watershed area may confound relationships at larger spatial scales. Furthermore, a number of fluvial geomorphic features that are commonly used as metrics of geomorphic condition are scale-dependent. For example, width-depth ratio, tendency toward braiding, and channel depth relative to stable bank height all commonly increase downstream. Other factors, such as the influence of vegetation, depend on protrusion relative to width and rooting depth relative to bank height. The temporal scale over which channel changes occur will be influenced by precipitation variability, in addition to the many physical factors already discussed.

These scale considerations, as well as previous discussion of factors influencing stream response, are important when determining the choice of both management tools and monitoring approaches. It is generally much easier to predict the direction of response than the magnitude. Accurate, detailed predictions of response are difficult to make, and they are generally only possible when applied to specific locations, using extensive data input, to answer very specific questions; even then they are subject to uncertainty. Policies or assessment methods aimed to address a range of streams and geographic conditions are better suited to probabilistic approaches that explicitly acknowledge uncertainty, as described further in subsequent sections.

2.7 Impacts on Fluvial Riparian Vegetation

Stream channel form and stability is closely linked with the ecology of instream and floodplain habitats (Figure 2-7). Spatial and temporal distributions of plant communities are tied to moisture availability and seasonality. The ability of vegetation to stabilize soils, trap sediments, and reduce flow velocities (*Sandercock et al.* 2007) can create positive feedback that promotes further vegetation establishment and enhancement of these stabilizing features. This can result in a strong influence on channel geometric features, specifically channel narrowing (*Anderson et al.* 2004). The change in frequency of overbank flows resulting from channel incision will also affect riparian processes, including nutrient transfer and seed dispersal. For example, it is believed that *Tamarix* dominance over native species along Western US rivers would be less extensive if not for anthropogenic alteration of streamflow regimes (most recently supported by Merritt and Poff (2010)).

Impacts to stream biota may occur through the alteration of habitat structure and habitat dynamics caused by hydrologic and geomorphic changes, as well as directly from hydrologic alteration.

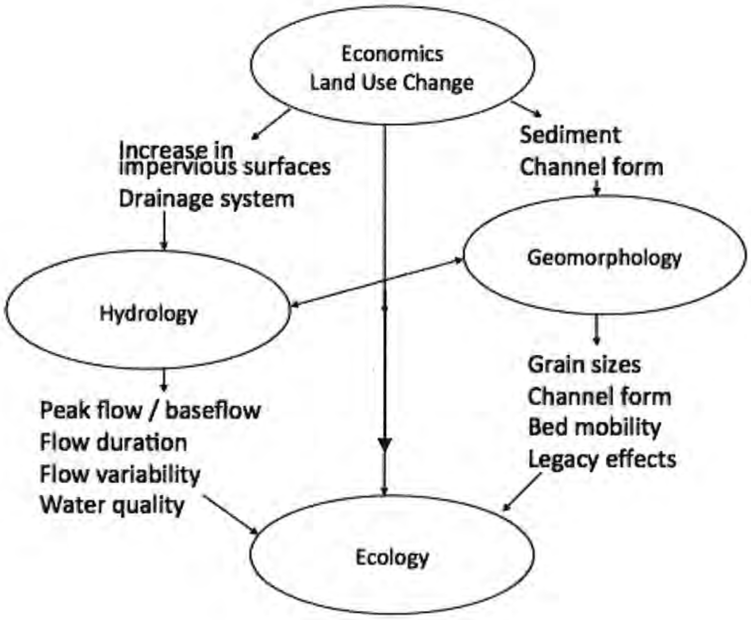

Figure 2-7. Land use changes, hydrology, geomorphology and ecology are closely and complexly interrelated. (Adapted from Palmer *et al.* 2004).

Vegetation changes not only are a result of morphological impacts but also can result directly from changes in streamflow. These findings continue to be supported by recent studies; for example, increases or decreases in baseflow or changes to the seasonal availability of water can determine the extent and type of riparian vegetation capable of thriving in that environment (*White and Greer* 2006). Vegetation changes can have cascading effects on indigenous fauna that require native plants for food or nesting (*Riley et al.* 2005). Channel incision can also result in phreatic draining of adjacent wetland and floodplain habitats and result in loss of key riparian species (*Scott et al.* 2000).

2.8 Impacts on In-Stream Biota

As shown in Figure 2-7, impacts to stream biota may occur through the alteration of habitat structure and habitat dynamics caused by hydrologic and geomorphic changes, as well as directly from hydrologic alteration. (The term biota is used here to refer to a range of non-plant species including algae, macroinvertebrates, amphibians, fishes, etc.) Because of these relationships, the condition of in-stream biota is considered to reflect the effects of all other impacts and has been recommended as an integrative measure of stream health (discussed further in Section 5).

Studies continue to build on Poff *et al.* (1997), who highlighted the importance of the "natural flow regime" and its variability as critical to ecosystem function and native biodiversity. Streamflow pattern or "regime" interacts with the geomorphic context to control the physical and biological response of streams to hydromodification. The basic characteristics of streamflow regimes are typically described in five ways: magnitude, frequency, duration, timing, and rate of change. There is a large body of science linking one or more of these five elements of flow regimes to geomorphic processes, physical habitat, and ecological structure and function. A few examples of linkages with physical habitat are provided in Table 2-1; these linkages describe the mechanisms by which flow changes can impact stream ecology through morphological alterations.

Table 2-1. Examples of Relationships between Flow Regime Attributes and Physical Habitat Characteristics (adapted from Roesner and Bledsoe 2002).

Flow Attribute	Example Relationships with Physical Habitat
Magnitude	• Determines extent to which erosion/removal thresholds for substrate, banks, vegetation, and structural habitat features are exceeded • Determines whether floodplain inundation/exchange occurs • Habitat refugia may become ineffective during extreme events
Frequency	• Flashiness can affect potential for recovery of quasi-equilibrium channel forms between events, bank stability, and streambank/riparian vegetation assemblages • Frequency of substrate disturbance can act as a major determinant of fish reproductive success and benthic macroinvertebrate abundance and composition
Duration	• Determines the impact of a threshold exceeding event, e.g., scour depths • Urbanization frequently increases the duration of geomorphically effective flows which also affect bank vegetation establishment and maintenance • Extended durations of high suspended sediment concentrations can act as chronic and acute stressors on fish communities
Timing	• The temporal sequence of flow events affects channel form and stability as geomorphic systems may be "primed" for abrupt changes. • Stream biota may use flow timing as a life-cycle cue • Predictability of flow can affect utilization of habitat refugia
Rate of Change	• Affects bank drainage regimes (bank stability) and sedimentation processes, e.g., re-suspended fine sediment concentrations during storm hydrographs, embeddedness, armoring • Rapid drawdown can result in stranding of instream biota • Rise and fall rates control riparian water table dynamics and seedling recruitment

The mechanisms of such impacts are also well detailed by Center for Watershed Protection (2003); for example, increased flows are related to a reduction in habitat diversity and simplification of habitat features such as pools; this in turn reduces the availability of deep-water cover and feeding areas.

Many studies support the conclusion that stream biota are also directly impacted by altered flow regimes, independent of channel instability and erosion. Konrad and Booth (2005) identified four hydrologic changes resulting from urban development that are potentially significant to stream ecosystems: increased frequency of high flows, redistribution of water from baseflow to stormflows, increased daily variation in streamflow, and reduction in low flow. They caution that ecological benefits of improving physical habitat and water quality may be tempered by persistent effects of altered streamflow and sediment discharge, and that hydrologic effects of urban development must be addressed for restoration of urban streams. Walsh *et al.* (2007) concluded that low-impact watershed drainage design was more important than riparian revegetation with respect to indicators of macroinvertebrate health. Bioengineered bank stabilization can also have positive effects on habitat and macroinvertebrates, but it cannot completely mitigate impacts of urbanization with respect to stream biotic integrity (*Sudduth and Meyer* 2006). Walters and Post (2011) and Brooks *et al.* (2011) found impacts to benthic macroinvertebrates due to upstream water abstractions, including reductions in total biomass of insects and reductions in abundance respectively.

2.9 Conclusions

Alterations in streamflow and sediment transport as a result of land use change can have severe impacts on streams. Common responses include changes in water balance, surface and near-surface runoff timing and magnitude, groundwater recharge, sediment delivery and transport, channel enlargement, widespread incision, and habitat degradation. The extent and consequences of these impacts depend on stream type, watershed context, and local controls on channel adjustment; as such, stream responses to hydromodification are complex and difficult to predict with any precision. Due to the direct impacts of streamflow modification on vegetation and biota, channel morphology cannot be the sole measure of hydromodification impacts. Thus, mitigation efforts that are narrowly focused on channel stability may be insufficient for sustaining key ecological attributes. Likewise, reach-scale stabilization of streams will not necessarily result in the return of comparable habitat quality and complexity (Henshaw and Booth 2000, Roesner and Bledsoe 2003). Hydromodification management should be considered in the context of an overall watershed-scale strategy that targets maintenance and restoration of critical processes in critical locations in the watershed. Furthermore, it is imperative that monitoring and adaptive management be focused on achieving desired objectives for aquatic life and overall stream "health" in addition to simply measures of geomorphic response.

3. FRAMEWORK FOR HYDROMODIFICATION MANAGEMENT

3.1 Introduction and Overview

The current approach to managing hydromodification impacts on a project-by-project basis is not sufficient to protect beneficial uses of streams. This section outlines a comprehensive, alternative framework that begins with watershed analysis and uses the results to guide the site-based management decisions that are the current focus of most hydromodification management strategies. It also recommends the implementation of a compensatory mitigation program in support of hydromodification management objectives identified in the watershed analysis. Figure 3-1 summarizes this approach and illustrates how current site-based management relates to the larger framework.

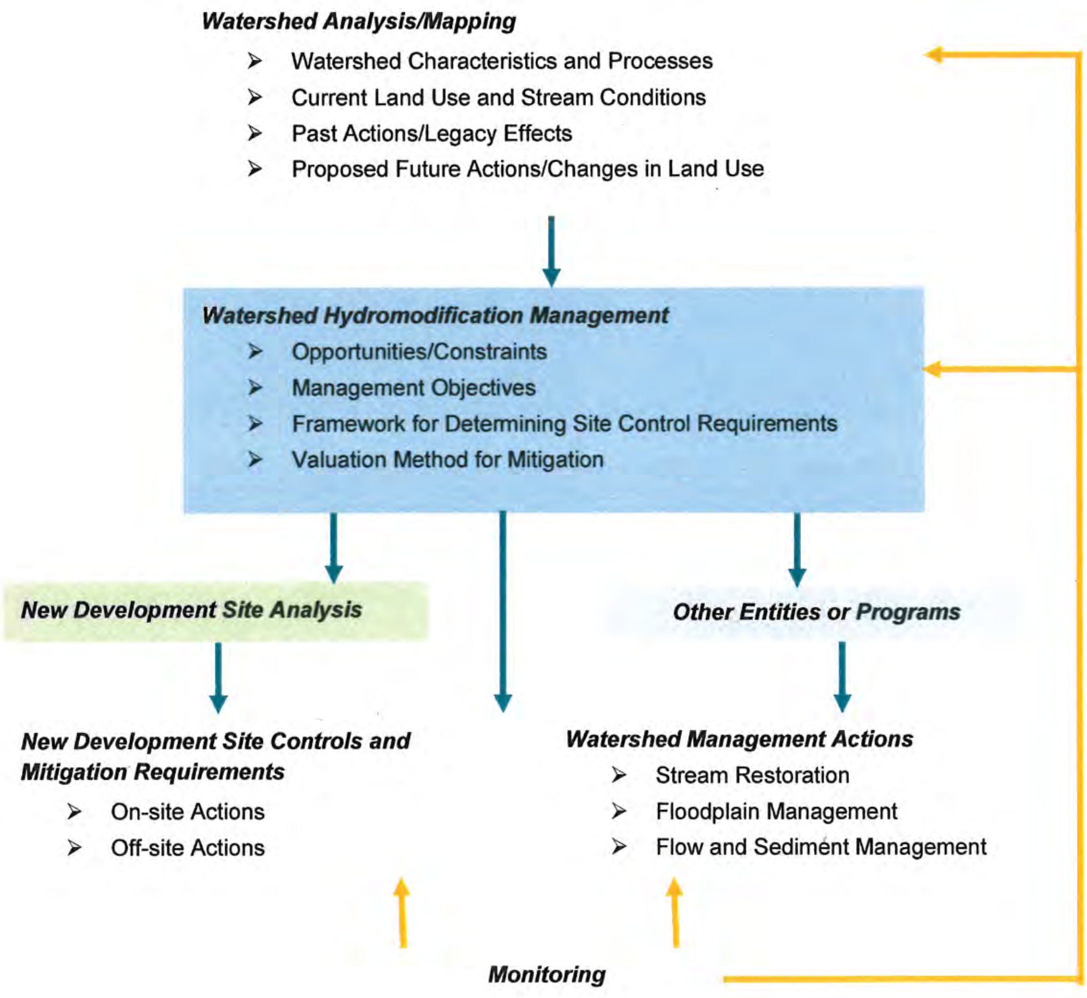

Figure 3-1. Framework for Integrated Hydromodification Management.

This section discusses the details of the integrated framework proposed in Figure 3-1. Key features of this comprehensive approach to hydromodification management are:

- Hydromodification management needs to occur primarily at the watershed scale. The foundation of any hydromodification management approach should be an analysis of existing and proposed future land use and stream conditions that identifies the relative risks, opportunities, and constraints of various portions of the watershed. Site-based control measures should be determined in the context of this analysis.
- Clear objectives should be established to guide management actions. These objectives should articulate desired and reasonable physical and biological conditions for various reaches or portions of the watershed. Management strategies should be customized based on consideration of current and expected future channel and watershed conditions. A one-size-fits-all approach should be avoided.
- An effective management program will likely include combinations of on-site measures (e.g., low-impact development techniques), in-stream measures (e.g., stream habitat restoration), and off-site measures. Off-site measures may include compensatory mitigation measures at upstream locations that are designed to help restore and manage flow and sediment yield in the watershed.
- Management measures should be informed and adapted based on monitoring data. Similarly, monitoring programs should be designed to answer questions and test hypotheses that are implicit in the choice of management measures, such that measures that prove effective can be emphasized in the future (and those that prove ineffective can be abandoned).
- Hydromodification potentially affects all downstream receiving waters; therefore, there generally should be no areas exempted from hydromodification management plans. However, the variety of types and conditions of receiving waters should result in a range of requirements. This also means that objectives, and the management strategies employed to reach them, will need to acknowledge pre-existing impacts associated with historical land uses.

A watershed-based approach to hydromodification management will allow integration of objectives with related programs such as water quality management, groundwater management, and habitat management and restoration through mechanisms such as Integrated Regional Water Resources Management Plans.

Implementation of this approach will likely require changes in the current administration of hydromodification management plans statewide, both in the development and promulgation of regulations by the State and Regional Water Boards and in the administration and execution of those regulations by local jurisdictions (Table 3-1). In the short term, municipalities will need to broaden the approaches to on-site management measures and expand monitoring and adaptive management programs based on the tools described in this document. In the long term, regulatory agencies will need to develop watershed-based programs that allow for implementation of management measures in the locations and manner that will have the greatest impact on controlling hydromodification effects. A watershed-based approach will also allow the integration of hydromodification management objectives with related programs such as water quality management, groundwater management, and habitat management and restoration through mechanisms such as Integrated Regional Water Resources Management Plans.

Table 3-1. Recommendations for implementation of watershed-based hydromodification management, organized by the scale of implementation and the time frame in which useful results should be anticipated.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Define the watershed context for local monitoring (at coarse scale) • Evaluate whether permit requirements are making positive improvements	• Evaluate whether specific projects/ regulations are meeting objectives • Identify the highest priority action(s) to take
Long-term (1+ decades)	• Define watershed context and setting benchmarks for local-scale monitoring (i.e., greater precision, if/as needed) • Demonstrate how permit requirements can improve receiving-water "health," state-wide (and change those requirements, as needed)	• Evaluate and demonstrate whether actions (on-site, instream, and watershed scale) are improving receiving-water conditions • Assess program cost-effectiveness • Identify any critical areas for resource protection

3.2 Background on Existing Strategies and Why They are Insufficient

Current hydromodification approaches and strategies, such as flow and sediment-control basins, have been long-recognized as insufficient to fully address hydromodification impacts (e.g., Booth and Jackson 1997, Maxted and Horner 1999). Present understanding of the causes and effects of urbanization suggest that such approaches must be expanded to include integrated flow and sediment management at the watershed scale, along with stream corridor/floodplain restoration (NRC 2009).

Flow management has its origins in flood-control basins intended to reduce peak discharge through stormwater detention (Dunne and Leopold 1978). A key shortcoming of these approaches for hydromodification management is that they do not address (and may exacerbate) cumulative erosive forces on the receiving channel because they trap sediment and release sediment-starved water to downstream areas. Simple detention can increase the frequency and duration with which channels are exposed to erosive effects (McCuen and Moglen 1988, Bledsoe *et al.* 2007), resulting in an increase in the downstream impacts of hydromodification.

Since the late 1980's in parts of the US, hydromodification management plans began to explore "flow-duration" control standards as a way to address this shortcoming. These standards require that the post-project discharge rates *and durations* may not deviate above the pre-project discharge rates and

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durations by more than a specific (and typically quite small) percent, across a broad range of discharges at and above the presumed threshold of instream erosion and sediment transport, as averaged over a multi-year period of measured (or simulated) record. This approach is a dramatic improvement over earlier methods, although it does not adequately address the issues of sediment deficit associated with urbanization (Chin 2006). In addition, current flow-duration standards do not fully account for the effects of flow alteration on in-stream habitat and biological functions (e.g., they do not address the seasonality of peak flows, rates of hydrograph rise and recession, low-flow magnitude and duration) and therefore may not be protective of all beneficial uses of downstream waterbodies.

Current strategies are also insufficient with respect to how municipal stormwater permits apply hydromodification standards. Currently, development triggers are established to determine if a project is subject to the standards. These triggers are generally specified by either project land use type in conjunction with size, or by project size alone (e.g., 20 units or more of single family residential housing, or 10,000 square feet or more of new impervious area). The exemption of many small projects from hydromodification controls can result in cumulative impacts to downstream waterbodies (see Booth and Jackson, 1997, for an example from western Washington of the cumulative effects of a small-project exemption); a move to include LID requirements that apply to all projects, regardless of size, is a positive development to begin to address this issue. There is usually also an exemption for projects discharging to hardened channels or waterbodies; however these exemptions may not be supportive of future stream restoration possibilities, and do not address the impacts of hydromodification on lentic and coastal waterbodies (as yet not fully understood). A further limitation of the current permit structure is that there is no consideration of project characteristics such as position within the watershed, sensitivity of the receiving stream reach, or level of coarse sediment production on the proposed project site. Finally, current programs rely solely on regulating new development and re-development to prevent hydromodification impacts without addressing pre-existing conditions which may limit the effectiveness of future management actions.

Shortcoming of current hydromodification standards that may limit their effectiveness include the exemption of many small projects, which can result in cumulative impacts to downstream waterbodies, and the reliance solely on regulating new development and re-development without addressing pre-existing conditions which may limit the effectiveness of future management actions.

When flow-control measures of whatever regulatory standard have failed to protect streams from erosion, hydromodification "management" typically consists of bank or channel armoring, drop structures, and other hard engineering approaches. Although these methods may reduce local hydromodification impacts, it is typically at the expense of other in-stream or riparian functions or beneficial uses. For example, channel armoring can reduce habitat and water conservation functions and services by direct habitat removal, increased bed scour, and decreased connectivity between the channel and its floodplain. In addition to loss of biological and physical stream function, many armoring solutions degrade or fail over time because they address only the localized channel instability rather than the overarching processes that led to the instability (Kondolf and Piegay 2004). For example, drop structures constructed to stabilize a specific channel reach will tend to shift downstream the consequences of an insufficient sediment load—the reach immediately upstream of the drop structure is "protected," but that immediately downstream is degraded even more severely. In extreme cases, the structure itself can be undermined by downstream erosion and headcutting that is exacerbated by the sudden shift in velocity and associated eddy effects (i.e., hydraulic jump) that often occurs downstream of grade stabilization (Chin 2006). Bank armoring can also fail due to being undermined by erosion at the toe of slope, which can lead to scour (Figure 3-2). In both cases, structural failures often lead to a sequence of incremental increases in the size and extent of the structural solution in an attempt to continually repair increasing channel degradation. In extreme cases, catastrophic failure of bank or grade stabilization can lead to sudden and dramatic changes in channel form, which can be associated with devastating loss of habitat, infrastructure, and property.

Figure 3-2. Undermining of grade control and erosion of banks downstream of structures intended to stabilize a particular stream reach. Left photo is looking upstream at drop structure; right photo is looking downstream from the drop structure.

3.3 Development of Comprehensive Hydromodification Management Approaches

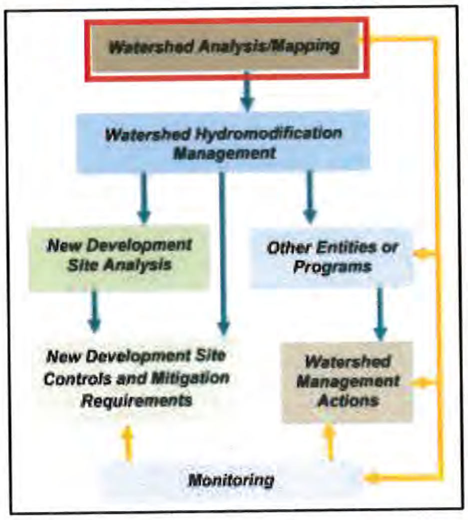
The goal of hydromodification management should be to protect and restore overall receiving water conditions, by maintaining or reestablishing the watershed processes that support those conditions, in the face of urbanization. Achieving these goals will require that hydromodification management strategies operate across programs beyond those typically regulated by NPDES/MS4 requirements. Successful strategies will need to be developed, coordinated, and implemented through land-use planning, non-point source runoff control, and Section 401 Water Quality Certifications and Waste Discharge Requirement programs in addition to traditional stormwater management programs. Thus, all levels of the regulatory framework—federal, state, and local—will need to participate in developing such a program, with program development occurring mainly through regulatory and resource protection agencies and program implementation occurring mainly through local jurisdictions.

As shown in Figure 3-1, watershed-scale hydromodification management should include all of the following key elements:

> **The goal of hydromodification management should be to protect and restore overall receiving water conditions, by maintaining or reestablishing the watershed processes that support those conditions, in the face of urbanization.**

- Watershed-wide assessment of the condition of key watershed processes, to understand the natural functioning of the watershed and what has been (or is at risk of being) altered by urbanization.
- Watershed-wide assessment of hydromodification risk, to categorize areas based on the likelihood of hydromodification impacts and to identify opportunities for restoration or protection of key reaches or sub-basins.
- Appropriate management objectives for various stream reaches and/or portions of the watershed.
- Process for selecting management actions and mitigation measures for project sites and stream reaches.
- Monitoring program that is consistent with the goals of the HMP so that information generated can be used to improve the HMP over time.

3.4 Watershed Mapping and Analysis – Identification of Opportunities and Constraints



Watershed analysis should be the foundation of all hydromodification management plans. Analysis should identify the nature and distribution of key watershed processes, existing opportunities and constraints in order to help prioritize areas of greater vs. lesser concern, areas.

"Watershed analysis" has several steps, of which the first is mapping. Mapping may occur at the watershed or regional (i.e., multiple watersheds) scale. Mapping should include data layers to facilitate the following analyses. Most of these data layers are freely available as online. Further information on analysis tools is provided in the next section. These maps should be designed for iterative updates over time as new information becomes available:

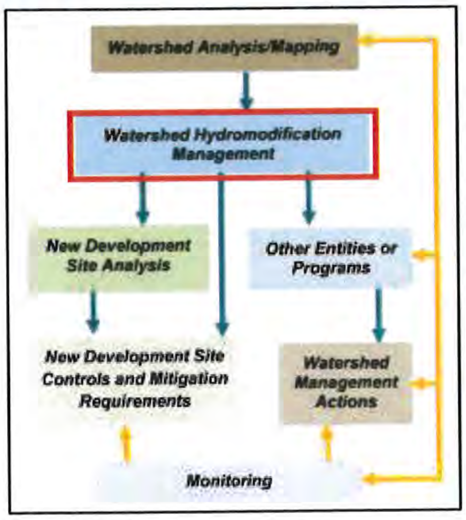
- <u>Dominant watershed processes</u> – analysis of topography (10-m digital elevation model), hydrology, climate patterns, soil type (NRCS soil classifications) and surficial geology can be used to identify the location and type of dominant watershed processes, such as sediment source areas and areas where infiltration is important or where overland flow likely dominates. This can provide a template for the eventual design of management measures that correspond most closely to the pre-development conditions, which support processes that promote long-term channel health. The Central Coast Hydromodification Control Program (the "Joint Effort"; see Booth *et al.* 2011) provides an example of this type of analysis.

- Existing stream conditions – At a minimum the National Hydrography Database (NHD) can provide maps of streams and lakes in the watershed. Additional information on stream condition should be included to the extent that it is available. This could include major bed material composition, channel planform, grade control locations and condition, and approximate channel evolution stage. These maps can also be used to conduct general stream power evaluations.
- Current (Past) and anticipated future land use - Current land use and land cover plus proposed changes due to general or specific plans. Historical information on past land use practices or stream conditions should be included if it is readily available. Classified land cover (NLCD 2006) is available from the Multi-Resolution Land Characteristics Consortium (MRLC).
- Potential coarse and fine sediment yield areas – methods such as the Geomorphic Land Use (GLU) approach (Booth *et al.* 2010) can be used that to estimate potential sediment yield areas based on geology, slope and land cover.
- Existing flood control infrastructure and channel structures – maps should include major channels, constrictions, grade control, etc. that affect water and sediment movement through the watershed. Any available information on water quality, flood control or hydromodification management basins should also be included.
- Habitat – both upland and in-stream and riparian habitat should be mapped to help determine areas of focus for both resource protection and restoration. This may be based on readily available maps such as the National Wetlands Inventory and National Land Cover Database, aerial photo interpretation, or detailed local mapping.
- Areas of Particular Management Concern – these may include sensitive biological resources, critical infrastructure, 303(d) listed waterbodies, priority restoration areas or other locations or portions of the watershed that have particular management needs.
- Economic and social opportunities and constraints – comprehensive watershed management includes consideration of opportunities for improving community amenities associated with streams, economic redevelopment zones, etc. Details on this are beyond the scope of this paper, but emphasize the need to include planning agencies in the development of hydromodification management plans.

Substantial resources will be necessary to implement a watershed analysis approach; therefore, opportunities for joint funding and leveraging of resources should be vigorously pursued.

Watershed analysis will be challenging especially for smaller municipalities with limited resources or where their jurisdiction only encompasses a portion of the watershed. Substantial resources will be necessary to implement this approach; therefore, opportunities for joint funding and leveraging of resource should be vigorously pursued. A cooperative approach should replace the current fragmented efforts among regions and jurisdictions. Furthermore, the State and Regional Water Boards should support completion of these maps and common technical tools as the foundation for future hydromodification management actions.

3.5 Defining Management Objectives



Results of the watershed analysis should be used to determine the most appropriate management actions for specific portions of the watershed. Management strategies should be tailored to meet the objectives, desired future conditions, and constraints of the specific channel reach being addressed.

Decisions should be based on considerations of areas suitable for specific ecosystem services, opportunities, and constraints as described above. Management objectives may be aimed at reducing effects of proposed future land use or mitigating for the effects of past land use, and they may apply to stream reaches or upland areas. Potential management objectives for specific stream reaches may include: protect, restore, or manage as a new channel form.

The specific manifestation of each of these strategies will differ by location, based on constraints of the stream, watershed plan objectives, etc. Decisions about appropriate objectives will need to consider current and future opportunities and constraints in upland, floodplain, and in-stream portions of the watershed. General definitions are provided below as a starting point for case-specific refinement.

Management strategies should be tailored to meet the objectives, desired future conditions, and constraints of the specific channel reach being addressed. Objectives for specific stream reaches may include:

- **Protect**
- **Restore**
- **Manage as a new channel form**

3.5.1 Protect

This approach consists of protecting the functions and services of relatively unimpacted streams in their current form through conservation and anti-degradation programs. This strategy should not be used if streams are degraded, or nearing thresholds of planform adjustment or changes in vegetation community. This strategy may apply following natural disturbances such as floods depending on the condition of the stream reach and the ability for natural rehabilitation to occur (due to how intact watershed processes are). The goal of this strategy is not to create an artificial preserve (such as a created stream running through an urban park) but rather a naturally function river system. Fully channelized systems are not considered in this framework. Examples of specific actions include:

- Preserving intact channel systems through easements, restrictions, covenants, etc. This should be considered in the watershed context to ensure adequate connectivity with upstream and downstream reaches of similar condition, and to ensure that the watershed processes responsible for creating and maintaining instream conditions will persist.
- Providing appropriate space for channel processes to occur (e.g., floodplain connectivity).
- Establishing transitional riparian and upland buffer zones that are protected from encroachment by infrastructure or development.

3.5.2 Restore

There are many definitions of "restoration". For the purposes of this document, restoration is considered re-establishing the natural processes and characteristics of a stream. The process involves converting an unstable, altered, or degraded stream corridor, including adjacent riparian zone (buffers), uplands, and flood-prone areas, to a natural condition. In most cases, restoration plans should be based on a consideration of watershed processes and their ability to support a desired stream type. The watershed analysis discussed above should be used to determine how and where watershed process should be protected or restored in order to best support stream and stream-corridor restoration. This process should be based on a reference condition/reach for the valley type and includes restoring the appropriate geomorphic dimension (cross-section), pattern (sinuosity), and profile (channel slopes), as well as reestablishing the biological and chemical integrity, including physical processes such as transport of the water and sediment produced by the stream's watershed in order to achieve dynamic equilibrium. Design of restoration structural elements must be based on existing and anticipated upstream land uses, and reflect the modified hydrology resulting from these uses. Restoration should apply to streams that are already on a degradation trajectory where there is a reasonable expectation that a more stable equilibrium condition that reflects previously existing conditions can be recreated and maintained via some intervention. Creating a stream system that differs from "natural conditions" is not considered restoration. All elements of the "protection" strategy should also be included once the restoration actions are complete. Examples of specific actions include:

- Floodplain and in-stream measures that restore natural channel form consistent with current and/or anticipated hydrology and sediment yield. Examples include recontouring, biotechnical slope stabilization, soft-grade control features (e.g., woody debris).
- Revegetation of stream banks and beds, including removal of invasive species.
- Preserving intact channel systems through easements, restrictions, covenants, etc. This should be considered in the watershed context to ensure adequate connectivity with upstream and downstream reaches of similar pristine condition.

- Providing appropriate space for channel processes to occur (e.g. channel migration at allowable levels, floodplain connectivity, and development of self-sustaining riparian vegetation).
- Establishing transitional riparian and upland buffer zones that are protected from encroachment by infrastructure or development.

3.5.3 Manage as New Channel Form

Once a stream channel devolves far enough down the channel evolution sequence, it is extremely difficult to recover and restore without substantial investment of resources. If critical thresholds in key structural elements, such as planform or bank height, are surpassed, streams should be allowed to continue progressing toward a new stable equilibrium condition that is consistent with the current setting and watershed forcing functions, if such progress does not pose a danger to property and infrastructure. Substantial alteration of flow or sediment discharge, slope or floodplain width may make it improbable that a stream can be restored to its previous condition. In such circumstances, it may be preferable to determine appropriate channel form given expected future conditions and "recreate" a new channel to match the appropriate equilibrium state under future conditions. For example, a multi-thread braided system may not be the appropriate planform based on new runoff and sediment pattern; instead, a single-thread channel or step-pool structure may be a more appropriate target. Examples of specific actions include:

- In-channel recontouring or reconstruction of channel form.
- Floodplain recontouring or reconstruction that improves connectivity with the channel.
- In extreme circumstances based on channel condition, position in the watershed, etc. this may involve hardening portions of the channel and focusing "mitigation" measures at off-site measures at a different part of the watershed. Off-site mitigation can be informed by "hydromodification risk mapping".
- Re-establishing longitudinal connectivity for sediment transport and ecological linkages.
- Preserving intact channel systems through easements, restrictions, covenants, etc. This should be considered in the watershed context to ensure adequate connectivity with upstream and downstream reaches of similar pristine condition.
- Providing appropriate space for channel processes to occur (e.g. floodplain connectivity).
- Establishing transitional riparian and upland buffer zones that are protected from encroachment by infrastructure or development.

Several authors have previously noted that in urban systems, natural channel state often can no longer be sustained under changed hydrological conditions. Thus, different management goals are probably appropriate for watersheds at varying stages of development (Booth, 2005) and at varying degrees of adjustment (Chin and Gregory 2005). In this context, identifying which channels are suitable for protection, restoration, or alternative channel form can be used to guide restoration and management efforts (Booth *et al.* 2004).

Upland objectives should be established to support management objectives for stream reaches. These objectives will have direct implications and will influence site-specific control requirements (discussed below). Potential management objectives for upland areas may include:

- *Conserve open space for infiltration*: Infiltration reduces the magnitude and duration of runoff to the stream channel and allows flow to re-enter the stream through diffuse overland flow, shallow subsurface flow, or groundwater recharge. This in turn reduces the work (energy) on the channel bed and banks and helps promote stability.
- *Conserve open space for stream buffers*: Buffers allow many of the same infiltration processes discussed above to occur. In addition, they provide space for channel migration and overbank flow, both of which function to reduce energy and allow the channel to better withstand potentially erosive forces associated with high flow events.
- *Conserve open space for coarse sediment production*: Course sediment functions to naturally armor the stream bed and reduce the erosive forces associated with high flows. Absence of coarse sediment often results in erosion of in-channel substrate during high flows. In addition, coarse sediment contributes to formation of in-channel habitats necessary to support native flora and fauna.
- *Encourage development on poorly-infiltrating soils*: The difference between pre and post development runoff patterns is less when development occurs on soils that have low infiltration rates and functioned somewhat like paved surfaces. Focusing development on these areas reduces changes in hydrology associated with transition to developed land uses.
- *Encourage urban infill*: Urban infill reduces the effect on watershed processes by concentrating development on previously impacted areas. This reduces disruption of hydrology and sediment process compared to developing on open space or other natural areas.

3.6 Selecting Appropriate Management Objectives

The combination of expected force acting on the stream channel (in terms of higher flow and less sediment) and estimated resistance (in the form of channel and floodplain condition) can be used to inform selection of an appropriate management objective for a specific stream reach, as shown in Figure 3-3. This figure represents a conceptual approach to selecting appropriate management objectives, in which modifications to runoff and sediment are compared against stream reach conditions. By weighing these factors within the context of watershed opportunities, constraints and resources, management objectives and specific actions can be determined. More complete decision support systems or guidance will need to be developed for individual

Selection of appropriate management objectives should consider changes to runoff and sediment, and existing stream reach conditions, within the context of watershed opportunities, constraints and resources.

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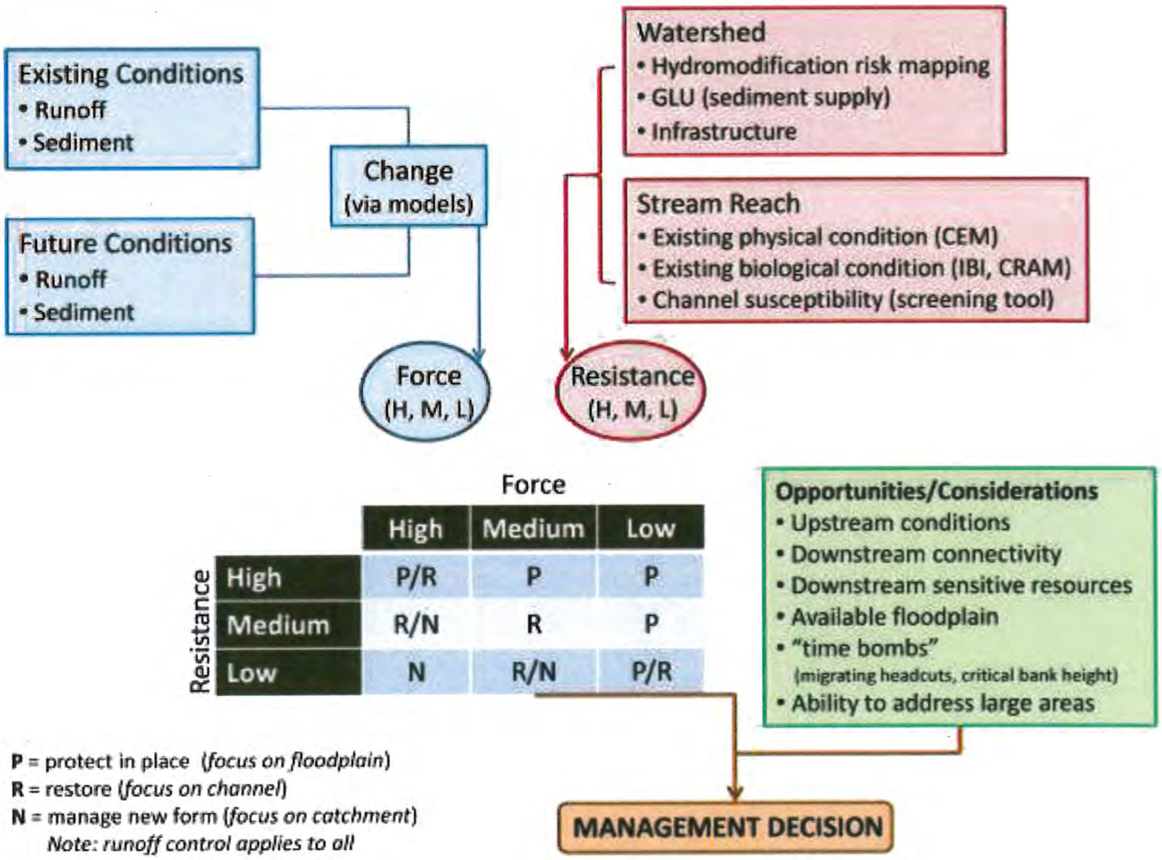
hydromodification management plans that account for other considerations such as upstream and downstream conditions, cost, infrastructure constraints, availability of floodplain area for restoration, presence of downstream sensitive resources, etc. All decisions should be made in the context of the watershed position of a project site relative to existing opportunities and constraints as discussed above.

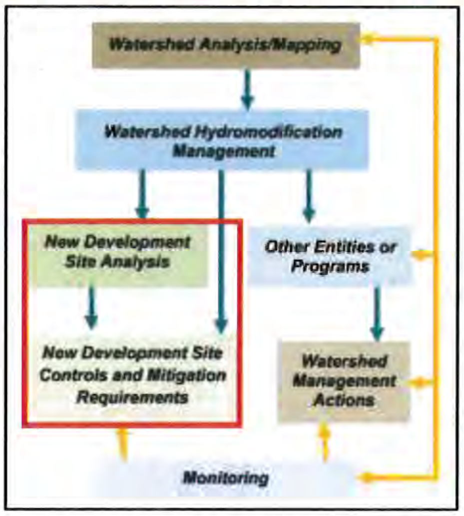
A number of tools are available to be used in conjunction with watershed mapping to inform this prioritization process. For example, GLU mapping (Booth *et al.* 2010) and hydromodification risk mapping can be used to assign high, medium or low ratings to watershed resistance (i.e., susceptibility to change). Similarly, field based tools such as the hydromodification screening tool (Bledsoe *et al.* 2010) or European tools such as Fluvial Audit or River Habitat Survey can be used to assign a rating of high, medium or low at the reach scale. In addition to geomorphic assessments, habitat assessments such as the California Rapid Assessment Method (CRAM; Collins *et al.* 2008) or biological evaluations via an index of biotic integrity (IBI; e.g., Ode *et al.* 2005) should be used as measures of biological condition to provide a more complete stream assessment. The next section provides an overview of hydromodification assessment and prediction tools, as well as further details on specific tools to support the selection of management objectives.



Resistance \ Force	High	Medium	Low
High	P/R	P	P
Medium	R/N	R	P
Low	N	R/N	P/R

Figure 3-3: Example of a hydromodification management decision-making process.

3.7 Framework for Determining Site-Specific Control Requirements



Once the watershed analysis is complete and opportunities, constraints and management objectives have been identified for both upland areas and stream reaches, a framework should be developed for site-specific project analyses and control requirements. The level of detail required for the analysis of proposed projects should be based on a combination of factors including project size, location within the watershed, and point of discharge to receiving waterbody.

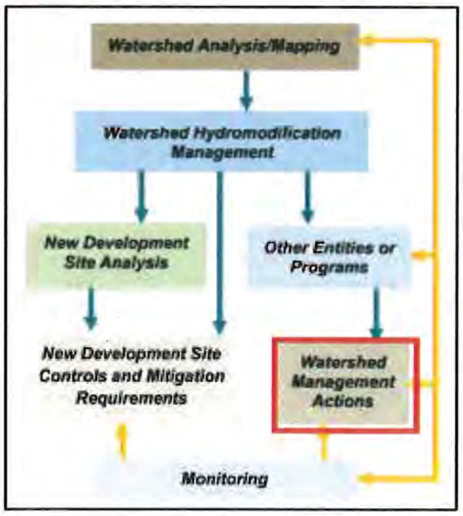
The HMP should specify how these factors will be evaluated within the context of the identified management objectives to determine analysis requirements. The HMP should also ideally contain scalable BMP designs (based on conservative assumptions and consistent with prevailing watershed conditions) that can be applied by small projects where appropriate to avoid overly burdensome requirements for site-specific analysis. The framework should include the following components:

- A set of standard on-site management measures/BMPs that should apply to all projects; no projects should be exempted from these measures as they will have broader water quality benefits beyond helping to control the effects of hydromodification. These management actions consist of reducing the effects of urbanization on catchment runoff and sediment yield. On-site management measures should attempt to reduce excess runoff, maintain coarse sediment yield (if possible) and provide for appropriate discharge to receiving streams to support in-stream biological resources. In some cases, common features or facilities may be able to accommodate these objectives. In other cases, separate features or facilities will be necessary to deal with distinct objectives. On-site measures should ***generally be applied in all cases*** as allowed by site-specific geotechnical constraints, with specific management practices informed by the watershed processes most important at particular locations in the watershed, as well as by the nature of downstream receiving waters:
    - Low impact development (LID) practices.
    - Disconnecting impervious cover through infiltration, interception, and diversion.
    - Coarse sediment bypass through avoidance of sediment yield areas or measures that allow coarse sediment to be discharged to the receiving stream.
    - Flow-duration control basins to reduce runoff below a threshold value.

- Specification of the level of analysis detail and design requirements for the project, depending on project location, discharge point, and project size. Levels of analysis and design requirements may include:
    - Application of scalable, standardized designs for flow control based on site-specific soil type and drainage design. The assumptions used to develop these scalable designs should be conservative, to account for loss of sediment and uncertainties in the analysis and our understanding of stream impacts.
    - Use of an erosion potential metric, based on long-term flow duration analysis and in-stream hydraulic calculations. Guidelines should specify stream reaches where in-stream controls would and would not be allowed to augment on-site flow control.
    - Implementation of more detailed hydraulic modeling for projects of significant size or that discharge to reaches of special concern to understand the interaction of sediment supply and flow changes.
    - Analysis of the water-balance for projects discharging into streams with sensitive habitat. This may include establishment of requirements for matching metrics such as number of days with flow based on the needs of species present.
- Guidelines for prioritization of on-site or regional flow and sediment control facilities. Watershed analysis will help identify opportunities for regional flow or sediment control facilities, which may help to mitigate for existing hydromodification impacts.

Appendix A provides detailed guidance on the appropriate application of tools to meet site control requirements.

3.8 Off-site Compensatory Mitigation Measures



In some cases, on-site control of water and sediment will not be sufficient to offset the effects of hydromodification on receiving waters. In these cases, off-site compensatory mitigation measures will be necessary (similar to the concepts used in the Section 401/404 permitting programs). Off-site measures could be implemented by project proponents or through the use of regional mitigation banks or in-lieu fee programs.

Off-site mitigation may be necessary for several reasons:

- Off-site measures may be more effective at addressing effects or at achieving desired management goals. This may be particularly true for sites near the bottom of a watershed where upstream measures may be preferred

- Off-site measures may be necessary to supply compensation for residual project impacts where on-site measures are limited by site constraints or solutions are beyond the scope of what can be accomplished on an individual site.
- Off-site measures may be necessary where accomplishing specified management objectives is not practical using on-site measures alone. Off-site measures may be desired to remedy legacy effects of prior land use or to achieve desired beneficial uses.

Performance monitoring and adaptive management must be a part of compensatory mitigation given its inherent uncertainty.

In cases where on-site control of water and sediment will not be sufficient to offset the effects of hydromodification on receiving waters, off-site compensatory mitigation measures will be necessary. Implementation of this approach will require that the State Water Board develop a valuation method to help determine appropriate off-site mitigation requirements in light of the anticipated impacts of hydromodification on receiving streams.

The location and type of mitigation should be determined in the context of the watershed analysis and should account for the size and nature of the impact, location in the watershed, pre-existing conditions in the watershed, and uncertainty associated with the success of the proposed mitigation actions. In some cases these measures may be near the project site (e.g., restoring a stream reach downstream of the project site), but in other cases the off-site mitigation may be in the form of in-lieu fee or "mitigation bank" type contributions to a project located in a different portion of the watershed (e.g. upstream grade control, protection of sediment source areas). Such off-site mitigation relatively far from the site will only be possible if conducted in the context of an overall watershed plan, as discussed above. Off-site measures may include:

- Stream corridor restoration
- Purchase, restoration and protection of floodplain/floodway habitat
- Purchase and/or protection of critical sediment source or transport areas
- Regional basins or other retention facilities
- Upstream or downstream natural/bio-engineered grade control
- Retrofit or repair of currently undersized structures (e.g. culverts, bridge crossings)
- Removal or hydrologically disconnecting impervious surfaces

A valuation method will be necessary for assigning appropriate mitigation requirements in light of the anticipated impacts of hydromodification on receiving streams. The valuation method should be developed by the State Water Board.

To support the management approaches discussed above, HMPs should provide general guidance for application of models and other tools based on the questions being asked and the desired outcomes of the HMP. Models can also be used to help communicate levels of uncertainty in particular management actions and to guide restoration / in-channel management actions. Modeling and other tools are discussed in detail in Section 4 and Appendices A and B.

Management endpoints should articulate the desired physical and biological conditions for various reaches or portions of the watershed. To the extent possible, these desired conditions should be expressed in numeric, quantifiable terms to avoid ambiguity.

Finally, management endpoints should articulate the desired physical and biological conditions for various reaches or portions of the watershed. To the extent possible, these desired conditions should be expressed in numeric, quantifiable terms to avoid ambiguity. Additionally, since regulatory strategies will invariably rely on quantifiable measures to determine whether stormwater management actions achieve these desired conditions, identifying appropriate numeric objectives will support determinations of regulatory compliance. As desired physical and biological watershed conditions are expressed in quantifiable terms to the extent possible, a similar need would apply to site control requirements. Control measures should be linked to, a) a desired condition (or goal), b) the parameter(s) that best define that condition, and c) quantifiable measures that serve to evaluate performance of the control measure. Direct measures (e.g., volume of runoff to be retained) as well as indirect or surrogate measures (IBI scores) are appropriate if they are quantifiable.

4. Overview of Assessment and Prediction Tools

4.1 Introduction

The previous section discussed a number of potential actions for managing hydromodification impacts. These ranged from high-level watershed-scale characterization to the site-specific design of a proposed development. This section provides an overview of the current and emerging assessment and prediction tools available to inform these management actions. An organizing framework helps explain the appropriate application of these tools, as well as their strengths and weaknesses. Specific tools that support the selection of management objectives are also discussed. Examples of "suites" of tools that are commonly used together to predict stream responses and formulate management prescriptions for channels of varying susceptibility are presented in Appendix B. Appendix A provides detailed guidance on the appropriate application of tools to meet site control requirements.

Municipalities are the primary audience for this section, as they select and incorporate these tools into their HMPs. However, the State and Regional Water Boards should be aware of the overall capabilities, appropriate uses, and gaps in our current toolbox. The development of new and improved tools should ideally be coordinated at the State level for optimum cost effectiveness and widest applicability. The table below identifies the key actions necessary at both the programmatic and local level to address the considerations discussed above, within the context of the goals of the framework described in Section 3.

Table 4-1. Recommendations for the application and improvement of tools in support of the proposed management framework.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Develop quality control and standardization for continuous simulation modeling • Perform additional testing and demonstration of probabilistic modeling for geomorphic response • Pursue development of biologically- and physically-based compliance endpoints	• Work cooperatively with adjacent jurisdictions to implement hydromodification risk mapping at the watershed scale • Implement continuous simulation modeling for project impact analysis
Long-term (1+ decades)	• Improve tools for sediment analysis and develop tools for sediment mitigation design • Develop tools for biological response prediction • Improve tools for geomorphic response prediction	• Expand use of probabilistic and statistical modeling for geomorphic response • Apply biological tools for predicting and evaluating waterbody condition

4.2 Background

In the context of hydromodification, tools and models are typically used to help answer one or more of the following questions involving an assessment of natural and human influences at various spatial and temporal scales:

- How does the stream work in its watershed context?
- Where is the stream going? For example, have past human actions induced channel changes? What are the effects on sediment transport and channel form? What is the magnitude of current and potential channel incision following land use conversion?
- How will the stream likely respond to alterations in runoff and sediment supply?
- How can we manage hydromodification and simultaneously improve the state of the stream?

Previous sections have underscored the variability and complexity of relationships among land use, the hydrologic cycle, and the physical and ecological conditions of stream systems. It follows that the process of assessing stream condition and predicting future conditions is highly challenging and subject to uncertainty. Therefore it is important to understand the inherent strengths and limitations of the available tools, especially with respect to prediction uncertainty and how it is expressed for various tools. Considerable judgment is needed to choose the appropriate model for the question at hand. In addition to prediction uncertainty, considerations in choosing the right model for a particular application include appropriate spatial and temporal detail, cost of calibration and testing, meaningful outputs, and simplicity in application and understanding (NRC 2001; Reckhow 1999a,b).

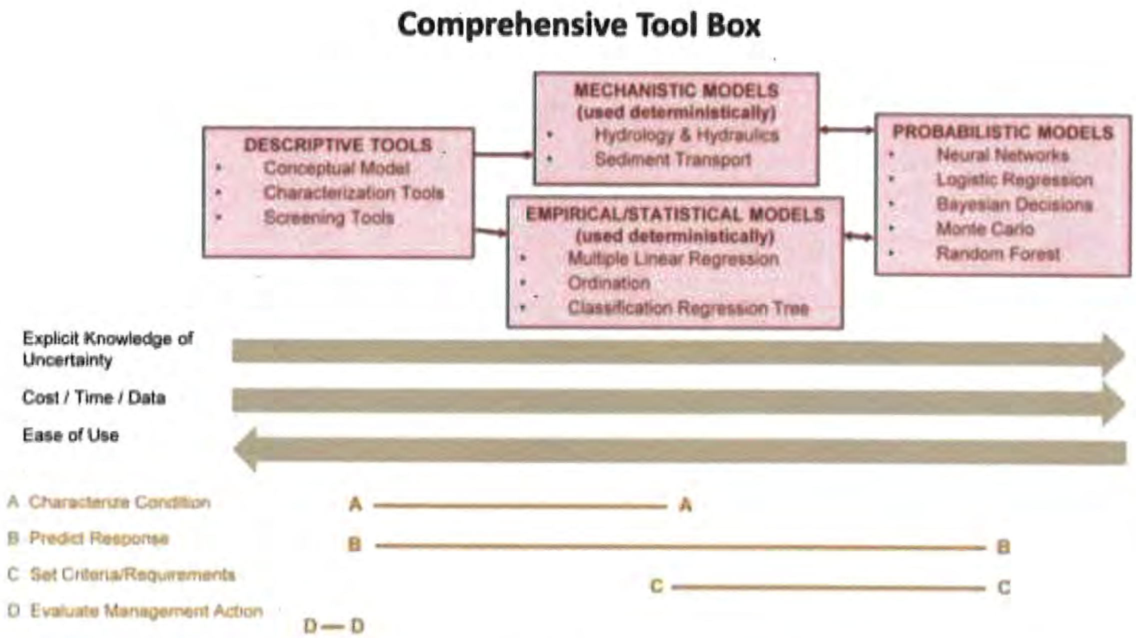


Figure 4-1. Organizing Framework for understanding hydromodification assessment and management tools.

4.3 Organizing Framework

Figure 4-1 presents an organizing framework by which to understand the available tools that may be applied in support of hydromodification management and policy development. Tools fall into three major categories: descriptive tools, mechanistic and empirical/statistical models that are used deterministically, and probabilistic models/predictive assessments with explicitly quantified uncertainty. The organizing framework relates these categories to the types of question the tools are designed to answer, specifically: characterization of stream condition, prediction of response, establishment of criteria/requirements, or evaluation of management actions. The framework also characterizes the tools according to the following features: intensity of resource requirements (i.e., data, time, cost), and the extent to which uncertainty is explicitly addressed. Subsequent sections of this section discuss each of the three major categories in turn, highlighting examples of specific tools within each category.

Given the uncertainty associated with predicting hydromodification impacts, probabilistic models should be incorporated into analysis and design, particularly where resource values or potential consequences of impacts are high.

Tools required to support the management framework presented in Section 3 include watershed characterization and analysis tools and project analysis and design tools. The level of resolution that is required will depend on the point in the planning process. At early stages, descriptive tools will be sufficient, but more precise tools will be required toward the design phase. Currently, most projects rely solely on deterministic models. However, given the uncertainty associated with predicting hydromodification impacts, probabilistic models should be incorporated into analysis and design, particularly where resource values or potential consequences of impacts are high.

4.3.1 Descriptive Tools

Descriptive tools include conceptual models, screening tools, and characterization tools. These tools are used to answer the question: *What is the existing condition of a stream or watershed?* Although descriptive tools are not explicitly predictive, they can be used to assess levels of susceptibility to future stressors by correlation with relationships seen elsewhere. The application of some type of descriptive tool, such as a characterization tool, is almost always necessary before applying a deterministic model. In particular, descriptive tools can aid in understanding the key processes and boundary conditions that may need to be represented in more detailed models.

Conceptual Models. A conceptual model, in the context of river systems, is a written description or a simplified visual representation of the system being examined, such as the relationship between physical or ecological entities, or processes, and the stressors to which they may be exposed. Conceptual models have been used to describe processes in a wide range of physical and ecological fields of study, including stream-channel geomorphology (Bledsoe *et al.* 2008). For example, Channel Evolution Models (CEMs) are conceptual models which describe a series of morphological configurations of a channel, either as a longitudinal progression from the upper to the lower watershed, or as a series at a fixed location over time subsequent to a disturbance. The incised channel CEM developed by

Schumm *et al.* (1984) is one of the most widely known conceptual models within fluvial geomorphology. This CEM documents a sequence of five stages of adjustment and ultimate return to quasi-equilibrium that has been observed and validated in many regions and stream types (ASCE 1998, Simon and Rinaldi 2000). The Schumm *et al.* (1984) CEM has been modified for streams characteristic of southern California, including transitions from single-thread to multi-thread and braided evolutionary endpoints (Hawley et al., in press).

Conceptual models also include planform classifications of braided, meandering and straight, and other general geomorphic classifications, which categorize streams by metrics such as slope, sinuosity, width-to-depth ratio, and bed material size. The qualitative response model described by Lane's diagram (1955), and discussed earlier in this report, is also a conceptual model.

Characterization Tools. Examples of characterization tools include baseline geomorphic assessments, river habitat surveys, and fluvial audits. A fluvial audit uses contemporary field survey, historical map and documentary information and scientific literature resources to gain a comprehensive understanding of the river system and its watershed. Fluvial audits, along with watershed baseline surveys are a standardized basis for monitoring change in fluvial systems. These types of comprehensive assessments are comprised of numerous, more detailed field methodologies, such as morphologic surveys, discharge measurements, and estimates of boundary material critical shear strength through measurements of resistance (for cohesive sediments) or size. Baseline assessments may also draw on empirical relationships such as sediment supply estimation models.

Screening Tools. Screening tools can be used to predict the relative severity of morphologic and physical-habitat changes that may occur due to hydromodification, as a critical first step toward tailoring appropriate management strategies and mitigation measures to different geomorphic settings. However, assessing site-specific stream susceptibility to hydromodification is challenging for several reasons, including the existence of geomorphic thresholds and non-linear responses, spatial and temporal variability in channel boundary materials, time lags, historical legacies, and the large number of interrelated variables that can simultaneously respond to hydromodification (Schumm 1991, Trimble 1995, Richards and Lane 1997).

Screening tools can be used to predict the relative severity of morphologic and physical-habitat changes due to hydromodification, as a critical first step toward tailoring appropriate management strategies and mitigation measures to different geomorphic settings.

Despite the foregoing difficulties, the need for practical tools in stream management have prompted many efforts to develop qualitative or semi-quantitative methods for understanding the potential response trajectories of channels based on their current state. For example, predictors of channel planform can be used to identify pattern thresholds and the potential for planform shifts (e.g., van den Berg 1995, Bledsoe and Watson 2001, Kleinhans and van den Berg 2010).

In addition, regional CEMs (discussed above) can partially address the needs of the hydromodification management community by providing a valuable framework for interpreting past and present response trajectories, identifying the relative severity of potential response sequences, applying appropriate models in estimating future channel changes, and developing strategies for mitigating the impacts of processes likely to dominate channel response in the future (Simon 1995).

More recent screening-level tools for assessing channel instability and response potential, especially in the context of managing bridge crossings and other infrastructure, have borrowed elements of the CEM approach and combined various descriptors of channel boundary conditions and resisting vs. erosive forces. For example, Simon and Downs (1995) and Johnson *et al.* (1999) developed rapid assessment techniques for alluvial channels based on diverse combinations of metrics describing bed material, CEM stage, existing bank erosion, vegetative resistance, and other controls on channel response. Although based on a strong conceptual foundation of the underlying mechanisms controlling channel form, these specific examples are either overly qualitative with respect to the key processes, or developed with goals and intended applications (e.g., evaluating potential impacts to existing infrastructure such as bridges or culverts) that differ from what is needed by current hydromodification management programs.

SCCWRP has recently proposed a general framework for developing screening-level tools that help assess channel susceptibility to hydromodification, and a new region-specific tool for rapid, field-based assessments in urbanizing watersheds of southern California (Booth *et al.* 2010, Bledsoe *et al.* 2010). The criteria used to assign susceptibility ratings are designed to be repeatable, transparent, and transferable to a wide variety of geomorphic contexts and stream types. The assessment tool is structured as a decision tree with a transparent, process-based flow of logic that yields four categorical susceptibility ratings through a combination of relatively simple but quantitative input parameters derived from both field and GIS data. The screening rating informs the level of data collection, modeling, and ultimate mitigation efforts that can be expected for a particular stream-segment type and geomorphic setting. The screening tool incorporates various measures of stream bed and bank erodibility, probabilistic thresholds of channel instability and bank failure based on regional field data, integration of rapid field assessments with desktop analyses, and separate ratings for channel susceptibility in vertical and lateral dimensions.

An example of a specific analysis component that predicts changes in post-development sediment delivery, and that can be applied within this screening tool framework, is a GIS-based catchment analyses of "Geomorphic Landscape Units" (GLUs). A GLU analysis integrates readily available data on geology, hillslope, and land cover to generate categories of relative sediment production under a watershed's current configuration of land use. Those areas subject to future development are identified, and corresponding sediment-production levels are determined by substituting developed land cover for the original categories and reassessing the relative sediment production. The resultant maps can be used to aid in planning decisions by indicating areas where changes in land use will likely have the largest (or smallest) effect on sediment yield to receiving channels.

Effective screening tools for assessing the susceptibility of streams to hydromodification necessarily rely on both field and office-based elements to examine local characteristics within their broader watershed context. Proactive mapping of flow energy measures (e.g., specific stream power) throughout drainage networks has the potential to complement field-based assessments in identifying hotspots for channel instability and sediment discontinuities as streamflows change with land use. Such analyses may partially guide subsequent field reconnaissance; however, this approach also has limitations in that some geomorphic settings are inherently difficult to map using widely available digital elevation data. In particular, maps of stream power in narrow entrenched valleys and low gradient valleys (ca. <1%) with sinuous channels should be carefully field-truthed and used with a level of caution commensurate with the accuracy of the input data.

Moreover, spatial variability in channel boundary materials and form cannot be accurately mapped at present using remotely sensed data. Thus, boundary materials and channel width are typically assumed in watershed-scale mapping efforts, thereby introducing potential inaccuracies. Coupling desktop analysis with a field-based assessment when using such an approach can help resolve variation in site-specific features such as the erodibility of bed and bank materials, channel width, entrenchment, grade control features, and proximity to geomorphic thresholds.

4.3.2 Mechanistic and Empirical/Statistical Models with Deterministic Outputs

Mechanistic/deterministic models are simplified mathematical representations of a system based on physical laws and relationships (*link to next*). Empirical/statistical models use observed input and output data to develop relationships among independent and dependent variables. Statistical analyses determine the extent to which variation in output can be explained by input variables. Both types of models are typically used to generate a single output or answer for a given set of inputs. These tools can be used to help answer such questions as: *What are the expected responses in the stream and watershed given some future conditions? What criteria should be set to prevent future hydromodification impacts?* However, hydromodification modeling embodies substantial uncertainties in terms of both the forcing processes and the stream response. Deterministic representations of processes and responses can therefore mask uncertainties and be misleadingly precise, unless prediction uncertainty is explicitly characterized as described later in this section.

Although valuable, deterministic representations (such as those derived from continuous simulation modeling) of processes and responses can mask uncertainties and be misleadingly precise unless prediction uncertainty is explicitly characterized.

Hydrologic Models are used to simulate watershed hydrologic processes, including runoff and infiltration, using precipitation and other climate variables as inputs. Some models, such as the commonly-used HEC-HMS, can be run for either single-event simulations or in a continuous-simulation mode which tracks soil moisture over months or years. Other hydrologic models that are commonly used for event-based and continuous simulation modeling include HSPF and SWMM. It is widely accepted that continuous simulation modeling, rather than event-based modeling, is required to assess long term changes in geomorphically-significant flow events (Booth and Jackson 1997; Roesner *et al.* 2001).

Several HSPF-based continuous simulation models have been developed specifically for use in hydromodification planning. These include the Western Washington Hydrology Model (WWHM) and the Bay Area Hydrology Model (BAHM). Hydromodification Management Plans (HMPs) in Contra Costa County, San Diego County and Sacramento County have developed sizing calculators for BMPs based on modeling done using HSPF models. To illustrate the point about uncertainly in mechanistic models, HSPF contains approximately 80 parameters, only about 8 of which are commonly adjusted as part of the calibration process.

Hydraulic Models are used to simulate water-surface profiles, shear stresses, stream power values and other hydraulic characteristics generated by stream flow, using a geometric representation of channel segments. The industry standard hydraulic model is the HEC River Analysis System (HEC-RAS).

Coupled Hydrologic and Hydraulic Models represent a valuable tool in hydromodification management. Because the streamflow regime interacts with its geomorphic context to control physical habitat dynamics and biotic organization, it is often necessary to translate discharge characteristics into hydraulic variables that provide a more accurate physical description of the controls on channel erosion potential, habitat disturbance, and biological response. For example, a sustained discharge of 100 cfs could potentially result in significant incision in a small sand bed channel but have no appreciable effect on the form of a larger channel with a cobble bed. By converting a discharge value into a hydraulic variable (common choices are shear stress, or stream power per unit area of channel relative to bed sediment size), a "common currency" for managing erosion and associated effects can be established and applied across many streams in a region. Such a common currency can improve predictive accuracy across a range of stream types. As opposed to focusing on the shear stress or stream power characteristics of a single discharge, it is usually necessary to integrate the effects of hydromodification on such hydraulic variables over long simulated periods of time (on the order of decades) to fully assess the potential for stream channel changes. By using channel morphology to estimate hydraulic variables across a range of discharges, models like HEC-RAS provides a means of translating hydrologic outputs from continuous simulations in HEC-HMS, SWMM, or HSPF into distributions of shear stress and stream power across the full spectrum of flows.

Sediment Transport Models such as HEC-6T, the sediment transport module in HEC-RAS, CONCEPTS, MIKE 11 and FLUVIAL12, use sediment transport and supply relationships to simulate potential changes in channel morphology (mobile boundary) resulting from imbalances in sediment continuity. This means that hydraulic characteristics are calculated as channel form and cross-section evolve through erosion and deposition over time. Such models have high mechanistic detail but are often difficult to apply effectively. Although it is not a mobile boundary model, the SIAM (Sediment Impact Analysis Method) module in HEC-RAS represents an intermediate complexity model designed to predict sediment imbalances at the stream network scale and to describe likely zones of aggradation and degradation.

Statistical Models use descriptive tools and empirical data to develop relationships that quantify the risk of specific stream behaviors. For example, Hawley (2009) developed a statistical model to explain variance in channel enlargement based on measures of erosive energy and channel features such grade control and median bed sediment size. Such models often include independent variables based on input from the mechanistic models described above; however, a key difference is that statistical models do not explicitly represent actual physical processes in their mathematical structure. Instead, these models simply express the observed correlations between dependent and independent variables. Like mechanistic models, the output from these models is commonly treated as precise results in management decisions, despite the fact that predictions from most statistical models could be readily (and more accurately) expressed in terms of confidence intervals with a range of uncertainty.

Probabilistic/Risk-based Models integrate many of the tools discussed above, using modeled changes in hydrology as input to hydraulic models, which in turn provide input to various types of statistical models to predict response. However, the predictions are not represented as deterministic outputs, instead, the range of (un)certainty in the likelihood of the predicted response is explicitly quantified. Although not commonly used for hydromodification management at this time, there are well established models based on these principals currently in use in other scientific disciplines. An example of a probabilistic approach that has been used for hydromodification management is a logistic regression analysis that was used to produce a threshold "erosion potential metric" that can be used to quantify the risk of a degraded channel state. More details on this approach are provided in Appendix B.

Risk-based modeling in urbanizing streams provides a more scientifically defensible alternative to standardization of stormwater controls across stream types, and can inform management decisions about acceptable levels of risk.

Risk-based modeling in urbanizing streams provides a more scientifically defensible alternative to standardization of stormwater controls across stream types. A probabilistic representation of possible outcomes also improves understanding of the uncertainty that is inherent in model predictions, and can inform management decisions about acceptable levels of risk.

Predictive Tools for Habitat Quality and Stream Biota. The tools discussed above focus on physical stream impacts; however, as discussed in the preceding chapter, it is recognized that maintenance of stream "stability" does not necessarily conserve habitat quality and biological potential. In general, the knowledge base for biota/habitat associations is not generally adequate to allow for prediction of how whole communities will change in response to environmental alterations associated with urbanization. Making such predictions deterministically requires a thorough knowledge of species-specific environmental responses, as well as an adequate (accurate) characterization of habitat structure and habitat dynamics (both of which are modified by urbanization). However, recent studies have demonstrated that the effects of hydrologic alterations induced by urbanization on selected stream biota can be quantitatively described without a full mechanistic understanding, using stressor-response type relationships and empirical correlations from field-measured conditions (Konrad and Booth 2005, Konrad *et al.* 2008, DeGasperi *et al.* 2009).

In moving beyond a narrow focus on linkages between flow alteration and channel instability, scientific understanding of hydrologic controls on stream ecosystems has recently led to new approaches for assessing the ecological implications of hydromodification. The essential steps in developing quantitative "flow-ecology relationships" have been recently described in the Ecological Limits of Hydrologic Alteration (ELOHA) process (Poff *et al.* 2010), a synthesis of a number of existing hydrologic techniques and environmental flow methods. ELOHA provides a regional framework for elucidating the key hydrologic influences on biota of interest, and translating that understanding into relationships between hydromodification and biological endpoints that can be used in management decision making. This requires a foundation of hydrologic data provided by modeling and/or monitoring, and sufficient biological data across regional gradients of hydromodification. Although hydrologic–ecological response relationships may be confounded to some extent by factors such as chemical and thermal stressors, there are numerous case studies from the US and abroad in which stakeholders and decision-makers reached consensus in defining regional flow standards for conservation of stream biota and ecological restoration (Poff *et al.* 2010; http://conserveonline.org/workspaces/eloha).

4.3.3 Strengths, Limitations and Uncertainties

The Organizing Framework shown in Figure 4-1 shows the applicability of the three major categories of tools in support of various management actions. This section addresses a range of issues relating to strengths, limitations and uncertainty of the tools discussed above. Detailed analysis of individual models is beyond the scope of this document, but EPA/600/R-05/149 (2005) contains an extensive comparison of functions and features across a wide range of hydrologic and hydraulic models.

> **Explicit consideration, quantification, and gradual reduction of model uncertainty will be necessary to advance hydromodification management.**
>
> **The uncertainty inherent to hydromodification modeling underscores the need for carefully designed monitoring and adaptive management programs.**

General Considerations. The well-known statistician George Box famously said that "all models are wrong, some are useful." The usefulness of a model for a particular application depends on many factors including prediction accuracy, spatial and temporal detail, cost of calibration and testing, meaningful outputs, and simplicity in application and understanding. There is no cookbook for selecting models with an optimal balance of these characteristics. Models of stream response to land-use change will always be imperfect representations of reality with associated uncertainty in their predictions. In addition to the prediction errors of standard hydrologic models, common limitations and sources of uncertainties include insufficient spatial and/or temporal resolution, and poorly known parameters and boundary conditions. Ultimately, the focus of scientific study in support of decision making should be on the decisions (or objectives) associated with the resource and not on the model or basic science. Each model has limitations in terms of its utility in addressing decisions and objectives of primary concern to stakeholders. Prediction error, not perception of mechanistic correctness, should be the most important criterion reflecting the usefulness of a model (NRC 2001; Reckhow 1999a,b). The predictive models discussed above may be thought of as predictive scientific assessments; that is, a flexible, changeable mix of small mechanistic models, statistical analyses, and expert scientific judgment.

Region-Specific Considerations. Because all models are vulnerable to improper specification and omission of significant processes, caution must be exercised in transferring existing models to new regional conditions. For example, mobile boundary hydraulic models are mechanistically detailed but not generally well-suited to many southern California streams given the prevalence of near-supercritical flow, braiding and split flow (Dust 2009). In addition, bed armoring and channel widening resulting from both fluvial erosion and mass wasting processes are key influences on channel response in semi-arid environments. These processes are not well-represented and constrained in current mobile boundary models. Accordingly, the appropriateness of existing models for addressing a particular hydromodification management question should be empirically tested and supported with regionally appropriate data from diverse stream settings.

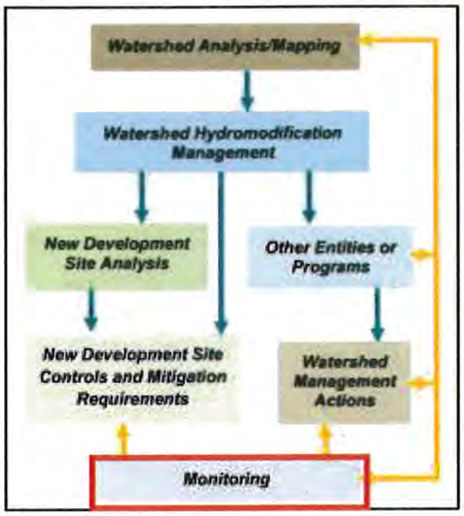
Managing Uncertainty. To date, hydromodification management has generally relied on oversimplified models or deterministic outputs from numerical models that consume considerable resources but yield highly uncertain predictions that can be difficult to apply in management decisions. Numerical models are nevertheless an important part of the hydromodification toolbox, especially in characterizing rainfall-response over decades of land-use change. It is challenging to rigorously quantify the prediction accuracy of these mechanistic numerical models; however, their utility of can be enhanced by addressing prediction uncertainties in number of ways (Cui *et al.* 2011). Candidate models can be subjected to sensitivity analysis to understand their relative efficacy for assessment and prediction of hydromodification effects. Moreover, it should also be demonstrated that selected models can reasonably reproduce background conditions before they are applied in predicting the future. Modeling results that are used in relative comparisons of outcomes are generally much more reliable than predictions of absolute magnitudes of response.

Hydromodification modeling embodies substantial uncertainties in terms of both the forcing processes and stream response. Deterministic representations of processes and responses can mask uncertainties and can be misleading unless prediction uncertainty is explicitly quantified. Errors may be transferred and compounded through coupled hydrologic, geomorphic, and biologic models. Accordingly, explicit consideration, quantification, and gradual reduction of model uncertainty will be necessary to advance hydromodification management. This points to two basic needs. First, there is a need to develop more robust probabilistic modeling approaches that can be systematically updated and refined as knowledge increases over time. Such approaches must be amenable to categorical inputs and outputs, as well as combining data from a mix of sources including mechanistic hydrology models, statistical models based on field surveys of stream characteristics, and expert judgment. Second, the uncertainty inherent to hydromodification modeling underscores the need for carefully designed monitoring and adaptive management programs, as discussed in Section 5.

A risked-based framework can provide a more rational and transparent basis for prediction and decision-making by explicitly recognizing uncertainty in both the reasoning about stream response and the quality of information used to drive the models. Prediction uncertainty can be quantified for any of the types of models described above; however, some types are more amenable to uncertainty analysis than others. For example, performing a Monte Carlo analysis of a coupled hydrologic-hydraulic model is a very demanding task. A simple sensitivity analysis of high, medium, and low values of plausible model parameters is much more tractable and still provides an improved understanding of the potential range of system responses. Such information can be subsequently integrated with other model outputs and expert judgment into a probabilistic framework. For example, Bayesian probability network approaches can accommodate a mix of inputs from mechanistic and statistical models, and expert judgment to quantify the probability of categorical states of stream response. Such networks also provide an explicit quantification of uncertainty, and lend themselves to continual updating and refinement as information and knowledge increase over time. As such, they have many attractive features for hydromodification management, and are increasingly used in environmental modeling in support of water quality (Reckhow 1999a,b) and stream restoration decision-making (Stewart-Koster *et al.* 2010).

Sediment Supply. As described above, a reduction in sediment supply to a stream may result in instability and impacts, even if pre- and post-land use change flows are perfectly matched. Thus, there is a need to develop management approaches to protect stream channels when sediment supply is reduced, and to refine and simplify tools to support these approaches. This continues to prove challenging because, the effects of urban development on sediment supply in different geologic settings are not well understood and poorly represented in current models. As a starting point, models used to analyze development proposals that reduce sediment supply could be applied with more protective assumptions with respect to parameters and boundary conditions (inflowing sediment loads). Effects of altered sediment supply on stream response could be addressed in a probabilistic framework by adjusting conditional probabilities of stream states to reflect the influence of reductions in important sediment sources due to land use change.

5. Monitoring



"Monitoring" can cover a tremendous range of activities in the context of stormwater management in general, and of hydromodification in particular. For example, the NPDES Phase 2 general permit for California (SWRCB, 2003 (*www.swrcb.ca.gov/**water**_issues/.../storm**water**/.../final_ms4_**permit**.p...)*, National Pollutant Discharge Elimination System (NPDES) General Permit No. CAS000004, p. 11) notes that the objectives of a monitoring program may include:

- Assessing compliance with the General Permit.
- Measuring and improving the effectiveness of stormwater management plans.
- Assessing the chemical, physical, and biological impacts on receiving waters resulting from urban runoff.
- Characterizing storm water discharges.
- Identifying sources of pollutants.
- Assessing the overall health and evaluating long-term trends in receiving water quality.

These objectives span multiple goals, ranging from verifying of compliance, evaluating effectiveness, characterizing existing conditions, and tracking changes over time. Each would likely require different monitoring methods, duration of measurement, and uses of the resulting data (Table 5-1). This variability emphasizes what we consider the key starting point of any monitoring program: to answer the questions, "What is the purpose of monitoring? How will the data be used?" Even secondary considerations can exert great influence over every aspect of the design of a monitoring program: "How quickly do you need to have an answer?" And, perhaps most influential of all, "What are the resources available to provide that answer?"

Table 5-1. The recommended purpose(s) of monitoring associated with hydromodification control plans, organized by the scale of implementation and the time frame in which useful results should be anticipated.

Time Frame	Programmatic: State and Regional Water Boards	Local: City and County Jurisdictions
Short-term (<10 years)	• Define the watershed context for local monitoring (at coarse scale) • Evaluate whether permit requirements are making positive improvements	• Evaluate whether specific projects/ regulations are meeting objectives • Identify the highest priority action(s) to take
Long-term (1+ decades)	• Define watershed context and setting benchmarks for local-scale monitoring (i.e., greater precision, if/as needed) • Demonstrate how permit requirements can improve receiving-water "health," state-wide (and change those requirements, as needed)	• Evaluate and demonstrate whether actions (on-site, instream, and watershed scale) are improving receiving-water conditions • Assess program cost-effectiveness • Identify any critical areas for resource protection

5.1 The Purpose of Monitoring

In the context of hydromodification assessment and management, we propose three interrelated purposes for monitoring that will guide the discussion and recommendations in this section:

- **Characterizing the conditions** of receiving waters downstream of urban development (including any trends in those conditions over time).
- **Evaluating the effectiveness** of hydromodification controls at protecting or improving the conditions of downstream receiving waters (and modify them, as needed).
- **Setting priorities** on the wide variety of hydromodification control practices, as promulgated by the State and Regional Boards and as implemented by local jurisdictions.

These needs give rise to several interrelated types of monitoring, all common to many watershed and stormwater monitoring programs. They are typically executed at different spatial and temporal scales, and if well-designed and executed they can collectively help guide management actions. We define them here, using terms and definitions that are common to the monitoring literature:

- **Performance monitoring,** by which is normally meant the evaluation of a particular stormwater facility relative to its intended (or designed) performance, but independent of whether that intended design is actually beneficial for downstream receiving waters.
- **Effectiveness monitoring,** by which we mean the assessment of how well specific management actions or suites of actions reduce or eliminate the direct impacts of stormwater on receiving waters. This type of monitoring can answer a question common to stormwater management: does a particular facility actually achieve its intended goal (e.g., flow releases from a stormwater facility protect the stream channel downstream from erosion)? More broadly, monitoring can evaluate the "effectiveness" of a suite of measures or an overall program designed to produce

beneficial outcomes (or avoid negative ones) in downstream receiving waters. In this context, the precise boundaries division between effectiveness monitoring and other types are blurry and unnecessarily artificial.

- **Trends monitoring,** by which we mean an integrative assessment of whether our "endpoint" indicators (physical, chemical, or biological) are showing any consistent, statistically significant change over time. Such monitoring rarely "proves" the direct impacts of a specific stressor on a receiving water, but it is critical to setting and evaluating progress towards integrative assessment endpoints at a regional scale. If well-designed, trend monitoring commonly provides useful information at smaller spatial scales as well, particularly in evaluating response to recent management actions or recovery from a prior disturbance.
- **Characterization monitoring**, by which is commonly meant the identification and (or) the quantification of various parameters in stormwater or a receiving-water body. Characterizing the condition of an outflow discharge or a water body at a particular time and place is always an outcome of the other kinds of monitoring; when it is called out as a goal in-and-of itself, however, it is can be useful to prioritize actions—but only if there is a preexisting standard for what constitutes a "good" or "acceptable" condition (also termed "status monitoring"), and a program to implement (or at least to set the priority for implementing) actions to improve the condition of waterbodies found to be "not good" or "unacceptable."

Without a context for evaluation, characterization monitoring is prone to generate large quantities of rarely used data. We strongly encourage that the purpose of any "characterization" monitoring be clearly articulated in hypothesis testing, priority setting, or systematic trend evaluation. As noted by NRC (2009, p. 508) with respect to this type of monitoring, "...monitoring under all three (NPDES municipal, industrial, and construction) stormwater permits is according to minimum requirements not founded in any particular objective or question. It therefore produces data that cannot be applied to any question that may be of importance to guide management programs, and it is entirely unrelated to the effects being produced in the receiving waters." We seek to proactively avoid this problem.

Monitoring should occur at two scales:

- **Regional or state-wide scale- this will require a time frame of one to several decades**
- **Local scale – this is required to evaluate the performance and effectiveness of specific management measures.**

In this sub-section, we focus our discussion on two interrelated scales at which these various types of monitoring should be applied as outlined in Table 5-1 at the beginning of this section. The first, which here and elsewhere in this document is termed "programmatic," has a regional or state-wide spatial scale; many of its key actions will require a time frame of one to several decades. Monitoring data from this scale should inform the broadly construed "health" of receiving waters to assess whether the range of hydromodification strategies being implemented is maintaining desired conditions across the (state-wide) range of physiography, climate, land-use change, and regulatory approaches of the regional boards. They should be used to identify particularly promising (or particularly ineffective) combinations of control strategies and landscape conditions. Finally, they should provide regionally tailored benchmarks for what constitutes "healthy watersheds" and "healthy receiving waters" so regulators and permittees alike know what still needs to be done, where it should be done, and how urgently it needs to happen.

The second scale of monitoring data we term "local." It comprises the generation of monitoring data to evaluate the performance and effectiveness of specific management measures (be they structural or nonstructural) at reducing the negative consequences of hydromodification on downstream receiving waters. Useful information at this scale will normally be generated in the time frame of an NPDES permit cycle (i.e., ~5 years) and should provide direct guidance on whether the evaluated management strategies are working, need refinement, or should be abandoned altogether. They should also provide guidance on the degree to which management efforts should be prioritized where regulatory flexibility exists, given the conditions (and, perhaps, the potential responsiveness) of downstream receiving waters. Over longer time frames, monitoring at this scale can also provide public demonstration of the value of regulatory and programmatic efforts, and it can also help identify the most cost-effective mix of publically funded projects and regulatory protection to achieve (or maintain) receiving-water health.

5.2 Programmatic Monitoring at the Regional Scale

5.2.1 Defining Watershed Context

Although not "monitoring" in the strictest sense of this word, establishing a watershed context for the measurement and evaluation of receiving waters is a hallmark of virtually all recommended monitoring strategies (e.g., Beechie *et al.* 2010, Brierley *et al.* 2010). Monitoring programs should be consistent with the watershed perspective that forms the basis for the management framework discussed in Section 3. In California (as in most other states), this can only be executed at a supra-jurisdictional scale, because most watersheds cross one or more city and/or county boundaries. This presents the long-term challenge that many jurisdictions do not have authority over parts of the landscape that can affect the quality of rivers and streams that pass through their boundaries; more immediately, however, it makes an inclusive watershed assessment almost impossible to execute at a local level.

5.2.2 Determining the Effectiveness of Permit Requirements

A second, more challenging contextual need at the regional scale is the definition of thresholds or endpoints against which to compare the results of monitoring or modeling. Both of these "assessment tools" can guide the application of hydromodification control strategies, evaluate their real or likely success, and predict the consequences of hydromodification on downstream receiving waters. However, they provide little insight into the question, "how good is good enough?" Answering this question requires a definition of "assessment endpoints" (borrowing the term from NRC 1994), which in turn requires objective, quantifiable criteria for evaluating progress or outright success.

Most existing HMPs require the permitted municipalities to develop programs and policies to assess the potential effects of hydromodification associated with new development and redevelopment, to include management measures to control the effects of hydromodification, and to implement a monitoring program that assesses the effectiveness of HMP implementation at controlling and/or mitigating the effects of hydromodification. Yet the appropriate objectives of such management measures, or a basis to evaluate success or failure of the HMP through monitoring data, are rarely provided in consort. Setting these endpoints is beyond the capacity of any but the largest municipalities—and even for those, neither the field of watershed science nor the arena of public policy is so clear that an unequivocally "correct" answer is likely to emerge without much additional work. Any such finding would also lack state-wide applicability; California is far too physically and ecologically diverse for an assessment endpoint developed in one part of the state to transfer everywhere without careful consideration.

For these reasons, we consider this aspect of monitoring at the regional scale to be a long-term, state-wide effort. This reflects the challenge of conducting meaningful characterization (or "status") monitoring: it requires a benchmark against which the measured condition can be compared, and to which an absolute rating ("good," bad," etc.) can be assigned.

In contrast, "trends" monitoring requires no such benchmark, only equivalent measurements undertaken at multiple times coupled with an understanding of what direction of change is desirable. For this reason, evaluating whether permit requirements are making positive improvements is a reasonable (and probably critical) short-term effort, one that can be conducted locally (see below). It should also be integrated and compiled at a regional level, however, the better to inform the continued development of hydromodification requirements.

5.3 Monitoring at the Local Scale

The needs of a monitoring program for local jurisdictions should complement those being satisfied at a regional scale. Showing net improvement is critical to maintaining support for regulatory actions and capital expenditures, but any monitoring program must reflect the typical constraints of showing rapid results while acknowledging constraints on staff resources and expertise (Scholz and Booth 2001). No less urgent is the need to identify what to do "next"—not necessarily establishing a multi-year capital improvement plan, but at least identifying key problems with one or two associated actions that would likely result in significant improvements in receiving-water conditions. Watershed characterization, as discussed above and applied to a specific jurisdiction, can provide useful guidance for such identification; even without it, local knowledge is commonly sufficient in-and-of itself. Targeted monitoring can normally confirm (or refute) such inferences in short order, which is why we place this monitoring application in the "short-term" category.

However, a monitoring program can also provide longer term guidance to local jurisdictions. When supported by the regional context of receiving-water conditions, local monitoring data can demonstrate trends over time that can lend support to (or indicate necessary changes to) hydromodification control plans. In combination with economic data, they can show long-term cost-effectiveness. Finally, site-specific monitoring data, when analyzed in the context of an appropriate scale of watershed characterization, can guide the stratification of less developed and undeveloped watershed areas into those where more assertive protection (or restoration) will be most worthwhile. None of these outcomes depend solely on collecting monitoring data, which is why none of them are presumed to be credible "short-term" applications of monitoring data. However, they have found expression in other parts of the country having long-term monitoring efforts, and they should provide similar benefits to California as well.

5.4 Developing a Monitoring Plan

"Monitoring" the effects of a management action, whether it is a new regulation, a change in operational procedures, or a constructed project, is commonly included by design or required by regulation. The collection of monitoring data may be seen as a worthwhile activity in its own right, but this discussion uses a more restrictive, implementation-based definition: any "monitoring" needs to demonstrate a direct connection to management actions, such that the results of monitoring are translated into on-the-ground management actions (or changes in management actions). This focus on the *use* of monitoring data requires clear linkages between a management action, the uncertainties associated with that action, the ways in which the effects of that action are expressed (and can be measured) in the world, and the management changes that should be implemented if monitoring results provide unanticipated (or equivocal) resolution to those uncertainties. This is the basis for establishing an "adaptive management" approach to hydromodification monitoring, discussed in more detail in Appendix C. Here, we discuss the design of a monitoring program and outline the variety of measurements that can be made, under the assumption that the intended use(s) of the monitoring data have already been established.

"Stormwater management would benefit most substantially from a well-balanced monitoring program that encompasses chemical, biological, and physical parameters from outfalls to receiving waters" (NRC 2009, p. 257). In pursuit of a comprehensive monitoring program we might also add regular documentation of weather and climate conditions and land-cover changes. As a practical matter, however, monitoring at a site scale is almost never coordinated with other equivalent efforts at other locations, nor placed in a broader spatial context being developed as part of a regional effort. For monitoring data to have greatest value, however, such coordination and context-setting is needed.

Stormwater management would benefit most substantially from a well-balanced monitoring program that encompasses chemical, biological, and physical parameters... (NRC, 2009)

5.4.1 Design of a Monitoring Plan

As noted at the beginning of this section, the overarching question that must be asked and answered at the beginning of any monitoring design effort is "What is its purpose?" The considerations enumerated below cannot be addressed without an explicit answer to this question, because the outcome of those considerations will depend on how the data are to be used. For certain common application of monitoring data we suggest guidance that will be widely appropriate, but there are no recommendations in this section (or any other monitoring guidance document) that apply universally.

Multiple authors have condensed their guidance for designing a monitoring plan into a short list of steps that should precede the first instance of field data collection (e.g., Shaver *et al.* 2007). Although all differ in details and intended audience, they share significant commonalities that can be distilled as follows:

- Articulate the purpose of the monitoring (the "management question").
- Identify key constraints, in particular the geographic range and scale over which the monitoring can occur, financial/staff resources available, and the time frame in which results must be generated.
- Evaluate existing information, model outputs, and/or regulatory requirements to identify promising metrics and specific sites appropriate to the management question.
- Identify the specifics of the monitoring plan: what parameter(s), where, for how often and for how long. This may include multiple iterations, wherein the guidance of Step 3 must align with the constraints of Step 2.

Most such guidance is written with site-specific, "local" monitoring in mind—the existing literature provides less direction for monitoring that is herein recommended to occur at a regional scale over the next one or more decades. However, the basic principles are the same at all scales: a coherent, explicit purpose needs to be articulated, resource constraints need to be acknowledged, and a credible strategy needs to be developed with its specifics fleshed out. Below we discuss some of the primary considerations in this last step, because they are common across a wide range of monitoring purposes, programmatic constraints, and indicator types.

5.4.2 Constraints (Step 2 of the Monitoring Plan)

Ideally, a monitoring program should be designed to detect trends, assess effectiveness and allow for source identification.

Scale. Ideally, a monitoring program should encompass multiple, nested scales of monitoring that are determined by the question(s) being addressed. For hydromodification applications, the broadest scale of monitoring is that of the integrated effect of stormwater impacts and stormwater management on receiving waters. *Trends monitoring* (and characterization monitoring, if regionally appropriate ranges of quality have been determined) addresses these questions, and it also allows stormwater and resource managers to measure the broad benefits obtained from management investments. Site-specific conditions normally cannot be traced back to specific generators of pollution (NRC 2009), and so monitoring at the broadest scales (i.e., many tens of square miles and larger) should not attempt to do so. Instead, identifying overall conditions and trends requires a broad spatial scale over long time frames (i.e., multiple years), the essence of trends monitoring. This level of effort is recommended as a regional responsibility, because the area(s) of interest will normally far exceed the geographic limits of any single jurisdiction.

If trends monitoring (or long-standing prior knowledge) indicates that there are impacts on beneficial uses, a second (and more site-specific) scale is invoked, that of *effectiveness monitoring:* which of our many stormwater-management actions are achieving the greatest reduction in downstream impacts (and which are not)? On the whole, such stormwater control measures, both structural and nonstructural, vary by land use—the measures suitable for a residential neighborhood will likely be impractical or ineffective (or both) in an industrial setting. We therefore anticipate that most effectiveness monitoring will be stratified by land use and conducted by individual jurisdictions (see, for example, such an approach in the Nationwide Stormwater Quality Database, which contains water-quality data from more than 8600 events and 100 municipalities throughout the country).

The finest scale of monitoring is that of *source identification*, a form of characterization monitoring: what specific locations and which parts of the landscape generate stormwater of sufficiently deleterious quantity and (or) quality to cause impacts to beneficial uses, be they direct or indirect effects? This question is widely posed in stormwater management programs, and a number of existing monitoring programs seek to provide answers. The science of stormwater already suggests where the greatest attention is probably warranted (NRC 2009), namely a particular focus on areas of well-connected (or "effective") impervious area, high vehicular traffic, and exposure to toxic chemicals. We therefore suggest these categories should define areas of highest priority for this type of targeted investigation, allowing even a resource-constrained jurisdiction to conduct a useful, well-focused monitoring effort with good efficiencies.

Siting. Site selection is most commonly guided by the location of the management action being evaluated while dictated by more mundane considerations of property ownership and access logistics. In general, sites need to meet a few following basic criteria.

- Appropriate scale: the upstream area should be dominated by, or at least significantly affected by, the management action of interest.
- Responsiveness: at the chosen location, the parameters being measured should be amenable to change in response to the management action (e.g., monitoring for geomorphic change in a concrete channel is ill-advised).
- Representativeness: the results at the chosen location should be credibly extrapolated to "similar" sites, and those sites in aggregate should constitute a widespread (or otherwise important) subset of the landscape as a whole.
- Access: the site should be easily reached by the appropriate personnel and equipment, and with a cost of doing so consistent with the frequency of measurements being made. Any equipment left unattended needs to be secure (or well-hidden).

There are institutional considerations in site selection as well. Multiple programs implement monitoring or impose monitoring requirements, and coordination can provide mutual benefits and efficiencies to all. In particular, monitoring driven by management actions at a particular location (i.e., a local scale) will always benefit from information from one or more regional-scale reference sites that can characterize natural or background variability. Local studies will rarely have resources to execute such an effort themselves, again emphasizing the importance of a nested (and coordinated) hierarchy of monitoring programs.

Time and Variability. Evaluating the effectiveness of management actions requires a preliminary judgment of the time frame over which effects can be recognized. For water-quality parameters, storm-specific grab samples or continuous flow-weighted sampling has been most common; for changes in geomorphic form or in the population attributes of benthic macroinvertebrates, one-time annual sampling that presumes to integrate the effects of the past year are typical. Flow metrics are normally extracted from "continuous" (i.e., 5-, 15-, or 60-minute) measurements of discharge. However, every measurement has some degree of variability, a consequence of "natural" variability, measurement errors, and induced change (i.e., the effects of the management action we are trying to perceive). Separating these components is a matter of statistical analysis (see next section) based on repeated measurements, either in time or in space (or both).

We note that many practices common to past monitoring efforts, particularly the use of individual grab samples to characterize stormwater quality, have yielded results with little to no subsequent value: "...to use stormwater data for decision making in a scientifically defensible fashion, grab sampling should be abandoned as a credible stormwater sampling approach for virtually all applications" (NRC 2009, p. 330).

The duration of a monitoring program is commonly determined by the desire for "timely" answers, although normally the ability to generate statistically significant results is a function of the system being evaluated and the indicators being measured. This often creates a conflict between the intended "mission" of the monitoring program and its ability to produce defensible results, a conflict that can only be avoided by a design that identifies meaningful variables to measure, conducts sufficiently frequent measurements to dampen random variability, and must persists for long enough to allow a management "signal" to emerge from the data. This is the essence of the iteration noted above in Step 4 of monitoring-plan design above.

The monitoring program design must persist long enough to a allow management "signal" to emerge from the data. Consequently, long-term records (i.e., one to several decades) will be needed to detect all but the most dramatic of trends in biological indicators.

In one of relatively few quantitative studies of variability in biological indicators, Mazor *et al.* (2009) found that year-to-year variability for the same site sampled in the same season showed a variability (i.e., $\pm 1\sigma$) was typically about 10 points for a benthic IBI. With average scores for their 5 sites ranging from 28–51 (on a 100-point scale), this reflects a coefficient of variation of about 25%. Individual metrics were even more variable. This emphasizes that long-term records (i.e., one to several decades) will be needed to detect all but the most dramatic of trends in biological indicators.

The duration of monitoring also needs to capture the events that are most important to the anticipated responses of the measured system. For evaluating the effects of hydromodification, frequent storms (i.e., those that are normally expected to occur one to several times per year) are commonly judged important and their effects would normally be captured by a monitoring effort of even just one or a few years' duration. Particularly in more semi-arid regions of the state, however, significant channel-altering events may occur only after many decades of relative quiescence and stability, and noticeable (or documentable) response of streams to hydromodification may only occur under certain circumstances or following specific combination of events. Therefore, the lack of channel response on an annual basis may not necessarily indicate that management actions are effective. Thus a long-term, ongoing monitoring effort is necessary to capture the responses to infrequent, stochastic events, but determining the likely duration of such a program requires some knowledge (or assumptions) of the critical drivers of those responses. It therefore requires a well-posed set of management questions underlying the monitoring effort as well.

For management questions concerning the effectiveness of hydromodification controls, monitoring will almost always benefit from long-term flow monitoring at multiple sites, especially those in the mid to upper watershed (and key tributaries, depending on the scale of the effort). Local rainfall measurements are nearly as essential, since flow data without rainfall data resolved at a similar spatial and temporal scale are useless at best, misleading at worst. Baseline (pre-project) monitoring normally is also invaluable. However, each of these elements will normally require some combination of a multi-scale, long-term, coordinated monitoring program with an investment of at least several years' duration in anticipation of (and follow-up after) a specific management action at a specific location. Despite the value for evaluating the effects of hydromodification (and hydromodification control efforts), such monitoring almost never occurs to this degree. To the extent this remains a practical constraint on implementation, the range of management questions needs to be commensurately narrowed as well.

Statistical Considerations. The statistical design of a monitoring program is beyond the scope of this section, because the range of possible requirements and approaches is tremendously broad. Several general principals are worth articulating, however, because they apply almost universally (and are commonly ignored):

- Although trends can be "suggested" by monitoring data, only statistically rigorous results can be offered as "proof." Thus, ignoring this dimension of monitoring program design severely limits future applicability of the results.
- Most natural parameters display high variability when measured outside a laboratory, and thus the magnitude of change caused by a management action also needs to be great before it can be recognized. There is a trade-off between the relative magnitude of change and the number of samples required to recognize it (i.e., large relative changes require fewer samples), but many monitoring efforts pay little attention to this basic fact. Where sampling can only occur during specified storm conditions or once during the same season each year, the duration of a monitoring campaign sufficient to detect even large changes in naturally variable parameters is likely to be a decade or longer. For many management applications, this is tantamount to generating no useful information at all (but is significantly more costly).
- The level of effort needed can be estimated *a priori* to help guide final monitoring design, but only if the degree of variability and the magnitude of change to be perceived are known or estimated ahead of time. One such example is given below, where the diagonal lines are labeled with the number of independent samples needed to achieve a typical level of statistical power for various combinations of permissible error from the "true" value (x axis), and the intrinsic variability in values across the population being measured (y axis) in Figure 5-1 below.

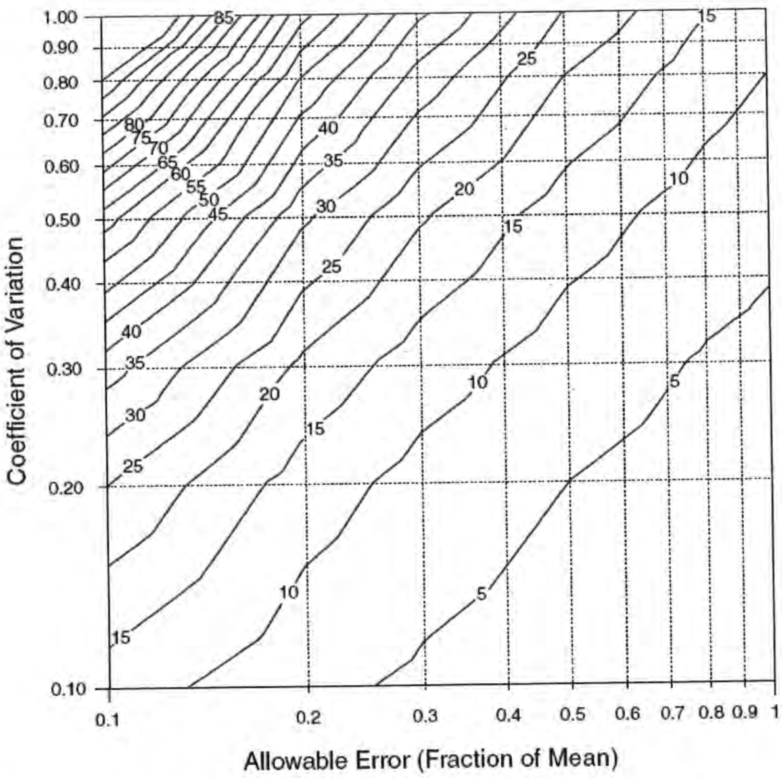


Figure 5-1. Sample requirements for confidence of 95% (α = 0.05) and power of 80% (β = 0.20). Figure from Pitt and Parmer 1995.

5.4.3 What to Monitor (Step 3 of the Monitoring Plan)

The choice of "what to monitor" follows from the choice of assessment endpoints, which in turn depends on the choice of management goals: for example, if "stable stream channels" is the intended outcome of an HMP, then measurement of the physical form of a channel over time would be appropriate. If diagnosing the cause of observed changes is also desired, then some evaluation of potential causal agents (e.g., hydrology, sediment input, or direct disturbance) would also be needed. Because management goals are now commonly (and appropriately) cast more broadly, however, they can embrace less clearly defined endpoints such as "watershed health" or "biological integrity." Many such endpoints fail the test of quantifiable objectivity.

However, these goals invoke a broad scope of concern, embracing not only physical stream conditions but also a range of chemical, hydrologic, and biological attributes. They encompass a broader catalog of receiving waters that may need to be evaluated. Finally, they emphasize the importance of looking more broadly to identify the cause of observed changes—both spatially, to conditions throughout a watershed that may have influence downstream; and temporally, to recognize ongoing adjustments to past disturbance (i.e., legacy effects) and to future environmental changes (e.g., climate change) that commonly lie well beyond the ability of local watershed managers to address. The imprecision of these goals should not obscure the importance of broadening the scope of stormwater and hydromodification assessments to include not only the traditionally emphasized characterization of selected water-quality constituents and channel stability, but also more integrative measures.

These considerations suggest two broad categories of assessments, which largely but not entirely align with the two scales of implementation (i.e., "programmatic" and "local") defined in Table 4–1:

- Integrative: defining an overall level of "health" of the watershed, as expressed in the condition(s) of its receiving waters. Current scientific consensus suggests that biological indicators are best suited to this scale of evaluation (Karr and Chu 1999), insofar as they integrate the consequences of multiple stressors on aquatic systems and because many management goals (and regulatory requirements) are cast in biological terms. To be meaningful, however, any such indicators need to be suitably chosen and stratified for their particular geo-hydro-climatological region (e.g., "ecoregions"; Omernick and Bailey 1997).
- Targeted: demonstrating the achievement of an established regulatory standard or a designated threshold (typically, a measured or modeled pre-development condition) by a particular parameter, commonly one or more chemical constituents or a specific hydrologic metric of flow. This can be evaluated at the outfall of a single stormwater facility, at the discharge point for a site, or in the receiving water itself. Many of these thresholds are important in their own right—to protect human health, to preserve riparian property from erosion, to avoid flooding of previously non-inundated lands. However, they should be recognized as providing only one-dimensional views of a much broader system. Thus, targeted monitoring can supplement but should not replace more integrative measures.

Integrative assessment endpoints require multiple lines of evidence to characterize receiving-water conditions. At their most comprehensive, they should include measures of flow, geomorphic condition, chemistry, and biotic integrity (Griffith *et al.* 2005, Johnson and Hering 2009). However, biological criteria are generally key to integrative assessment: "In general, biological criteria are more closely related to the designated uses of waterbodies than are physical or chemical measurements" (NRC 2001, p. 8). In most applications, such assessments are compared to one or more reference sites where conditions have been independently judged as "excellent," or where human disturbance is minimal and so best-quality conditions are assumed.

Integrative assessment endpoints require multiple lines of evidence to characterize receiving-water conditions. At their most comprehensive, they should include measures of flow, geomorphic condition, chemistry, and biotic integrity.

The task of identifying and quantifying reference conditions in California streams is presently being carried out by the Reference Condition Management Program (RCMP) of the State Water Board's Surface Water Ambient Monitoring Program (SWAMP; see 2009 Recommendations). About 600 sites have been recognized by this program as "reference" based on having minimal human disturbance, and they have been geographically stratified into the 12 Level III ecoregions mapped for the state of California (by USEPA 2000). The metrics chosen to characterize their biologic conditions should provide an appropriate list for the evaluation of impaired (or potentially impaired) streams.

An equivalent set of reference sites and conditions for other receiving-water types does not presently exist. California also presently lacks a systematic basis for defining relative categories of "poor," "fair," "good," or "excellent" based on numeric values of biological indicators, such as exists in parts of the Pacific Northwest. Several regions, however, now have multimetric biological indicators with defined reference conditions (see below).

Elsewhere, however, there is as yet no context for setting assessment endpoints for biological indicators in California receiving waters. Such an effort is in progress, at least for streams, and its eventual completion to support the management application of more local monitoring results is a key recommendation of this report. Biological assessment endpoints will need to be established region by region on an as-needed basis; in the interim, locally collected data can be very useful for trend monitoring of receiving water but not for defining existing levels of "health."

5.4.3.1 An Example from Washington State

The Puget Sound region of western Washington State provides an instructive example for identifying indicators and establishing desired assessment endpoints. Multiple agencies over the last two decades have sought to measure the overall ecological health of the region and to define targets for recovery. Following the most recent three-year process, the lead agency for the current effort released its set of 20 "dashboard indicators" designed both to express scientific understanding of conditions needed for ecological health and to communicate that understanding in a public-accessible manner (http://www.psp.wa.gov/pm_dashboard.php; accessed September 5, 2011). They cover physical, chemical, and biological indicators: all expressed in terms of relative improvement or quantified conditions to be reached by the year 2020.

This level of target-setting is possible only after extensive study and public discussion; it falls far beyond the scope of the present document. It is instructive for the state of California, however, in several regards as it looks to the future:

- The physiographic scope of the indicators and their target values is well-constrained to a particular geographic region with broadly similar geologic, hydrologic, and climatological attributes. Multiple parallel efforts would almost certainly be needed for a more diverse region (such as the entire state).
- Each indicator has a strong scientific basis for inclusion and at least some scientific basis for specific targets. Their communication value with the public was also an explicit criterion for inclusion.
- The most numerous indicators are biological, and they address multiple levels of the trophic chain from top predators to plants (a planktonic metric, however, was rejected as requiring too much additional scientific study and offering little communication value to the general public).
- Although emphasizing biology, the indicators are broadly distributed amongst biological, chemical, and physical metrics; most are broadly integrative in nature (e.g., reference to "bug populations" (the Puget Sound B-IBI) and a "freshwater quality index").

- The set of physical indicators is most parsimonious for instream conditions, and excluding marine nearshore and estuary conditions is restricted to a single hydrologic metric (chosen for its presumed influence on fish). This stands in stark contrast to most existing hydromodification monitoring plans, which emphasize measures of channel geomorphology and a wider range of hydrologic metrics. Such indicators may provide useful performance measures, but they should not be mistaken for more integrative measures of ecosystem or watershed "health."
- Although each indicator has a specified, numeric goal to be reached by 2020, there are no articulated changes to the current management plan if any of those goals are not reached (or if interim measures suggest that they will not be reached). This is a recognized shortcoming of the present plan but there is no mechanism yet in place to address it. As such, it does not currently meet the test for "adaptive management" (see Appendix C).

In California, such a list of integrative assessment indicators (let alone quantified endpoints for those indicators) cannot presently be defined, except in a few specific localities where data collection and analysis have been ongoing for many years. Thus, we recognize the value of such targets but must guide the present development of monitoring in recognition of their near-complete absence. Rectifying this shortcoming is the central recommendation for long-term program development; in the interim, short-term monitoring at both the regional and local levels need to acknowledge the absence of an integrative context in which to interpret their results.

In California, a list of integrative assessment indicators (let alone quantified endpoints for those indicators) cannot presently be defined, except in a few specific localities. Rectifying this shortcoming is the central recommendation for long-term program development.

Regulatory standards are established on the assumption that "clean water" will result in "healthy streams," but the elements of a watershed are far too complexly interrelated to permit such a simplistic perspective. Although the inverse ("polluted water results in unhealthy streams") is almost always true, the challenge for inferring causality from typical monitoring data is that *many* such stressors can all yield the same, degraded outcome. For this reason, targeted monitoring can provide useful diagnostic information and demonstrate regulatory compliance, but it cannot provide sufficient information to address integrative assessment endpoints.

5.4.3.2 Indicators from Existing Programs

We now turn to some of the most common indicators used in monitoring programs today, recognizing that their suitability in any given application depends on the questions being asked, the characteristics of the natural system being measured, and the practical constraints imposed on the monitoring program.

Hydrologic Indicators. Historically, the effects of urbanization on flow were characterized exclusively in terms of peak flow increases (e.g., Leopold 1968, Hollis 1975). Study since those early works has emphasized the degree to which other attributes of a stream hydrograph are changed by watershed imperviousness, and the importance of assessing the *duration* of moderate flows that are capable of transporting channel sediments and the frequency with which those geomorphically active flows occur

(Section 2). Thus, monitoring relevant to a particular hydromodification management application will likely include a variety of flow metrics (e.g., Konrad and Booth 2005, Degasperi *et al.* 2009).

In moving beyond a narrow focus on linkages between watershed urbanization, flow alteration, and in-stream effects, scientific understanding of hydrologic controls on stream ecosystems has recently led to new approaches for assessing the ecological implications of hydromodification. For example, the ecological limits of hydrologic alteration (ELOHA) framework is a synthesis of a number of existing hydrologic techniques and environmental flow methods that allows water-resource managers and stakeholders to develop socially acceptable goals and standards for streamflow management (Poff *et al.* 2010). The central focus of the ELOHA framework is the development empirically testable relationships between hydrologic alteration and ecological responses for different types of streams. This requires a foundation of hydrologic data provided by gaging and/or monitoring, and sufficient biological data across regional gradients of hydromodification. Although hydrologic–ecological response relationships may be confounded to some extent by factors such as chemical and thermal stressors, there are numerous case studies from the US and abroad in which stakeholders and decision-makers have reached consensus in defining regional flow standards for conservation and ecological restoration of streams and rivers (Poff *et al.* 2010).

Hydrologic monitoring provides essential information needed for establishing flow–geomorphology–ecology relationships, validating conceptual models, and assessing effectiveness of management actions in developing watersheds. Implementing regional flow standards should proceed in an adaptive management context, where collection of monitoring data or targeted field sampling data allows for testing of flow alteration–geomorphic–ecological response relationships. This allows for a fine-tuning of flow management targets based on improved understanding of the actual mechanisms; however, such monitoring can be expensive and it may take many years to adequately characterize the full spectrum of streamflows. Thus, hydrologic monitoring programs should be carefully planned and executed so that they are cost-effective and address the key uncertainties In this paper we primarily focus on indicators that do not require additional, extensive data collection.

Hydrologic indicators provide essential information needed for establishing flow–geomorphology–ecology relationships, validating conceptual models, and assessing effectiveness of management actions in developing watersheds.

Geomorphic indicators have been long-recognized as simple, easy-to-measure, and relatively responsive indicators of changes to the flow regime or sediment supply of a river or stream.

Biological indicators provide an integrative view of river condition, or river health.

Hydrologic monitoring is feasible in the context of a short-term program only if the purpose is to evaluate the engineering performance of a particular facility. For most applications, however, at least two (and commonly many more) years are necessary to measure a range of variable conditions sufficient to capture significant geomorphic and/or biological effects. Measurement of precipitation, generally a less cost-intensive effort than flow monitoring, must occur in consort for the data to be useful. In an effort to minimize the cost of continuous long-term flow modeling, a hydrologic model may be calibrated on one or two years of actual data and then used *in lieu* of further data to predict flow conditions. Whether the level of imprecision so introduced is appropriate will depend on the management questions being asked, but in general such an approach is normally judged more appropriate for comparative results (e.g., did a specified flow magnitude increase in frequency or duration?) than for absolute results (what is the magnitude of the 2-year discharge?).

Geomorphic Indicators. Geomorphic indicators have been long-recognized as simple, easy-to-measure, and relatively responsive indicators of changes to the flow regime or sediment supply of a river or stream (e.g., Leopold 1968). They require little specialized equipment, many commonly can be measured "in the dry" (or close to it), they typically change little from week-to-week (and so are often measured only once per year), and the morphologic features of interest provide the physical template on which a wide range of biological conditions are expressed.

Scholtz and Booth (2000) recognized five geomorphological "channel features" commonly measured as part of monitoring programs:

- Channel geometry (cross sections, longitudinal profile).
- Channel erosion and bank stability.
- Large woody debris.
- Channel-bed sediment.
- In-stream physical habitat (pools, riffles, etc.).

To this list, others have also added:

- Floodplain connectivity.
- Channel planform (meandering, braiding, rates of channel shifting).

Each metric has well-defined methods for field (or, in some cases, airphoto) measurements that need not be repeated here. However, despite broad agreement on *how* to measure each parameter, there is substantially less agreement on the meaning of particular measurements, or indeed under what circumstances (if any) such measurements should be made at all. Most contentious are the various protocols for assessing instream physical habitat (#5 above)—seemingly the most "relevant" for a host of biological applications and for evaluating restoration success. However, a variety of studies have documented a high level of uncertainty imposed by observer bias:

> "Habitat-unit classification was not designed to quantify or monitor aquatic habitat. At the level necessary for use as a stream habitat monitoring tool, the method is not precise, suffers from poor repeatability, cannot be precisely described or accurately transferred among investigators, can be insensitive to important human land-use activities, is affected by stream characteristics that vary naturally and frequently, and is not based on direct, quantitative measurements of the physical characteristics of interest. Relying on habitat-unit classification as a basis for time-trend monitoring is time-consuming, expensive, and ill-advised." (Poole *et al.* 1997, p. 894)

Other geomorphic metrics, in contrast, can provide a robust, albeit coarse, characterization of the channel boundaries. Some changes, particularly if consistently expressed by multiple adjacent cross-sections, can provide clear documentation of systematic channel changes over time that can be credibly associated with upstream changes (e.g., increased discharge from urbanization leading to channel enlargement). Other changes, however, may have a more indirect or uncertain association with upstream conditions (e.g., grain-size changes) because of the potential for rapid, ill-described changes over time without a corresponding human "cause." This emphasizes the importance of having a well-crafted purpose for the monitoring program into which the utility of any chosen parameter can be clearly described.

Biological Indicators. Biological indicators have been long-applied in society's evaluation of stream conditions, but historically that application has been rather informal. Observation of major fish kills, for example, is the application of a "biological indicator," but it provides little diagnostic or discriminatory information except in those streams where conditions are so poor that even casual awareness is inescapable. As a more refined assessment tool, however, their application to freshwater streams is only a few decades old. As such, the science is still under construction and some basic principles are still debated.

The rationale behind using biological indicators, however, is relatively undisputed. Karr (1999) has provided a useful summary of that rationale, of which the key elements are:

- Biological monitoring and biological endpoints provide the most integrative view of river condition, or river health.
- Biological monitoring is essential to identify *biological* responses (emphasis added) to human actions.
- Communicating results of biological monitoring to citizens and political leaders is critical if biological monitoring is to influence environmental policies.

Some of the earliest references to biological monitoring are associated with the development of RIVPACS, the River Invertebrate Prediction and Classification System, developed by the Centre for Ecology and Hydrology in the United Kingdom and now applied in a number of countries worldwide to predict instream biological conditions from a suite of watershed and channel variables. Since that beginning, other approaches have been advanced and practiced (e.g., the US Environmental Protection Agency's *Rapid Bioassessment Protocols*) that provide alternative, but likely near-equivalent results (e.g., Herbst and Silldorf 2004).

In this section we compare several biological indicators recently applied in various regions of California. This not intended as a comprehensive comparison of all available approaches potentially applicable to California; rather, it simply provides a few examples that illustrate the differences, and the similarities, of the various approaches. As the comparisons demonstrate, there is no "right" approach—but all share commonalities that are likely to be valuable elements of any biological monitoring program. We focus exclusively on benthic macroinvertebrates (BMI), because these have seen the longest and most widespread application (both in California and worldwide) given their species diversity and their relative geographic immobility. However, a variety of other biological metrics (particularly fish and periphyton) have relevance to biological monitoring and strong advocates in the scientific community. Their omission here is not a judgment on their value, merely a reflection of the broader applicability and richer scientific development of BMI-based indicators.

Multimetric indices are presently completed for four areas of the state (Eastern Sierra, North Coast, Central Valley, and Southern Coast). They are not standardized or calibrated state-wide (nor should they necessarily be), and they do not provide statewide coverage. In addition, the City of Santa Barbara (Ecology Consultants 2010) has sponsored development of its own BMI index (geographically embedded within the Southern Coast region), with both commonalities and differences between it and the others.

Eastern Sierra Nevada. Herbst and Silldorf (2009) developed an IBI based on streams from the upper Owens River north to the Truckee River. Their purpose was both to provide a region-specific IBI for future use and to evaluate the results of such an approach with others that also make use of BMIs to assess stream conditions. They evaluated the performance of 12-, 10-, and 8-metric indices, recommending the 10-metric index as providing the best overall performance included in the 12-metric index were these 10 and also predator richness and EPT% abundance:

- % tolerant percent richness (% of taxa with TV= 7,8,9,10).
- Richness (total number of taxa).
- Chironomidae Percent Richness (% of taxa that are midges).
- Ephemeroptera (E) Richness (number of mayfly taxa).
- Plecoptera (P) Richness (number of stonefly taxa).
- Trichoptera (T) Richness (number of caddisfly taxa).
- Dominance 3 (proportion of 3 most common taxa)
- Biotic Index (modified Hilsenhoff, composite tolerance).
- Acari richness (number of water mite taxa).
- Percent shredders (% of total number that are shredders).

A statistical analysis suggests that as many as 10 distinct classes can be discriminated using this IBI, although their recommended application uses only five categories of quality.

North Coast. Rehn *et al.* (2005) developed an IBI based on coastal-draining streams from Marin County north to the Oregon border. They evaluated 77 individual metrics, testing them for responsiveness to human disturbance and redundancy, and ultimately settled on eight:

- EPT richness.
- Coleoptera richness.
- Diptera Richness.
- Percent intolerant individuals.

- Percent non-gastropod scraper individuals.
- Percent predator individuals.
- Percent shredder taxa.
- Percent non-insect taxa.

Their statistical analysis indicated that five categories of quality could be discriminated; response was driven most strongly by watershed land cover (natural vs. unnatural) and percent of substrate that was sand-sized or finer. They also suggested a set of thresholds for rejecting potential "reference" sites (Rehn *et al.* 2005; Table 5-2), which was also used in the Southern Coast study (Ode *et al.* 2005; see below):

Table 5-2. Thresholds for rejecting potential "reference" sites.

Stressor	Threshold
Percentage of unnatural land use at the local scale	> 5%
Percentage of urban land use at the local scale	> 3%
Percentage of total agriculture at the local scale	> 5%
Road density at the local scale	> 1.5 km/km^2
Population density (2000 census) at the local scale	> 25 ind./ km^2
Percentage of unnatural land use at the watershed scale	> 5%
Percentage of urban land use at the watershed scale	> 3%
Percentage of total agriculture at the watershed scale	> 5 %
Road density at the watershed scale	> 2.0 km/km^2
Population density (2000 census) at the watershed scale	> 50 ind./ km^2

Central Valley. Rehn *et al.* (2008) also developed an IBI for Central Valley streams, evaluating 80 candidate metrics to yield a final list of five:

- Collector richness.
- Predator richness.
- Percent EPT taxa.
- Percent clinger taxa.
- Shannon diversity (a composite measure of taxonomic richness and evenness of abundance).

They found that reach-scale physical habitat variables were more critical in their data set than water chemistry or land use. They also presented their findings with greater caution than with other regions of the state, noting the difficulty of identifying truly "unimpaired" reference conditions and the geographic concentration of much of their source data.

Southern Coast. Ode *et al.* (2005) developed a BMI index of biological integrity based on 61 potential metrics from reference sites drawn from relatively undisturbed coastal-draining watersheds from Monterey Bay south to the Mexican border. They included seven final metrics:

- Percent tolerant taxa.
- Percent collector-gatherer + collector-filterer individuals.
- Predator richness.
- Percent intolerant individuals.
- EPT richness.
- Percent noninsect taxa.
- Coleoptera richness.

They note that the last two on the list are not common in other multimetric B-IBIs but were statistically appropriate for their data set. They judge that this "SoCal B-IBI" can discriminate 5 categories of condition, using 5 categories evenly divided along a 100-point scale. Particularly strong correlations amongst all seven metrics were displayed in comparison to road density and percent "watershed unnatural."

A portion of the Southern Coast region has also been the subject of independent IBI development over the past decade (Ecology Consultants 2010, 2011). The region of study spans the Santa Barbara coastal streams from the Ventura County line west about 45 miles to Gaviota Creek. Their work led to the development of an IBI using the following 7 metrics:

- # of insect families
- # of EPT families
- % EPT minus Baetidae
- % PT
- Tolerance value average
- % sensitive BMIs
- % predators + shredders

In the course of this work, tolerance values were adjusted for certain taxa based on local observations of presence/absence relative to the level of watershed disturbance. With these changes, they found strong statistical basis for discriminating five categories of biological quality. They also found that considering both watershed-level land use patterns and localized physical habitat conditions were necessary to achieve the best prediction of biological integrity.

<u>Summary</u>. A compilation of the various metrics (Table 5-3) demonstrates only broad commonalities between the various regional IBI's presently available for specific parts of California, suggesting that additional work needs to be done before comprehensive recommendations for biological monitoring can be made. At present, perhaps half(?) of the state's area is covered by existing multimetric indices as noted above, and for these areas they provide the best (indeed, the only) guidance for meaningful collection and interpretation of biological data. Elsewhere, however, only a few general points can be made:

- Biological monitoring in un-assessed regions of the state cannot be used to identify absolute conditions of biological health (i.e., "status" monitoring). However, they will likely be useful for "trends" monitoring, where only the change relative to a prior state is being sought.
- Despite the variability in metric choices amongst the various regions (Table 5-2), some broad commonalities are apparent. In particular, several types of metrics are likely to provide useful indicators of change in a known direction (i.e., an increase or decrease in the metric can be confidently assigned to a change in quality in a known direction):
    - One or more measures of tolerance or intolerance
    - One or more measures of predator prevalence
    - One or more measures of EPT taxa or taxa richness

This list does not purport to describe a true multimetric B-IBI, nor to provide a basis to evaluate instream biological health on an absolute scale (i.e., from "poor" to "excellent"). In the absence of any region-specific guidance, however, changes in one or more of these metrics are each likely to provide some initial, useful indication of temporal trends in biological health until such time as the types of studies referenced above can be conducted.

Table 5-3. Compilation of metrics used in the five regional B-IBI's described in the text.

METRIC	Eastern Sierra	North coast	Central Valley	Southern coast	Santa Barbara
Percent intolerant individuals		X		X	X
% tolerant (% of taxa with TV= 7,8,9,10)	X			X	
Tolerance value average					X
# of insect families					X
Percent non-insect taxa		X		X	
Percent shredders (% of total number that are shredders)	X	X			
Percent predator individuals		X			
% predators + shredders					X
Predator richness			X	X	
Collector richness			X		
Percent non-gastropod scraper individuals		X			
Percent clinger taxa			X		
Percent collector-gatherer + collector-filterer individuals				X	
EPT richness		X		X	X
Percent EPT taxa			X		
% EPT minus Baetidae					X
% PT					X
Ephemeroptera (E) Richness (number of mayfly taxa)	X				
Plecoptera (P) Richness (number of stonefly taxa)	X				
Trichoptera (T) Richness (number of caddisfly taxa)	X				
Coleoptera richness		X		X	
Diptera Richness		X			
Chironomidae Percent Richness (% of taxa that are midges)	X				
Richness (total number of taxa)	X				
Dominance 3 (proportion of 3 most common taxa)	X				
Biotic Index (modified Hilsenhoff, composite tolerance)	X				
Acari richness (number of water mite taxa)	X				
Shannon diversity index			X		

5.5 Recommendations

Based on this review of monitoring theory, current applications, and current needs, the following steps are recommended to advance a state-wide program of monitoring to support the management of hydromodification control plans.

5.5.1 Programmatic Monitoring

Over the next several years, the following actions should be implemented at the state and/or regional level:

- Executing broad-scale, GIS-based watershed characterization;
- Identifying a set of representative indicator watersheds, and a basic suite of regular measurements that are suitable for establishing trends in physical, chemical, and biological indicators;
- Identifying (and multi-metric monitoring within) a relatively small set of watersheds that have implemented recent hydromodification control plans to initiate the long-term evaluation of downstream trends.

Over the course of the next several NPDES permit cycles (i.e., one or more decades), the following actions should also be undertaken as a regional responsibility:

- Setting regionally appropriate endpoints for biological health of receiving waters;
- Identifying particularly promising (or particularly ineffective) combinations of control strategies across a range of different landscape conditions;
- Providing supplemental data collection at reference sites to support trends monitoring by local jurisdictions;
- Compiling local results to guide development and refinement of regionally appropriate hydromodification control strategies.

5.5.2 Local Monitoring

Over the next several years, the following actions should be implemented by local jurisdictions at a local scale:

- Implementing a program of source identification at one or more high-risk locations (e.g., high vehicular traffic, high imperviousness, toxic chemical storage/transport);
- Demonstrating the hydrologic performance of one or more representative hydromodification control facilities;
- Monitoring trends at one or more representative receiving waters, ideally at a regionally identified site (see the second bullet under "Programmatic monitoring," above);

- Conducting a synoptic evaluation of waterbodies, stratified by watershed type (see the first bullet under "Programmatic monitoring," above), to identify highest priority systems for protection or rehabilitation, if not already known.

Over the course of the next several NPDES permit cycles, the following long-term actions should also be undertaken as a local responsibility:

- Monitoring representative conditions to evaluate whether management actions are improving overall receiving-water health;
- Evaluating cost-effectiveness of implemented hydromodification control measures;
- Identifying critical areas for resource protection by virtue of existing high-quality conditions.

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APPENDIX A: GUIDANCE FOR APPROPRIATE APPLICATION OF HYDROLOGIC AND HYDRAULIC ANALYSES

Information contained in this document is intended solely for guidance purposes only. It is not intended to be an instruction manual and use of any of the guidance provided herein is at the risk of the user. No other person or entity shall be entitled to rely on the services, opinions, recommendations, plans or specifications provided in the document.

1. INTRODUCTION AND PURPOSE

The purpose of this Appendix is to provide technical guidance on hydrologic and hydraulic analyses, including the use of Continuous Simulation (Hydrologic) Modeling (CSM), in support of hydromodification assessment and mitigation. CSM is the industry standard developed since the early 2000s for use in the assessment and mitigation of hydromodification. The fundamental difference between CSM and peak flow hydrologic modeling, is that CSM considers the full range of flow events over a long period of record, typically 30 years or more, to develop flow duration curves, whereas peak flow hydrologic modeling generally considers synthetically (usually calibrated to measured data) produced event-based hydrographs (2-, 10-, 50-, 100- and 200-year return frequency events). CSM allows flow duration curves and other derived hydraulic metrics to be compared between existing and proposed conditions in order to assess hydromodification impact potential and to develop mitigation strategies. The guidance provided in this appendix is the product of the experience gained in the application of hydromodification management strategies to multiple urban development projects. This appendix is not intended to be an instruction manual but to provide guidance to engineers, planners and regulatory staff on specific modeling elements involved with HMPs.

MODELING METOHDOLOGY REVIEW

Modeling Approaches

A common approach to mitigating hydromodification impacts from development projects is to construct best management practices (BMPs) which capture, infiltrate and retain runoff, where possible. In such cases, the water is detained and released over a period of time at rates which more closely mimic pre-project hydrology. Methods commonly used to size hydromodification BMPs include hydrograph matching (matching pre and post-project flow regimes), volume control and flow duration control. Hydrograph matching is most traditionally used to design flood detention facilities for a specific storm recurrence interval, such as the 100-year storm, whereby the outflow hydrograph for a project area matches the pre-project hydrograph for a design storm. Volume control matches pre- and post-project runoff volume for a project site; however, the frequency and duration of the flows are not controlled. This can result in higher erosive forces during storms. Flow duration control matches both the duration and magnitude of a range of storm events for pre- and post-project runoff. The complete hydrologic record is taken into account, and runoff magnitudes and volumes are matched as closely as possible.

It is generally accepted that flow duration control matching is the most appropriate method to be used in the design of hydromodification BMPs. The flow duration control approach has been used in at least half a dozen HMPs in California, all of which used a CSM to match flow durations. However, differences exist in how the continuous simulation modeling is used between programs.

OVERVIEW OF APPENDIX

This appendix covers the following specific topics, addressed in the order in which they would arise as part of a hydromodification analysis for a major development project:

Section 2 addresses calculation of a flow control range, including identification of an acceptable low flow value, based upon critical flow for incipient motion of the channel material. .

Section 3 addresses the development of evaluation criteria to assess the effectiveness of a proposed mitigation design, including a discussion of flow duration matching and the erosion potential metric.

Section 4 addresses CSM, including precipitation data requirements, hydrologic time steps, model calibration and validation, and other modeling considerations and tips.

2. METHOD FOR SELECTION OF A FLOW CONTROL RANGE

INTRODUCTION TO FLOW CONTROL

Most hydromodification plans (HMPs) in California have adopted a flow control approach, which establishes a range of flow magnitudes discharging from the proposed site that must be controlled. The magnitude of the flow range is commonly expressed in terms of a percentage of the return period flow to which it is equivalent; for example: from 10% of the Q2 to 100% of the Q10. Flow magnitudes within the prescribed range must not occur more frequently under the proposed condition than they do in the existing (or pre-project) condition. Another way of expressing this is that the long term (decadal) cumulative duration of these flows must not be longer in the post-project condition compared to the pre-project condition. Generally, a small exceedance tolerance is allowed. For example, the following is a typical criterion that has been used in HMPs:

> For flow rates ranging from 10% of the pre-project 2-year recurrence interval event (XQ2) to the pre-project 10-year runoff event (Q10), the post-project discharge rates and durations shall not deviate above the pre-project rates and durations by more than 10% over and more than 10% of the length of the flow duration curve. The specific lower flow threshold should be influenced by results from the channel susceptibility assessment.

The rationale behind setting an upper limit is the understanding that when less frequent, high intensity/volume precipitation events occur, the watershed reaches a saturation level and responds in a similar manner for undeveloped and developed conditions. Furthermore, while these less frequent, high magnitude events do induce significant geomorphic change, they occur so infrequently that over a long time period, they comprise only a small portion of the work done on a channel. For example GeoSyntec (2007) used a hydro-geomorphic model to assess cumulative sediment transport on Laguna Creek (near Sacramento) and determined that 95% of the total erosion and sediment transport in the creek is accomplished by flow rates less than Q_{10}.

The purpose of determining a low flow range is one of practical design consideration when meeting a requirement for flow duration matching. The requirement to match flow durations between a pre- and post-project condition requires that runoff be detained and infiltrated within a BMP (e.g. open basin or underground vault). If flow matching is required to be achieved for all flows down to zero, the BMP volume will be significantly larger (and therefore more costly) than if there were some low flow below which runoff could be discharged at durations longer than in the pre-project condition. A key assumption underlying the concept of a low-flow discharge is that the increase in discharge durations below this rate will not increase channel erosion because the flows are too small to initiate movement of channel materials to any significant extent. Another critical assumption in the flow duration matching approach is that a single discharge value is valid across the range of grain sizes and geometries in the streams to which that low flow value applies.

For a specific set of hydraulic conditions (e.g., cross sectional shape, channel slope, bed and bank roughness), the flow rate can be calculated where the critical shear strength value is reached. Thus with an estimate of the critical shear strength of the materials composing a channel's bed or banks, and the hydraulic conditions occurring at the same location, the critical flow rate can be determined at which transport (or erosion) begins. This critical flow rate (Q_c) can then be compared to the magnitude of a flood peak which occurs every two years (Q_2) to establish the estimate of percent Q_2 to be used as the lower flow threshold.

Thus in order to calculate the lower flow threshold as expressed by a percentage of Q_2, three values must be determined for each analysis location (described in further detail below):

- The critical shear strength (τ_c) of bed and bank materials;
- The critical flow rate (Q_c) at which this critical shear strength is reached and exceeded;
- The magnitude of a flood peak which occurs every two years (Q_2).

In contrast, when using an erosion potential (Ep) metric (rather than flow duration matching) for BMP sizing, the Ep analysis incorporates channel geometry to estimate shear stresses generated at various flow rates, and then compares these to estimated critical shear stresses (i.e., shear stress required to initiate transport) for the grain size distribution within the stream. However, for either flow duration matching or for erosion potential analysis, the first step is to determine the critical shear stress for incipient motion of channel materials.

DETERMINATION OF CRITICAL SHEAR STRESS

The composition and condition of the bed and banks of a stream channel are the best indicators of how a channel will react (i.e., its susceptibility) to hydrologic changes resulting from development projects (i.e., hydromodification). Channels composed of materials more resistant to erosion are less susceptible to excessive erosion due to hydromodification than channels composed of less resistant materials. Channel material type can vary widely between, as well as within, watersheds. Figure 2-1 **Error! Reference source not found.**a. and b. illustrate stream incision through (a) relatively loosely consolidated, non-cohesive sand and gravels, and (b) relatively cohesive silty-clays. The resistance of bed and bank materials is quantified by their critical shear strengths, (τ_c) that is, the value where entrainment or transport begins.

Typical stream erosion in a southern California stream (granular, non-cohesive
(Photo courtesy of Eric Stein, SCCWRP)

Typical stream erosion in a northern California stream (generally cohesive silty clays)
(Photo cbec, inc.)

Notes:	cbec	*Guidance on the Use of Continuous Simulation Hydrologic Modeling* **Examples of Stream Erosion in Southern and Northern California**		
		Project: 11-1001	Created By: CBB	**Figure 2-1**

Figure 2-1. a. Example of a loosely consolidated, non-cohesive sand and gravel stream bed. b. Example of a relatively cohesive silty-clay stream bed.

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Several methods are available for the estimation of critical shear stress, including laboratory studies (e.g., flume studies) and field measurements, with different methods utilized for cohesive materials and non-cohesive materials.

Estimating Critical Shear Stress for Non-Cohesive Materials

The most common method for determining the critical shear stress of a non-cohesive material is through the application of the Shields relationship. This relationship is applicable to the calculation of critical shear stress for a uniform size mixture of sediment with a known particle size and specific gravity. Since it was originally proposed by Shields in 1936, the relationship has been tested and further investigated by several other researchers, resulting in a variety of modifications, primarily through variation of the Shields parameter. The original value of the Shields parameter proposed by Shields was 0.06, however, values from 0.03-0.06 have been suggested, with 0.045 acknowledged as a good approximation. Recent research has demonstrated that a value of 0.03 may be more appropriate for estimating incipient motion in streams with gravel beds (Neill 1968, Parker et al. 2008, Wilcock et al. 2009), where D50 estimates are based upon data collected via pebble count. The decision of what value of Shields parameter is used can have a large influence on the resulting τ_c estimate. For example, if a value of 0.06 is used, it results in twice as large of an estimate of τ_c than if a value of 0.03 is used.

While the Shields relationship was developed for a mixture of uniform sized sediment, it can be applied to a mixture of sediment with varying sizes as long as the distribution is uni-modal and does not have a high standard deviation of grain sizes (Wilcock 1993). In contrast, for sediment mixtures which are bimodal (e.g., if there is a large amount of sand in addition to gravel), a different approach (e.g., Wilcock and Crowe 2003) is recommended. For a more in depth discussion of sediment transport and incipient motion, the reader is referred to Wilcock et al. (2009).

In order to apply the Shields relationship to determine τ_c, the median grain size (d50) present on the channel surface must be determined. River channels are often armored; meaning that coarser material is present on the surface than is present underneath the armor layer. However to access and transport the finer material beneath, the surface layer must first be mobilized. The median grain size is determined by analysis of a particle size distribution.

A particle size distribution can take the form of: 1) a cumulative *frequency* distribution which is determined by way of a pebble count or photographic analysis, or 2) a cumulative *weight* distribution. For a cumulative frequency distribution a subset of particles present on the surface are measured, and the frequency of particles within different size class bins is used. **Error! Reference source not found.** shows a sample particle size distribution graph developed from a pebble count. For a cumulative weight distribution, a bulk sample of the surface material is collected, and then sorted using a set of sieves with different screen sizes. The amount of material retained by each sieve is weighed and then used to plot the cumulative weight distribution. Both approaches have advantages and disadvantages.

A pebble count is a relatively straightforward field technique that is easily applied in streams which are wadable. **Error! Reference source not found.** shows photographs of pebble counts being conducted in the field. They can be performed relatively quickly, which means more samples can be collected to better characterize the conditions present in a reach. However, there are a variety of ways a pebble count can be conducted, and there is tremendous opportunity to introduce bias to the measurement. Furthermore, while studies often cite Wolman (1954) as the method employed in data collection, strict adherence to this protocol is not always achieved. Rather than the method suggested by Wolman (1954), a refined, more regimented approach has been suggested by Bundte and Abt (2001a), and is recommended. In addition, it should be noted that pebble counts generally do a poor job of characterizing sand and smaller sized material. In addition to pebble counts, software can be used to process a digital image of an area of the bed. The software samples a subset of particles present in the image, and using assumptions regarding the amount of given particle that is visible, is able to provide a cumulative frequency distribution.

Collecting a bulk sample for sieve analysis is another method frequently employed to determine values for typical characteristic indices of a particle size distribution. In this method a sample is collected from the channel surface, and then the sample is segregated into various size classes with sieves. One advantage of this approach is that it utilizes all the data available from the sampled area (as opposed to a pebble count which uses a subset of the entire population, e.g., ~100 particles as opposed to thousands), however the sampled area is typically smaller than the area sampled within one pebble count. One disadvantage is the size of sample that is necessary. Because the resulting particle size distribution is based upon weight, the largest particles present can have a very large influence on the resulting particle size distribution. Research has suggested that the weight of the entire sample must exceed 100x the weight of the largest particle present to escape this possible bias. This means large (volume and weight) samples are often required. Some sieving can occur on site through the use of shaker sieves, but typically some portion of the sample is also taken back to the lab for further analysis. Thus, bulk samples typically require more effort and equipment to establish a particle size distribution, however they provide a much more accurate estimate, especially when a large fraction of the sample is sand sized (2mm) and smaller.

For a more in depth discussion of sampling methods to determine particle size distributions in wadable streams, the reader is referred to Bunte and Abt (2001).

Estimating Critical Shear Stress for Cohesive Materials

The methods described above are not appropriate for cohesive materials, which due to chemical cohesion between particles exhibit larger τ_c values than would be estimated by consideration of particle size/weight in isolation (i.e., cohesive properties not considered). One method that allows for the determination of τ_c *in situ* is the application of a jet test (ASTM 2007). The jet-testing apparatus and analytical methods were developed by researchers at the USDA Agricultural Research Station (Hanson and Cook 1999; Hanson et al. 2002; Hanson and Cook 2004; ASTM 2007). The method uses a submerged impinging jet of water directed perpendicularly at the material surface, in order to erode the material. As erosion occurs, a scour hole is created. The depth of this hole is measured periodically as time progresses through the test. As the scour hole increases in depth, the strength of the jet is reduced because it is travelling longer distance through water from the jet orifice to the soil surface. Eventually, the energy of the jet is dissipated enough that it no longer has energy in excess of the material's shear strength and erosion stops. **Error! Reference source not found.** shows a photograph of a jet testing rig deployed in a stream bank.

In addition to jet testing, *in situ* testing of shear strength can be obtained through the application of a field vane shear test (ASTM 2008). This method provides τ_c values based upon the assumption that the bed or bank will fail via large blocks (composed of thousands of particles), as opposed to erosion occurring particle by particle. As such, the values measured by a shear vane are often several orders of magnitude larger than those obtained via testing with the jet-device.

Estimating Critical Shear Stress Through the Use of Literature Values

An alternative to the measurement/calculation of τ_c, is the use of values found in the literature. Indeed, several HMPs have several HMPs have been developed through assumption of material resistance properties found in the literature based upon literature based upon a textural description of the material. An often-cited reference is Fischenich (2001), which provides a (2001), which provides a summary (compiled from the relevant literature) for critical shear strength values for various values for various materials. An extract from this reference is provided in

Figure 2-5.

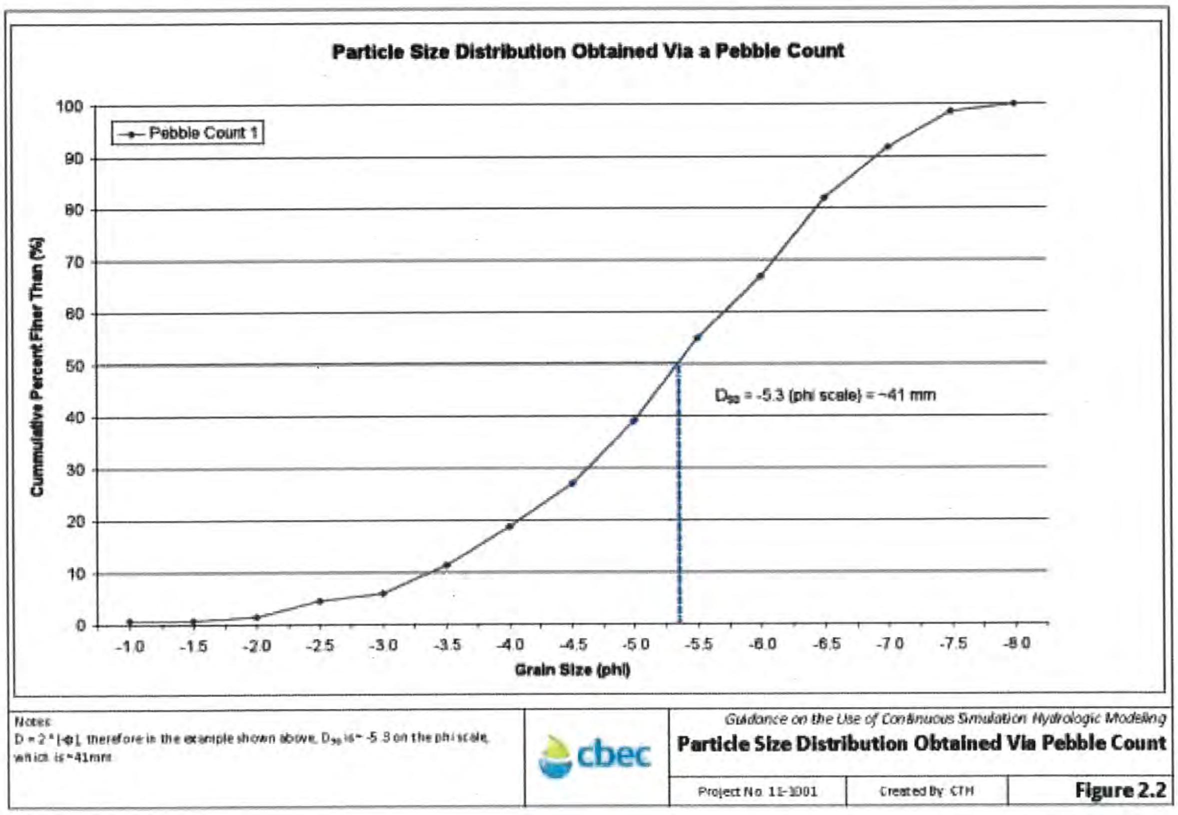

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Figure 2-2. Particle Size Distribution Graph Developed from a Pebble Count

Notes:	cbec	*Guidance on the Use of Continuous Simulation Hydrologic Modeling* **Pebble Counts Being Conducted in the Field**		
		Project: 11-1001	Created By: CBB	**Figure 2-3**

Figure 2-3. Pebble Counts Being Conducted in the Field

Typical installation of jet testing equipment in stream bank

Hole created in cohesive bank material by jet impinging on surface

Notes:	cbec	*Guidance on the Use of Continuous Simulation Hydrologic Modeling* **Jet Testing Equipment Deployed in a Stream Bank**		
		Project: 11-1001	Created By: CBB	**Figure 2-4**

Figure 2-4. Jest Testing Equipment Deployed in a Stream

Table 2. Permissible Shear and Velocity for Selected Lining Materials[1]

Boundary Category	Boundary Type	Permissible Shear Stress (lb/sq ft)	Permissible Velocity (ft/sec)	Citation(s)
Soils	Fine colloidal sand	0.02 - 0.03	1.5	A
	Sandy loam (noncolloidal)	0.03 - 0.04	1.75	A
	Alluvial silt (noncolloidal)	0.045 - 0.05	2	A
	Silty loam (noncolloidal)	0.045 - 0.05	1.75 – 2.25	A
	Firm loam	0.075	2.5	A
	Fine gravels	0.075	2.5	A
	Stiff clay	0.26	3 – 4.5	A, F
	Alluvial silt (colloidal)	0.26	3.75	A
	Graded loam to cobbles	0.38	3.75	A
	Graded silts to cobbles	0.43	4	A
	Shales and hardpan	0.67	6	A
Gravel/Cobble	1-in.	0.33	2.5 – 5	A
	2-in.	0.67	3 – 6	A
	6-in.	2.0	4 – 7.5	A
	12-in.	4.0	5.5 – 12	A
Vegetation	Class A turf	3.7	6 – 8	E, N
	Class B turf	2.1	4 – 7	E, N
	Class C turf	1.0	3.5	E, N
	Long native grasses	1.2 – 1.7	4 – 6	G, H, L, N
	Short native and bunch grass	0.7 - 0.95	3 – 4	G, H, L, N
	Reed plantings	0.1-0.6	N/A	E, N
	Hardwood tree plantings	0.41-2.5	N/A	E, N
Temporary Degradable RECPs	Jute net	0.45	1 – 2.5	E, H, M
	Straw with net	1.5 – 1.65	1 – 3	E, H, M
	Coconut fiber with net	2.25	3 – 4	E, M
	Fiberglass roving	2.00	2.5 – 7	E, H, M
Non-Degradable RECPs	Unvegetated	3.00	5 – 7	E, G, M
	Partially established	4.0-6.0	7.5 – 15	E, G, M
	Fully vegetated	8.00	8 – 21	F, L, M
Riprap	6 – in. d_{50}	2.5	5 – 10	H
	9 – in. d_{50}	3.8	7 – 11	H
	12 – in. d_{50}	5.1	10 – 13	H
	18 – in. d_{50}	7.6	12 – 16	H
	24 – in. d_{50}	10.1	14 – 18	E
Soil Bioengineering	Wattles	0.2 – 1.0	3	C, I, J, N
	Reed fascine	0.6-1.25	5	E
	Coir roll	3 - 5	8	E, M, N
	Vegetated coir mat	4 - 8	9.5	E, M, N
	Live brush mattress (initial)	0.4 – 4.1	4	B, E, I
	Live brush mattress (grown)	3.90-8.2	12	B, C, E, I, N
	Brush layering (initial/grown)	0.4 – 6.25	12	E, I, N
	Live fascine	1.25-3.10	6 – 8	C, E, I, J
	Live willow stakes	2.10-3.10	3 – 10	E, N, O
Hard Surfacing	Gabions	10	14 – 19	D
	Concrete	12.5	>18	H

[1] Ranges of values generally reflect multiple sources of data or different testing conditions.

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Notes:	cbec	*Guidance on the Use of Continuous Simulation Hydrologic Modeling* **Permissible Shear Strength and Velocity for Selected Lining Materials**
		Project No: 11-1001 / Created By: CBB / **Figure 2-5**

Figure 2-5. Permissible Shear and Velocity for Selected Lining Materials

DETERMINATION OF CRITICAL FLOW (Q_c)

For a specific set of hydraulic conditions at a location (i.e., cross sectional shape, channel slope, bed and bank roughness), the flow rate at which critical shear values are reached can be calculated. These calculations can be made with a programed spreadsheet analysis, or with a hydraulic model (e.g., HEC-RAS, Brunner 2010). Because of their ease of use and the ease at which multiple flow rates can be assessed (in order to determine when τ_c is reached), hydraulic models are typically employed for this part of the analysis. Average boundary shear stress is calculated with the following equation:

$$\tau = \rho g R s$$

where *p* represents the density of water, *g* represents the gravitational constant, R represents the hydraulic radius (defined as the wetted area dived by the wetted perimeter), and *s* represents the slope. For wide channels the value of the hydraulic radius is approximately equal to the average depth of the cross section. The hydraulic model calculates the value for R for a given discharge based on the channel dimensions.

Typically one-dimensional approximations are used for this analysis, which means that the value of Q_c determined is that where the cross sectional average of τ_c is reached, not the highest value which is occurring at the deepest point of the cross section. This is typically considered reasonable because the grain size is determined for the bed of the cross section, not just the shallow or deep area.

Analyses can be conducted at a station, or in other words just looking at one cross section in isolation using normal depth calculations, or within a larger hydraulic model constructed for the entire reach (i.e., multiple distributed cross sections upstream and downstream of the location of interest). The advantage of looking at the cross section of interest within the context of the entire reach is that conditions downstream (e.g. a constriction which causes a backwater condition) may affect the flow depth (or hydraulic radius), yielding different results than would be obtained if the cross-section was analyzed in isolation.

It is important that the determination of τ_c (via pebble count or other means) and the hydraulic calculations to determine Q_c, occur at the same location. Typically the analysis is undertaken at a riffle because these are the high points of a long profile and are what are controlling incision in the system. Bed material characterization in a pool is much more difficult (because of the depth of water), in addition the resulting calculated shear values are typically much higher, because of the added depth.

If HEC-RAS is used (which is typical), the way the bank markers are set can have a dramatic influence on the calculated shear results. The bank markers are used to delineate differences in roughness across the channel and flood plain (typically higher values are used on the lateral margins to include the influence of vegetation roughness in the resulting depth calculations). The shear values calculated by HEC-RAS are segregated by these bank markers, and thus may include values for each of the floodplains as well as the channel. If bank markers are set too wide, and the shear stress calculation may include a portion of the floodplain too, and subsequently the conditions in the actual channel will be greatly underestimated. Remember that the model is essentially using the average depth for the entire cross section (as limited by the bank markers), so including floodplain with shallow depths greatly influences the average depth and thus the resulting calculated shear value.

DETERMINATION OF Q_2

The determination of a value of Q_2 is the third and final piece of the equation used to determine what percent of Q_2 the lower threshold should be. As with the other two pieces, several options are available, and again the decision on what method is used can have a profound influence upon the final results. Q_2 can be determined through the results of a calibrated and validated hydrologic model (e.g., HEC-HMS, HSPF, SWMM, etc.) which uses precipitation, sub basin area, soil conditions, etc. to calculate a runoff hydrograh. This type of model can be used in one of two ways, to simulate a single precipitation event or to simulate a long term (e.g., 50 year) precipitation record. The first approach produces a single runoff hydrograph resulting from a "design" storm, from which the peak magnitude can be determined. As such the results are largely controlled by the precipitation hyetograph, so a good understanding of how that was developed is important. This method has been used considerably less than the approach detailed below. The advantage of this method is that, if any existing model has already been developed (e.g., SacCalc; DFCE 2001), it will be cheaper and easier for an agency to review. However, it can yield different values for Q_2, due to differing assumptions employed in the modeling.

The second method uses a long-term precipitation record for simulation which results in a flow record containing a large number of runoff events of varying magnitudes (i.e., which are subsequently analyzed to determine the magnitude of the 2 year recurrence interval event). This method is more typical for HMP assessments, but again methodical decisions can have a large influence on the results. The rigor of the model calibration and validation has a strong influence. If the model is not representing through simulation what is actually occurring, then the simulation results are questionable.

Assuming the model has been calibrated and satisfactorily validated or verified, the manner in which the simulated runoff record is analyzed is important. The first basic distinction is whether an annual maximum series (AMS) or a partial duration series (PDS) is used. In an AMS analysis, just the single largest flood peak of any given year is used in the analysis, and the second and third largest events of the year are ignored. This is the method typically utilized when analyzing the flood frequency of large, less frequently occurring flood events. In the second approach, PDS, multiple flood events are considered in any given year. This is important when the second or third largest flood events in one year are greater than the annual maximum of another year. Because more large events are included, the resulting estimate of the given return period event (e.g., Q_2) is larger. For example, Langbein (1960) showed that a 1.45 year event determined with PDS is the same magnitude as a 2 year event with an AMS, and a 2 year event determined with PDS is a 2.54 year event with an AMS. Thus the value of Q_2 determined by PDS is larger than the value of Q_2 determined by AMS. While significant differences are apparent for smaller magnitude, more frequently occurring events (e.g., Q_2), for return periods greater than 10 years, there is almost no difference between the results obtained from the AMS and PDS.

When compiling a PDS for a recurrence interval analysis, the manner in which events are identified as independent can also have an effect upon the results. One typical method is to include all flood peaks above a certain base magnitude. This base value is often selected as equal to the lowest annual maximum flood of record, however can also be chosen such that the PDS only contains as many peaks as there are years of record. Some analysts have established a base value (e.g., 0.002 cfs/acre), and then added a duration below this base value as well (i.e., flow must be below 0.002 cfs/acre for at least 24 hours for events to be considered independent). One additional method is to identify individual events by extracting the highest peak (not just the maximum value) within a moving time window (e.g., 3 days), and therefore determine independence through time, rather than the discharge rate receding to a non-storm condition. With all of these options available, and no prescribed standard, the use of a PDS can have different Q_2 results even if an identical flow time series is used.

SUMMARY

The determination of the lower flow threshold, defined as a percentage of Q_2, is heavily influenced by three primary inputs: τ_c, Q_c, and Q_2. The determination of each of these values is sensitive to a variety of factors determined by the particular methodology. To demonstrate the sensitivity of the lower flow threshold to methodological decisions, a few examples are provided below.

- If 0.06 is used rather than 0.03 for Shields parameter in Shields relationship, τ_c increases, subsequently Q_c increases and ultimately the lower limit increases
- If bank markers are set too wide (including the floodplain and not just the channel) in the hydraulic analysis, a larger value for Q_c is calculated (because of a reduction of the hydraulic radius due to the inclusion of extensive shallow floodplain areas), resulting in an increase of the lower limit.
- If an annual maximum series is used in place of a partial duration series, the calculated Q_2 will be less than that obtained by a PDS analysis, and the ratio of Q_c to Q_2 will be higher if the AMS is used.

3. DEVELOPMENT OF EVALUATION CRITERIA

FLOW DURATION CONTROL AND PEAK FLOW CURVE MATCHING

Flow Duration Control (FDC) and Peak Flow Curve (PFC) matching criteria in their current form for many counties in CA are similar in form to the curve matching criteria from WA (WADOE, 2001). The curve matching criteria typically include a goodness of fit or variance due to the difficulty in achieving a precise match across the range of flows. The criteria are typically applied at the subwatershed scale based on continuous simulation flow results for pre- and post-project conditions to size individual BMP or LID features. In this instance, flow matching at the subwatershed scale assumes that there are no routing or timing effects in the treated runoff when it rejoins the receiving waterbody; however, this may not be true in all cases. For example, if treated runoff is delayed and rejoins the upstream runoff such that there is an increase in flow rates and durations or an increase in the peak flows in the receiving waterbody, then there is the potential to impair the receiving waterbody. To address this potential concern, the FDC and PFC criteria could be applied to the routed flows in the receiving waterbody as a check.

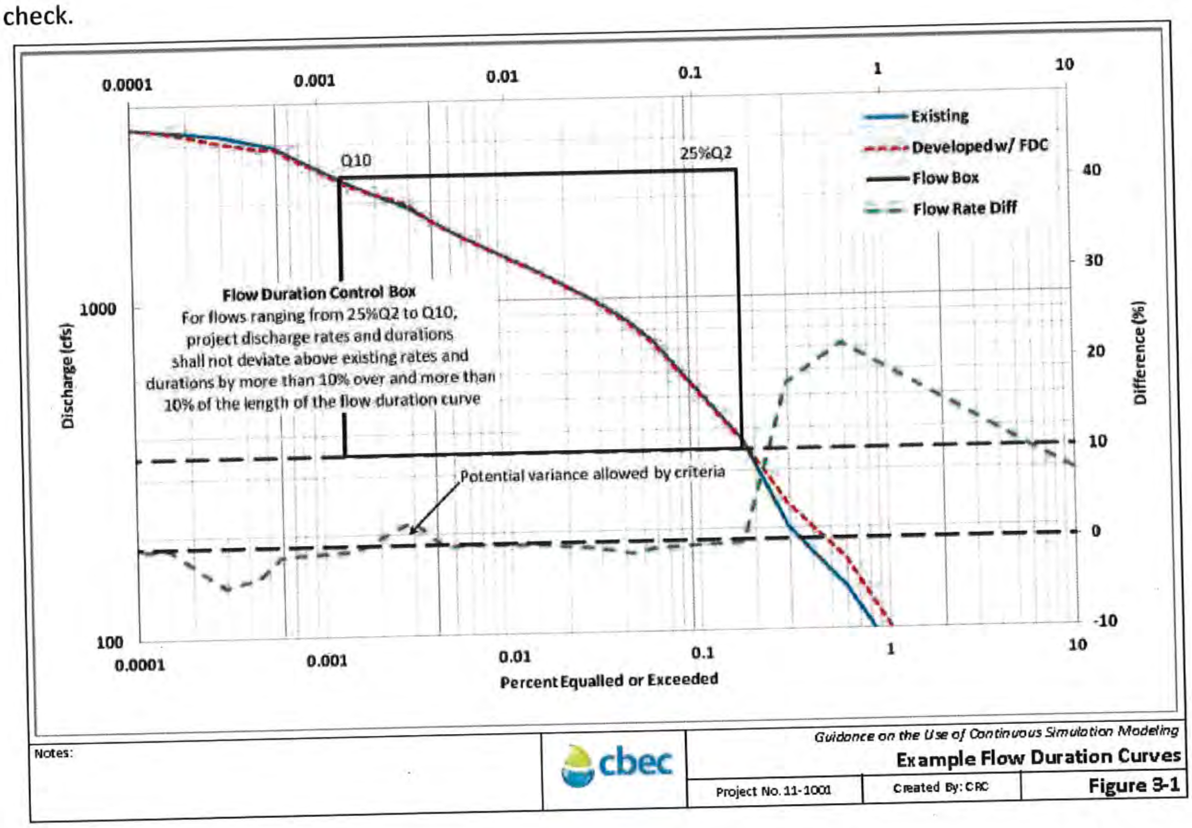

Figure 3-1 shows an example of FDC matching on the routed flows within a receiving waterbody with an example of the variance allowed by the criteria. However, it is cautioned that the FDC variance (e.g., "...by more than 10 percent over and more than 10 percent of the length...") may need to be reduced to something less than 10 percent (perhaps based on a ratio of watershed areas) to account for cumulative effects if there remain the potential for continued development in the watershed.

EROSION POTENTIAL

Erosion Potential (EP) is an index to indicate the impact of increased flows on stream stability and is based on bed mobility and an integration of work (as a function of velocity and excess shear stress in the channel only) over time, expressed as a ratio of post-project work divided by pre-project work in the receiving waterbody. Total work is based on integrating effective stream power as:

$$W = \sum_{i=1}^{n} (\tau_i - \tau_c)^e \cdot V_i \cdot \Delta t_i$$

where W is the total work done (ft-lbf/ft^2), τ is the average channel shear stress, τ_c is the critical shear stress to initiate erosion, e is an exponent varying from 1 to 2.5 to account for the exponential rise in stream power with flow, V is the velocity (ft/sec), and Δt is the numerical time step (sec). The EP index is then calculated as the ratio of W_{dev} / W_{ex} where W_{ex} and W_{dev} is the total work for existing and developed conditions, respectively. EP can be calculated at any location in the waterbody based on continuous simulation time series of flow, velocity, and excess shear stress in the channel as derived from hydraulic model outputs.

EP criteria are not widely integrated into HMPs. Notably Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) included EP criteria in their HMP, but in so much as it was used to inform their overall management objective (i.e., post-project runoff shall not exceed estimated pre-project rates and/or durations) and the development of their FDC / PFC criteria. In the SCVURPPP (2005) final HMP, an EP ratio <= 1.0 was recommended as the instream target value to be maintained for stream segments downstream of the point of discharge for HMP management. From a risk management perspective, the chance of a stream becoming unstable at an EP of 1.0 is 9%, meaning that 1 in 11 streams could become unstable even with controls (SCVURPPP, 2005). As such, instream EP must be evaluated considering the effects of the cumulative changes that have or may take place in the watershed.

Even though EP criteria are not widely promoted in county HMPs, that does not preclude analyses based on EP from being used, especially when instream measures permit more robust geomorphic analyses (e.g., SCVURPPP final HMP; SSQP draft HMP). While EP analyses are more time and data intensive, there is the potential outcome to discharge runoff at higher rates and durations than FDC / PFC criteria would allow, thus resulting in possibly smaller onsite measures. The time and data intensiveness of EP analyses stem from the need to evaluate the hydraulic and geomorphic conditions of the receiving waterbody to be protected at multiple locations based on continuous simulation hydraulic model outputs and geomorphic data. Potential hydraulic model considerations when performing EP calculations are addressed below.

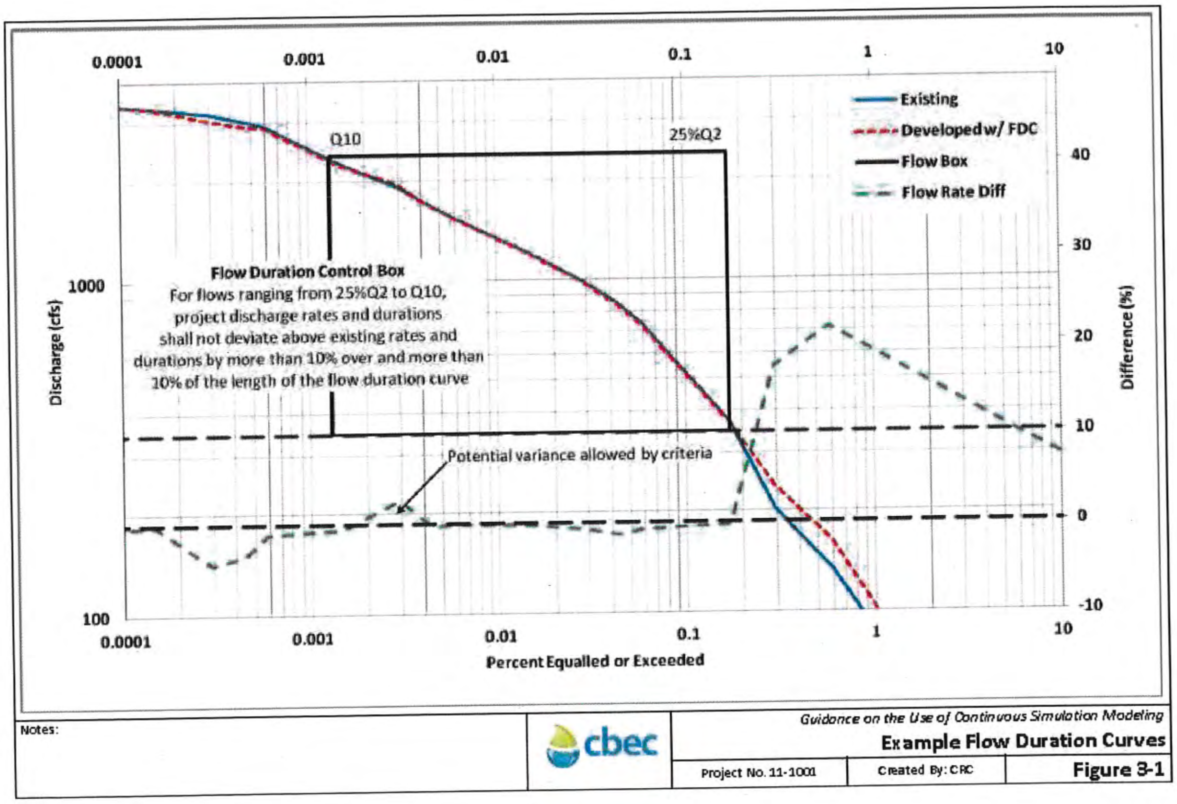

Figure 3-1. Example Flow Duration Curves

4. DATA REQUIREMENTS FOR CSM AND HYDRAULIC ANALYSIS

Hydrologic models capable of performing long-term continuous simulation to support HMPs include, but are not limited to, HSPF, HEC-HMS soil moisture accounting (SMA) method, and other hydrology models, such as the Bay Area Hydrology Model (BAHM). The first two are public domain software models and the third is a proprietary software model customized for specific counties that uses HSPF as its computational engine. A fourth modeling tool based on continuous simulation results, and also using HSPF as its computational engine, are the suite of BMP sizing calculators specifically designed for HMP management for select counties. These have been developed for Contra Costa and San Diego County and Sacramento County (in draft form). All four suites of models use site conditions (i.e., topography, soils, vegetation, and land use) and long-term precipitation data to calculate the various components of the hydrologic cycle (i.e., infiltration, surface runoff, soil moisture, evapotranspiration, percolation, interflow, and groundwater). Specific details about each model and model comparisons (e.g., TetraTech, 2011) are not discussed here, but can be reviewed in available literature.

Following model selection, hydrologic models are created for existing and project conditions based on various considerations, some of which are discussed in subsequent sections. For project conditions, county specific HMP measures need to be specified to manage project runoff to meet the evaluation criteria identified above. The BMP sizing calculators and BAHM-type hydrology models do have optimization routines to size BMP and LID measures. Automatic sizing allows for efficient and quick sizing of such features based on county specific, model specific (e.g., the sizing calculator for San Diego and Contra Costa County is based on pre-defined sizing factors such that site specific continuous simulations do not need to be performed, and is limited to drainage management units of less than 100 acres), and user-defined (e.g., the BAHM-type hydrology models require site specific continuous simulation with a wide selection of measure configurations) assumptions and limitations. As standalone models, HSPF and HEC-HMS offer flexibility as it relates to model configuration, model inputs, and user-defined parameters. However, these models do not have optimization routines to size various BMP and LID measures, thus requiring manual iteration to achieve a satisfactory solution.

PRECIPITATION DATA

Long-term precipitation data in the range of 30 to 50 years is typically needed to generate a sufficiently long flow record from which FDC and PFC analyses and/or subsequent hydraulic analyses can be performed. The precipitation data observation interval should ideally be no coarser than hourly, and if available, can be sub-hourly (e.g., 15 minutes) to coincide with a finer continuous simulation time step.

The precipitation data should ideally be located near the project site, and if needed, scaled to the project site based on a ratio of mean annual precipitation as derived from county specific mapping or regional sources (e.g., PRISM [http://www.prism.oregonstate.edu/]) and reviewed to ensure that it captures key IDF characteristics from county specific mapping or regional sources (e.g., NOAA Atlas 14 [http://www.nws.noaa.gov/oh/hdsc/index.html]). A variety of precipitation data sources exist, and include, but are not limited to:

- ALERT system for individual counties (e.g., Sacramento [http://www.sacflood.org/])
- Western Region Climate Center (WRCC [http://www.wrcc.dri.edu/])
- NOAA National Climatic Data Center (NCDC [http://www.ncdc.noaa.gov/])
- California Irrigation Management Information System (CIMIS [http://wwwcimis.water.ca.gov/])

HYDROLOGIC SIMULATION TIME STEP

The continuous simulation time step and output reporting interval for the four models identified above has traditionally has traditionally been hourly. However, an hourly time step is often significantly larger than the time of concentration for concentration for developed subwatersheds relative to existing subwatersheds, especially those commonly configured commonly configured developed subwatersheds that are limited to less than 100 acres. The sizing calculator and BAHM-type calculator and BAHM-type models are hardwired at hourly, but the public domain software still affords the user to go to a the user to go to a finer time step. As such, a sub-hourly time step and output reporting interval is preferred in order to preferred in order to adequately resolve and sample flow from developed subwatershed elements where time of where time of concentrations are typically less than one hour. As shown by

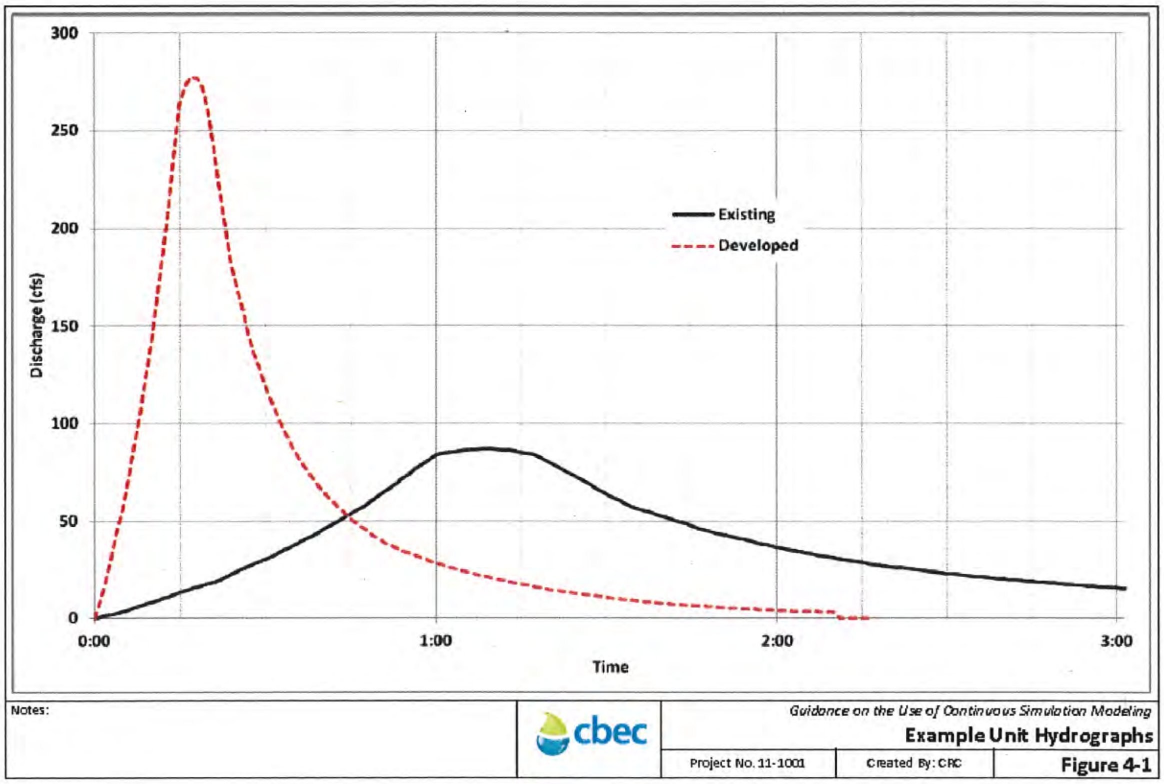

Figure 4-1 for a typical developed subwatershed, the unit hydrograph for developed conditions is flashier, peaks quicker (well within one hour), and the recession limb becomes small quickly. While a sub-hourly time step and output reporting interval may not be desirable due to the volume of model output that will be generated, it is possible to bias the results in favor of the developed condition due to under sampling of the flashier and larger developed flows under an hourly time step.

HYDROLOGIC MODEL CALIBRATION AND VALIDATION

In developing continuous simulation models, the model parameters describing soil characteristics, land use descriptions, and evapotranspiration should be derived from published data (e.g., soil survey, local studies, county standards, etc.). These parameters should be calibrated and validated, where applicable, by comparing modeled flows to measured or observed flows with the receiving waterbody for specific overlapping periods when there is adequate precipitation, evapotranspiration, and flow data. In the absence of site-specific data for calibration and validation, calibrated model parameters from neighboring watersheds within the region could be used so long as proper justification is provided that said parameters are appropriate. However, it is not recommended that local studies rely upon calibrated parameters from other regions where soil characteristics and land use descriptions are markedly different. Rather, when calibration cannot be performed, general review and comparison of continuous simulation model outputs (e.g., hydrograph shape, AMS, etc.) to standardized event-based approaches could be performed to demonstrate that continuous simulation results are generally consistent with local standards and methodologies.

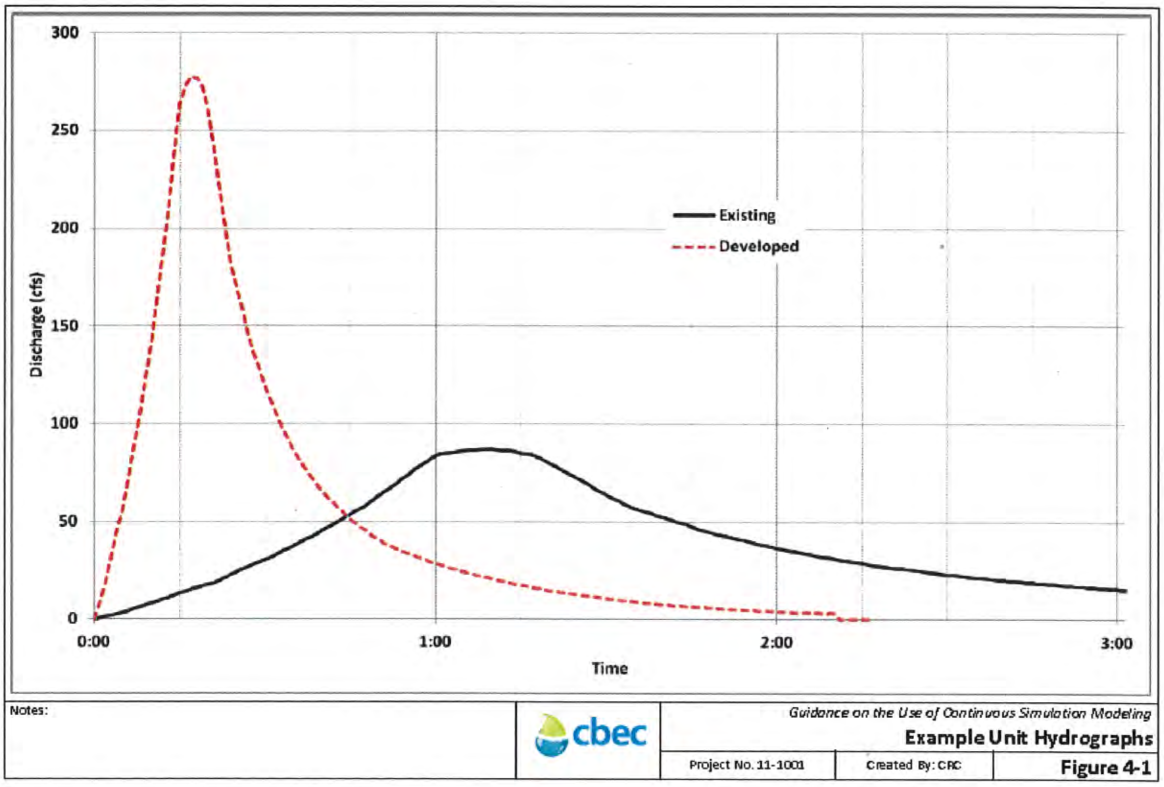

Figure 4-1. Unit Hydrograph Method

For example, continuous simulation modeling in Sacramento County for some developments has relied up conversion of SacCalc (HEC-1 pre- and post-processor) event-based models to the SMA method within HEC-HMS. This conversion often involves retaining the surface infiltration rate determined by SacCalc based on accepted land use descriptions, but parameterizing the subsurface based on soil survey information and local studies, using local potential evapotranspiration data, and reviewing model hydrographs for reasonableness.

HYDRAULIC MODEL CONSIDERATIONS

Sometimes hydraulic models are needed since the basic flow routing within the hydrologic models is not adequate to characterize the potential changes to the hydraulic and geomorphic character of the receiving waterbody, especially when instream measures are suggested or EP is used as the evaluation criteria. Potential considerations and issues encountered when developing and using hydraulic models for continuous simulation include:

1. Low flow instabilities can introduce anomalies into model output (which is commonly encountered in HEC-RAS), so careful hydraulic model selection is important for accuracy and efficiency
2. The sensitivity of the hydraulic model outputs (i.e., velocity and shear stress) to accurate hydraulic description of the receiving waterbody (i.e., cross section geometry (i.e., is it based on LiDAR influenced by vegetation or ground survey), proper definition of channel transitions, proper definition of channel bank markers, appropriate Manning's n-values, etc.)
3. Selection of appropriate compliance points that are representative of the reach and capture flow changes (e.g., downstream of points of discharge and not in backwater areas).

All of these issues have the potential to introduce error and subjectivity into long-term hydraulic analyses and care should be taken to systematically address each source of error.

GENERAL TIPS

A series of general tips are provided as follows. These can be used to increase efficiency and accuracy when performing CSM.

- To shorten the simulation time, the precipitation record can be truncated to only the rainy season (e.g., October through May) by removing the dry summer months from the simulation, especially in ephemeral systems where applicable.
- Hourly precipitation data does not prohibit the continuous simulation model from being run at a sub-hourly time step.
- Subwatershed delineation between existing conditions and developed conditions can often result in relatively large existing subwatersheds compared to relatively small developed subwatersheds. It is commonly known that smaller subwatersheds have flashier flows, so making existing and developed conditions subwatershed sizing consistent is recommended to provide a more meaningful comparison.

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APPENDIX B: APPLICATION OF SUITES OF MODELING AND ASSESSMENT TOOLS

Introduction. This appendix provides a discussion of four example "suites of tools" that can be used to perform predictive scientific assessments and address specific questions related to hydromodification assessment and management. The suites are changeable mixes of mechanistic models, statistical analyses, and expert scientific judgment that incorporate a number of the tools discussed in Chapter 4, combined in various ways. For example, some suites apply a series of cascading models, in which the output from one is used as input to the next; other suites apply a number of models in parallel to develop an assessment based on the weight of evidence. The suites of tools discussed below are used to perform a baseline stability assessment, a channel forming discharge analysis, an erosion potential analysis, and a sediment transport analysis. Most of these standard tools (with the exception of the erosion potential suite) have been widely employed in a variety of stream management activities for decades, and are considered essential components of the broader fluvial geomorphology toolbox. This is far from a comprehensive list of tools, as there are many other important tools (focused on both geomorphic and biologic endpoints) relevant to hydromodification management (Kondolf et al. 2003; Poff et al. 2010); however, the purpose of this appendix is to briefly illustrate how several standard tools can be integrated to answer key questions about stream responses and to provide a stronger technical basis for hydromodification management.

Application of these tools provides basic geomorphic data and knowledge that are typically needed to manage a stream for some desired future state in a watershed with changing land uses. This critical information comes at a cost—the tools require substantially more time and effort to apply than has been the norm in hydromodification management because they involve examining streams within their watershed context with a deeper level of geomorphic analysis. Stormwater management programs typically have made the "practical" assumptions that stream reaches can be managed in isolation from the larger systems of which they are a part, and that effective management prescriptions can be formulated with little or no substantive geomorphic analysis. ***These assumptions are in direct conflict with current understanding in fluvial geomorphology and stream ecology, which indicates that protection of stream integrity is often predicated upon careful assessments of geologic and historical context, performing detailed hydraulic and sedimentation analyses where appropriate, and developing basic understanding of streamflow-ecology linkages***. If hydromodification management policies are to have a reasonable chance of actually achieving their aims, then it will most likely be necessary to reject these simplifying assumptions and instead rely on approaches rooted in current scientific understanding of stream systems.

The suites of tools described below go beyond screening level assessments that are designed, in part, to identify which streams lend themselves to relatively straightforward management prescriptions versus which streams do not. For streams that do not lend themselves to generic management prescriptions, the level of analysis performed with these tools should increase with the level of risk and geomorphic / biologic susceptibility of the streams. This does not mean that every stream will require in-depth analysis by local permitting agencies. It is not possible to carry out sufficient geomorphic analyses with the tools illustrated below on a permit-by-permit basis, and local governments may lack the resources and/or technical capacity to effectively apply these tools. Instead, ***the vital information provided by these tools***

will need to be obtained through proactive regional studies that involve baseline assessments followed by progressively more in-depth analyses as necessary to provide local governments with a sound basis for effective project-by-project decision-making within a broader watershed management framework.

1. **Baseline Stability Assessment**. This suite of tools is designed to answer the following key questions:
   - What is the trajectory of the stream's form over time?
   - How has the channel form responded to changes in water and sediment supply over the years?
   - Is the channel close to a geomorphic threshold that could result in rapid, significant change in response to only minor flow alteration?
   - How can past channel responses provide insight into potential responses to future watershed change, and so aid in prediction of future hydromodification-induced changes?
   - What level of subsequent geomorphic analysis is appropriate given the complexity of the situation and the susceptibility of the streams of interest?

   The goals of a baseline stability assessment are to:
   - Document the historical trends of the system;
   - Establish the present stability status of the system and identify the dominant processes and features within the system;
   - Provide the foundation for projecting future trends with and without proposed project features;
   - Provide critical data for calibration and proper interpretation of models; and
   - Provide a rational basis for identification and design of effective alternatives to meet project goals.

   The key tools that comprise this suite include:
   - GIS mapping of topography, soils, geology, land use/land cover across the contributing watershed (e.g., Thorne 2002)
   - Analysis of hydro-climatic data, e.g. streamflow gauge records, changes in stage-discharge relationships over time (e.g., Thorne 2002)
   - Analysis of aerial photos and historical data (e.g., Thorne 2002)
   - Field reconnaissance (e.g., Thorne 1998)
   - Qualitative response (e.g., Lane 1955b, Schumm 1969, Henderson 1966 relations)
   - Classification systems - (e.g., Thorne 1997; Schumm et al. 1982; and channel evolution model developed for S CA by Hawley et al. in press)
   - Relationships between sediment transport and hydraulic variables
   - Regional hydraulic geometry (e.g., Hawley 2008; Haines in prep)
   - Regional planform and stability predictors (e.g., Hawley et al. in press, Bledsoe et al. in press, Dust and Wohl 2010)

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- Bank stability analysis (e.g., BSTEM http://www.ars.usda.gov/Research/docs.htm?docid=5044, Hawley (2009), Bledsoe et al. in press, Osman and Thorne 1988; Thorne et al. 1998)
- Sediment budgets (Booth et al. 2010; Reid and Dunne 1996)
- Fluvial audit (Thorne 2002 – a comprehensive framework for performing baseline assessments)

A baseline assessment is completed by integrating information from all the available data sources and analytical tools. Analysis with each of the individual tools may yield a verdict of aggradation, degradation, or dynamic equilibrium with respect to the channel bed, and stable or unstable with respect to the banks. The individual assessments can produce contradictory results. In this case, one should assign a level of confidence to the various components based on the reliability and availability of the data, and the analyst's own experience level. As is often the case in the management of fluvial systems, there is no "cookbook" answer, and we must always incorporate sound judgment.

A process-based channel evolution model (CEM) is a particularly useful element of the baseline assessment process. A CEM aids in identifying the dominant processes and trends of channel change and provides a framework for subsequent, more detailed modeling (ASCE 2008). In some locations, CEMs have already been developed and calibrated with regional data. For example, the CSU / SCCWRP Screening Tool (Bledsoe et al. 2010) grew out of a regional CEM (Hawley et al. in press) and integrates several baseline assessment tools including regionally-calibrated braiding, incision, and bank stability thresholds, and sediment supply analysis with "Geomorphic Landscape Units" (Booth et al. 2010). In locations where a CEM has not been sufficiently defined, the baseline assessment suite of tools can provide the data and understanding needed to develop a regionally calibrated CEM.

The following are example outputs from a baseline stability assessment, including channel stability and bank stability diagrams associated with key geomorphic thresholds of management concern in the channel evolution sequence (i.e. braiding, incision, and bank failure):

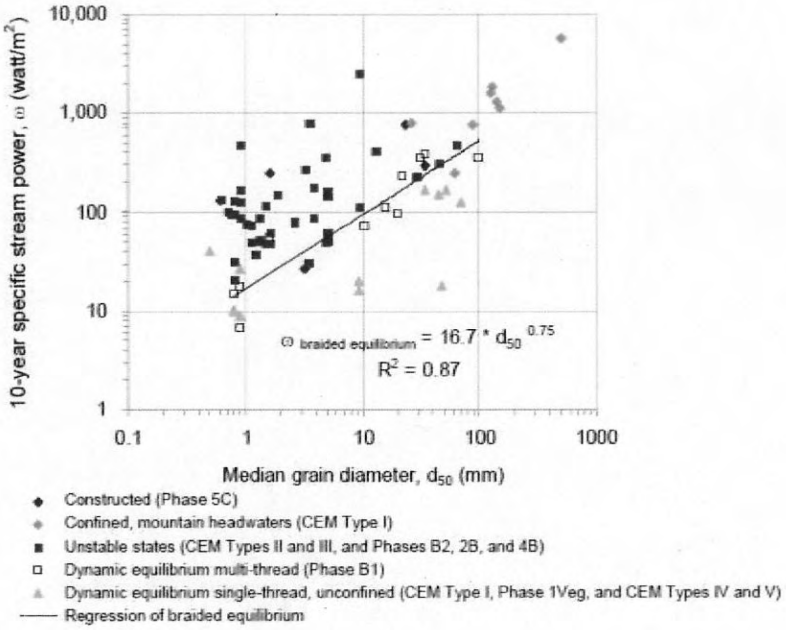

Figure B-1. Stability thresholds for channel types of southern CA, as identified through the development of a regional CEM (Hawley et al., in press).

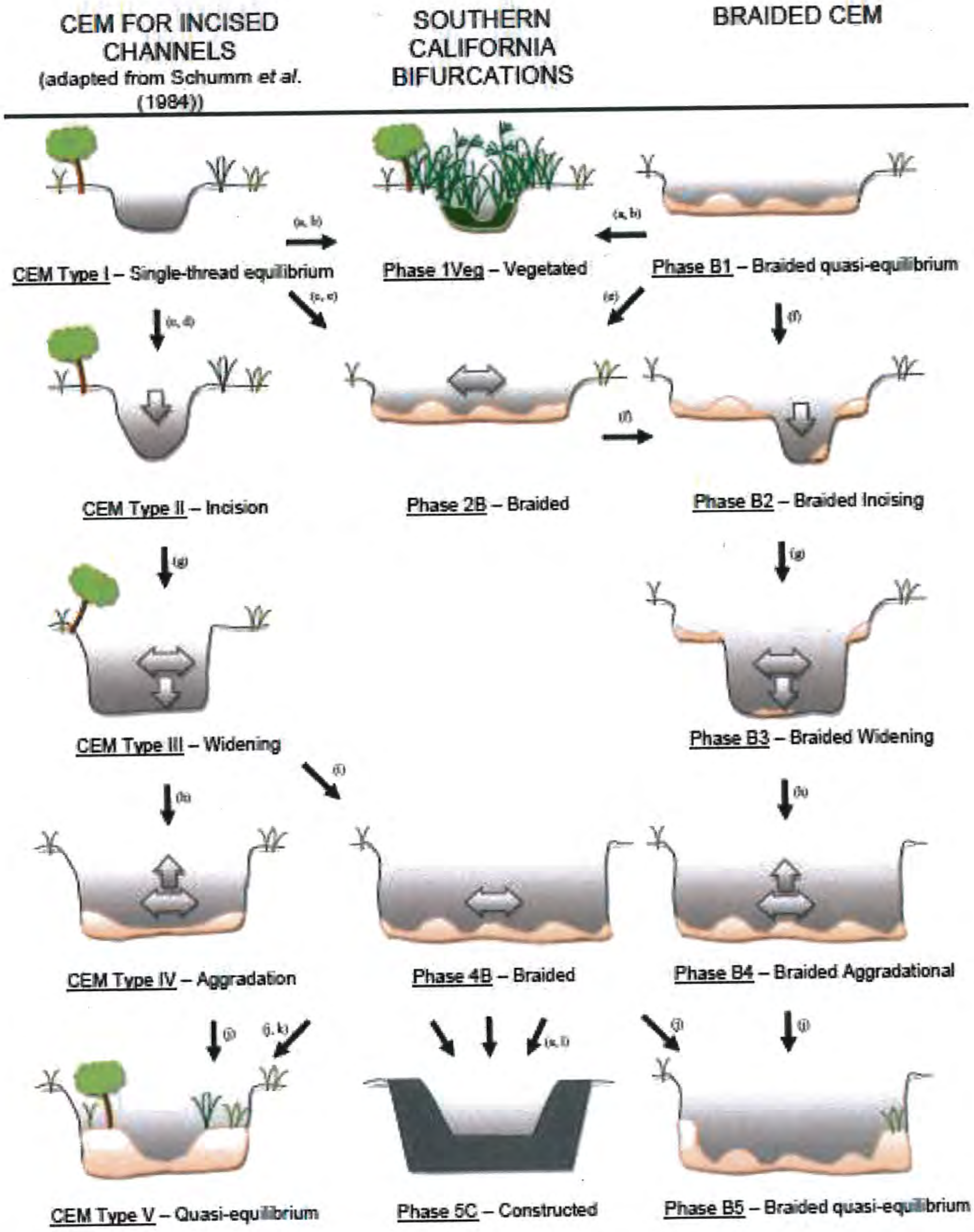

Figure B-2. Channel evolution model of response to hydromodification in southern California (Hawley et al. in press). Red and blue ovals highlight geomorphic thresholds that may be quantified using the baseline assessment suite of tools. By developing a general physical understanding of channel evolution sequences commonly observed in urbanizing watersheds of southern CA, two braiding thresholds and a bank stability threshold of management concern were identified. Channels may shift from single thread to braided planforms if widening is the dominant mode of initial adjustment. Alternatively, single thread channels may become braided after an initial period of incision that triggers geotechnical instability and failure of the banks. Quantitative predictors of these thresholds of braiding, incision, and bank failure can be developed in the baseline assessment process to evaluate the proximity of streams to these critical stages of channel evolution and instability.

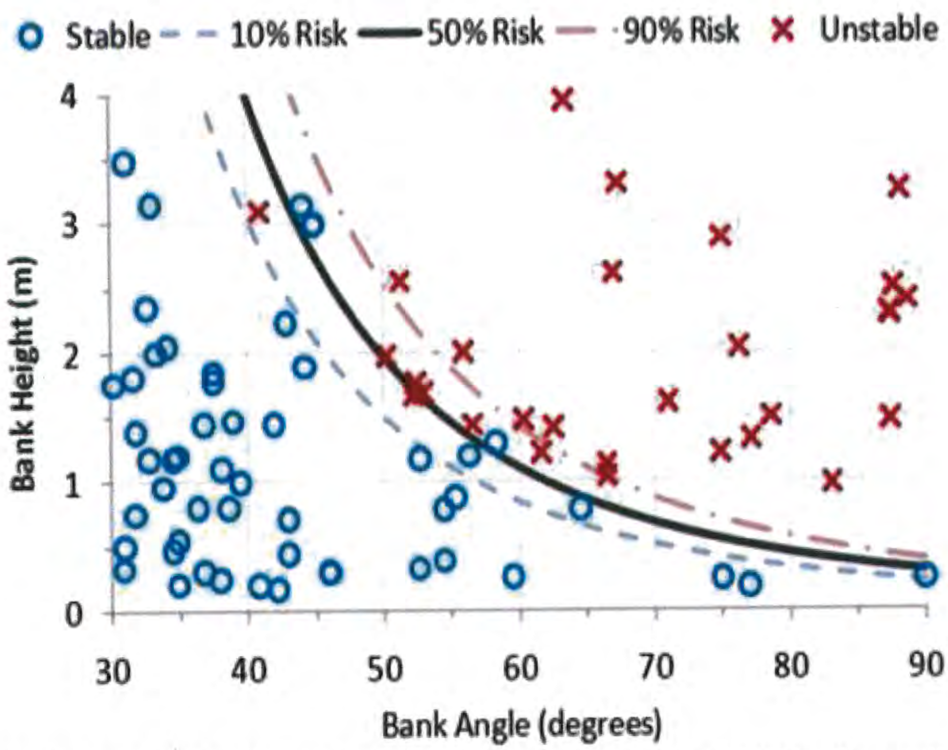

Figure B-3. Bank stability threshold for mass wasting identified through analysis of field data from southern California streams with stable and unstable banks (Bledsoe et al., in press).

2. **Channel-forming discharge suite of tools.** This suite of tools is designed to answer the following key questions:
   - What ranges of discharges are most influential in controlling channel form and processes over decadal time scales?
   - What channel-forming discharge should be used in sediment transport analyses to identify sediment transport capacity, equilibrium slope and geometry, etc.?

   The tools that comprise this suite include the following:
   - Effective discharge computations (e.g., Soar and Thorne 2001; Biedenharn et al. 2000; GeoTools – Bledsoe et al. 2007). An effective discharge analysis directly quantifies the range of discharges that transport the largest portion of the annual sediment yield over a period of many years.
   - Field identification of high water elevations, depositional surfaces, and "bankfull" features
   - Flood frequency analysis
   - Un-gauged site analysis (e.g. USGS StreamStats) http://water.usgs.gov/osw/streamstats/california.html; Hawley and Bledsoe (2011), regional flow duration curve extrapolation – Biedenharn et al. 2000)

This suite incorporates a number of parallel analyses that can be used to establish likely upper and lower bounds to the range of influential discharges, and that can be assessed through a weight-of-evidence evaluation. The following is an example output from the channel forming discharge suite of tools:

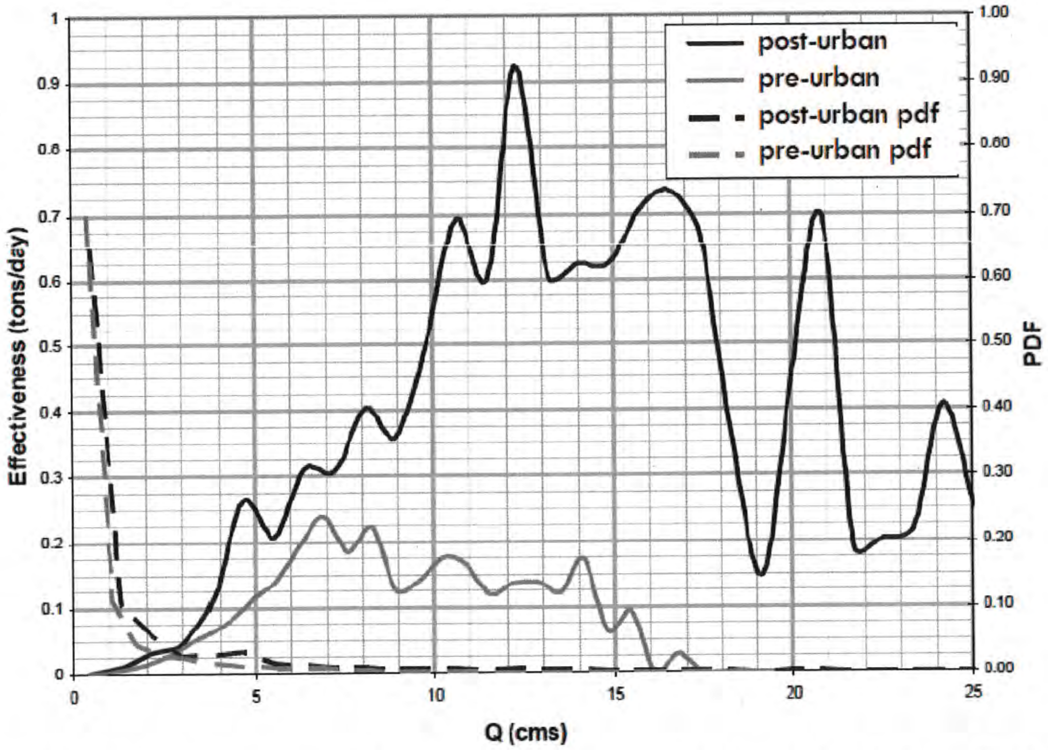

Figure B-4. Flow effectiveness curves for continuous series of pre-urban and post-urban discharges (Biedenharn et al. 2000; Bledsoe et al. 2007). Cumulative sediment yield is approximated by the area under the respective curves. If the stream bed is the most erodible channel boundary, the ratio of areas under these curves would be the erosion potential metric described below in the next suite of tools.

3. **Erosion potential suite of tools.** This suite of tools is designed to answer the following key questions:
   - How do proposed land-use changes or channel alteration affect the capacity of a channel to transport the *most erodible material in its boundary* over a period of many years (erosion potential – Ep)?
   - Do proposed mitigation approaches match the pre- vs. post- development erosion potential over the full spectrum of erosive flows?
   - Do past changes in erosion potential correspond to different states of channel stability and degradation in this region?
   - Does a proposed change in streamflow make it more likely that a channel will enter an alternative / degraded state?

The underlying premise of the erosion potential approach advances the concept of flow duration control (discussed in Chapters 2 and 3) by addressing in-stream processes related to sediment transport. An erosion potential calculation combines flow parameters with stream geometry to assess long term (decadal) changes in the sediment transport capacity. The cumulative distribution of shear stress, specific stream power and sediment transport capacity across the entire range of relevant flows can be calculated and expressed using an erosion potential metric, Ep (e.g., Bledsoe, 2002). This erosion potential metric is a simple ratio of post- vs. pre-development sediment transport capacity over a period of many years. The calculated capacity to transport sediment can be based on the channel bed material or the bank material, depending on which one is more erodible.

This Ep suite of tools has been applied in two primary ways:

a) At a project-level analysis, it has been applied to answer the first two questions above. A municipal stormwater permit may require a project design to achieve an erosion potential (Ep) value of 1.0. This means that a project must be designed so that the long-term erosion potential of the site's stormwater discharge is equal to the erosion potential of the pre-development condition. Section 3.1 below explains the process by which this analysis is conducted.
b) At a regional level, this suite of tools can be applied to answer the third and fourth questions above and to provide further guidance to project-level assessments. For example, practical engineering considerations generally require that a tolerance be permitted around a target design value. It is unlikely that a project design can match an Ep target of 1.0 across all conditions and through all stream reaches, due to variations in a multitude of contributing factors. The selection of an acceptable tolerance or variance from 1.0 is a management decision that should be informed by regional data presented in a risk-based format. Section 3.2 below explains how such a study has been conducted, using the Santa Clara Valley example from northern California.

3.1. *Project-Level Analysis.* As applied to the analysis of project impacts and mitigation design, the steps and associated tools that comprise this suite include the following (Figure B-5):

- Perform continuous simulation of hydrology (e.g. SWMM, HEC-HMS, HSPF) for the project site, for both pre-project condition and post-project condition with the proposed mitigation design.
- Convert discharges and field surveys to hydraulic parameters (shear stress and specific stream power) – e.g., for uniform flow analysis use Manning's equation, GeoTools; for varied flow analysis use HEC-RAS
- Convert hydraulic parameters into sediment transport capacity – e.g., at-a-station hydraulic geometry, HEC-RAS, GeoTools, sediment transport relationships (bedload and total load)
- Integrate Ep over time – e.g., GeoTools

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- Compare Ep values for pre-development and post development to determine if the proposed mitigation design is adequate. Adjust stormwater controls as necessary to meet target Ep.

Continuous Hydrologic Modeling ~ 3 decades
for Pre-development and Proposed conditions
(e.g. SWMM, HEC-HMS, HSPF)

↓

1. Perform hydraulic modeling to translate discharges from continuous simulations into shear stress, stream power, or other descriptors of sediment transport capacity
2. Calculate metrics of time-integrated sediment transport capacity relative to limiting channel boundary (e.g., GeoTools) for pre-development and proposed conditions

$$Ep = \frac{\int_{time} post - development\ transport\ capacity}{\int_{time} pre - development\ transport\ capacity}$$

↓

If Ep is not equal to 1.0 +/- allowed tolerance,
revise proposed mitigation design until target is met

Figure B-5: Steps involved in a project-level Erosion Potential analysis

3.2. *Risk-Based Regional Analysis*. Risk-based modeling estimates the probability of stream geomorphic states. Decision-makers can then choose acceptable risk levels based on an explicit estimate of prediction error. The foundation of risk-based modeling in the context of hydromodification management is the integration of hydrologic and geomorphic data derived from the output of continuous hydrologic simulation models to generate metrics describing expected departures in the most important stream processes. These physical metrics are provided as inputs to probabilistic models that estimate the risk of streams shifting to some undesirable state. Because the decision endpoint is often categorical (e.g., stable, good habitat) the statistical tools of choice are often logistic regression, classification and regression trees (CART), and/or Bayesian probability networks.

The steps below are used to develop a risk-based framework (Fig. B-6) for assessing how hydromodification may impact streams within a region, and for understanding the relationships between deviation from an Ep of 1.0 and the likelihood of channel instability. Illustrating figures are taken from a risk-based approach was used in the development of the Santa Clara Valley Urban Runoff Program Hydromodification Management Plan (www.SCVURPPP.org). This study demonstrated that a time-integrated index of erosion potential based on continuous hydrologic simulation and an assessment of stream power relative to the erodibility of channel boundary materials could be used to distinguish between channels of a particular regional type that are stable vs. degraded by hydromodification in urban watersheds.

- Perform project-level analysis as described in section 3.1 above for existing developments throughout the study watersheds.
- Perform stream surveys throughout the study watersheds to characterize condition (i.e., stable, unstable)
- Create statistical relationships between Ep and different channel states – e.g., logistic regression in R, SAS, Statistica, Minitab, etc. Note that standard regression techniques are applied when the dependent variable and the explanatory variables are quantitative and continuous. To analyze a binary qualitative variable (e.g., 0 or 1, stable or unstable, healthy or degraded) as a function of a number of explanatory variables, alternative techniques must be used. The regression problem may be revised so that, rather than predicting a binary variable, the regression model predicts a continuous probability of the binary variable that stays within 0–1 bounds. One of the most common regression models that accomplishes this is the logit or logistic regression model (Menard, 1995; Christensen, 1997).

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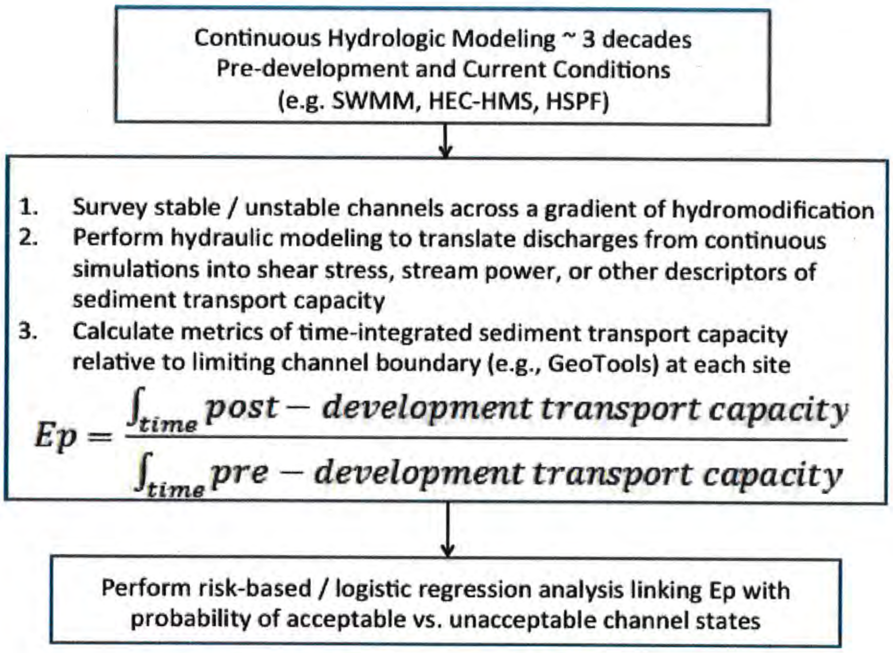

Figure B-6: Steps involved in a Risk-Based Erosion Potential analysis

The variables included in risk-based models of stream response are not limited to erosion potential. Additional multi-scale controls could be included. For example, simple categories of physical habitat condition and ecological integrity could be predicted by augmenting erosion potential metrics with descriptors of the condition of channel banks and riparian zones, geologic influences, floodplain connectedness, hydrologic metrics describing flashiness, proximity to known thresholds of planform change, and BMP types. Furthermore, although most of the emphasis to date has been on predicting geomorphic endpoints, the risk-based approach can be extended to the prediction of biological states in urban streams if the necessary data are available.

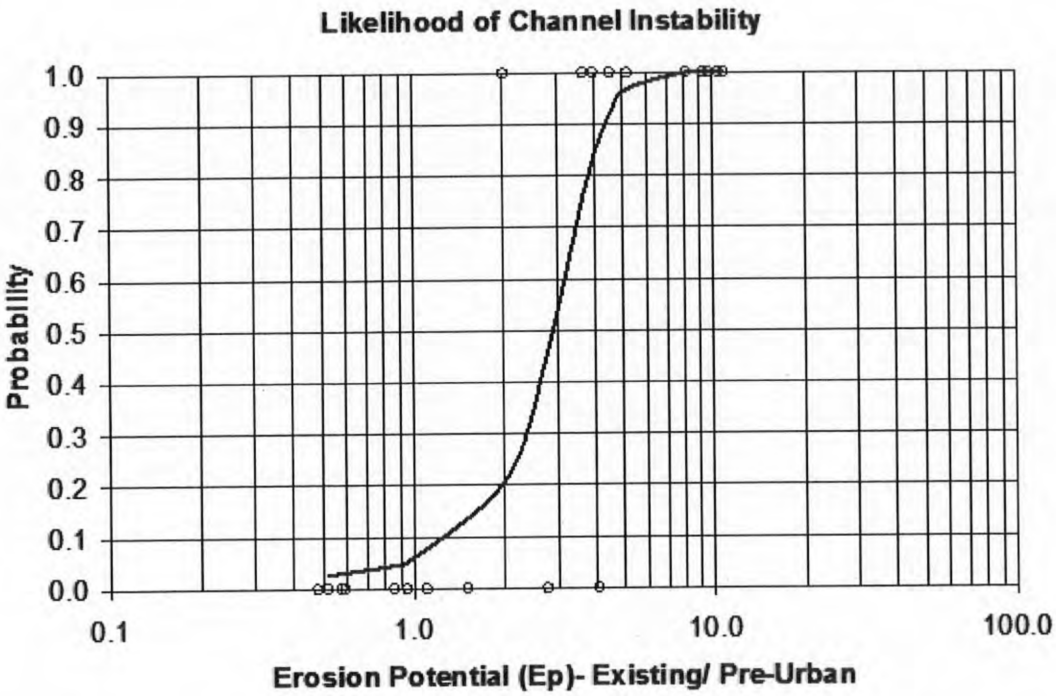

Figure B-7: Example of a logistic regression analysis of stable vs. unstable channels (Bledsoe and Watson, 2001; Bledsoe et al., 2007). The vertical axis represents the probability of stream instability which increases rapidly for channels with sediment transport capacity increased by urban hydromodification (Ep > 1).

3.3. *Strengths and Limitations.* The Erosion Potential approach combines a sound physical basis with probabilistic outputs and requires a substantial modeling effort. Such an effort is necessary to adequately characterize the effects of hydromodification on the stability of streams that are not armored with very coarse material such as large cobbles and boulders. Although policies based on this approach should reduce impacts to channel morphology, they may still fail to protect stream functions and biota. Key simplifying assumptions and prediction uncertainty in the inputs (hydrologic modeling, assumptions of static channel geometry in developing long term series of shear stresses or stream powers, assumptions of stationarity in sediment supply, etc.) have not been rigorously addressed. Its effectiveness also depends on careful stratification of streams in a region such that fundamentally different stream types are not lumped together (e.g. labile sand channels vs. armored threshold channels with grade control) in developing general relationships for instability risk. Endpoints to date have been rather coarse, e.g. stable vs. unstable; as such, they do not provide sufficient resolution for envisioning future stream states. However, the Erosion Potential approach provides promise as an important tool for hydromodification management; it is recommended that it be refined to address sediment supply changes and to provide more finely resolved endpoints for improved predictive capabilities.

4. **Sediment transport analysis suite of tools.** This suite of tools is designed to answer the following questions:
   - Do I need to incorporate sediment transport analysis in predicting channel response to hydromodification, i.e. what is the sensitivity of channel slope and geometry to inflowing sediment load?
   - At what discharges are different fractions of bed material mobilized in a particular stream segment?
   - What is inflowing sediment load to a stream segment, i.e. what is the water discharge Q(t) and sediment supply rate Qs(t) and grain size D(t) delivered to the upstream end of the channel segment of interest?
   - How will the available flow move the supplied sediment through the segment of interest?
   - What is the new equilibrium slope given some change in streamflow, and how much incision would be necessary to achieve this new slope?
   - What is the sediment transport capacity of the segment of interest *relative to* the inflowing sediment load from *upstream* supply reaches?
   - What is the sediment transport capacity of the segment of interest *relative to* the capacity of *downstream* reaches?
   - At the network scale, where are zones of low vs. high energy, aggradation vs. degradation potential, and coarse sediment constriction located?

   The primary tools that comprise this suite include the following:
   - Tools for estimating watershed sediment supply (Reid and Dunne 1996), including the RUSLE (Renard et al. 1997; http://www.ars.usda.gov/Research/docs.htm?docid=5971) and WEPP (Laflin et al. 1991; http://www.ars.usda.gov/Research/docs.htm?docid=10621) models.
   - Effective discharge analysis (see above)
   - Incipient motion analysis (tractive force, e.g. ASCE 2008; Brown and Caldwell 2011; Buffington and Montgomery 1998; Lane 1955a)
   - Sediment continuity analysis at single dominant discharge with an appropriate sediment transport relation – e.g., HEC-RAS, Bedload Assessment for Gravel-bed Streams (BAGS -Pitlick et al. 2009; GeoTools)
   - Equilibrium slope / geometry analysis e.g., HEC-RAS – Copeland et al. 2001, iSURF-NCED 2011)
   - Sensitivity to inflowing sediment load analysis e.g., Copeland's method in HEC-RAS, iSURF-NCED 2011)
   - Sediment continuity analysis over the entire flow frequency distribution e.g., Capacity-Supply Ratio of Soar and Thorne (2001), BAGS, GeoTools

- Network scale sediment balance – Sediment Impact Analysis Methods (SIAM) module in HEC-RAS

Movable bed / mobile boundary models also provide a mechanistic tool for estimating the trend and magnitude of changes in channel geometry due to hydromodification. However, a recent study evaluated the potential applicability of various movable bed and/or boundary models to streams in southern CA (Dust 2009), including HEC-RAS, CONCEPTS (Langendoen, 2000), and FLUVIAL 12 (Chang, 2006). The results of tests performed on urban streams in southern CA indicate that these models are difficult to apply and have high prediction uncertainty due to flows near critical, split flow conditions, and lack of fidelity to complex widening, bank failure, and armoring processes.

The following figures depict example outputs from an application of the sediment-transport suite of tools:

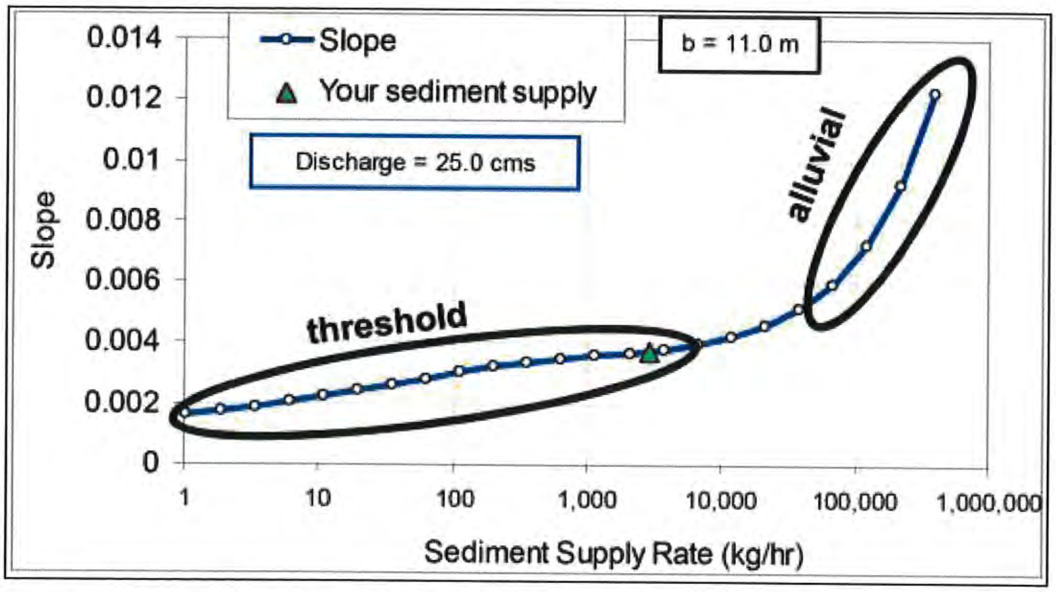

Figure B-8. Sensitivity analysis of equilibrium channel slope to inflowing sediment load (from iSURF, NCED 2011). Slopes of alluvial channels with high sediment supply are much more sensitive than threshold channels with relatively low sediment supply. Channels with beds composed of sand and fine gravels are generally much more geomorphically sensitive to hydromodification than threshold channels in which coarse bed sediments are primarily transported at relatively high flows.

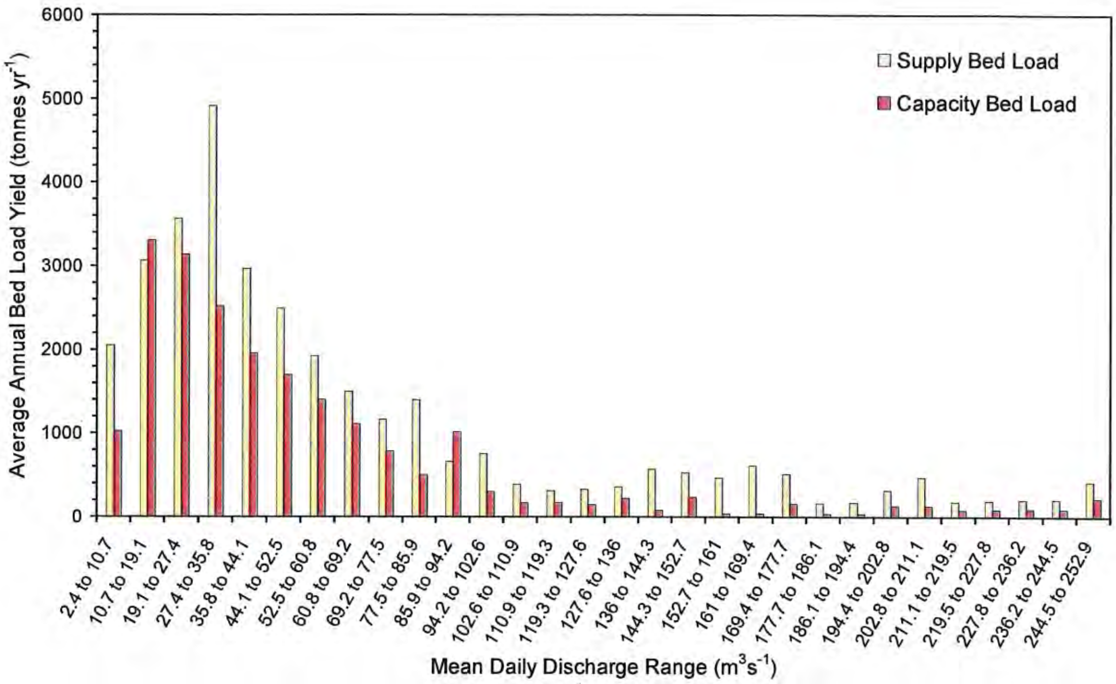

Figure B-9. Analysis of sediment transport capacity vs. inflowing sediment load over the full spectrum of stream discharges (capacity-supply ratio; Soar and Thorne 2001). In this case, the time-integrated capacity to transport bedload is 64% of the supplied bedload and significant aggradation is expected.

5. **Relationship to Management Framework**. These suites of tools could be applied to establish project-specific requirements for hydromodification assessment and mitigation, as recommended in the Management Framework presented in Chapter 3. In the example shown in the diagram below, results of the Baseline Assessment are used as a screening tool to assign high, moderate or low risk levels for stream reaches, in conjunction with the proposed land-use changes. Thus, the Baseline Assessment suite of tools is crucial in determining whether a detailed survey-level assessment and additional suites of tools are necessary for an adequate analysis. The need to apply additional suites of tools in formulating a management approach is commensurate with the level of risk and susceptibility of the stream. More complex and rigorous analysis with multiple suites of tools is necessary in predictive assessments for relatively susceptible stream types such as alluvial channels with sand beds.

   Although a stream may have relatively low susceptibility for overall geomorphic change, it may nevertheless have ecological attributes that are highly susceptible to hydromodification. Thus, suites of tools focused on both geomorphic and biological endpoints must be used to fully assess stream susceptibility to hydromodification. More work will be required to develop tools for prediction of biological response to flow alterations throughout California, as noted in Chapter 3 (see Poff et al., 2010 and http://conserveonline.org/workspaces/eloha).

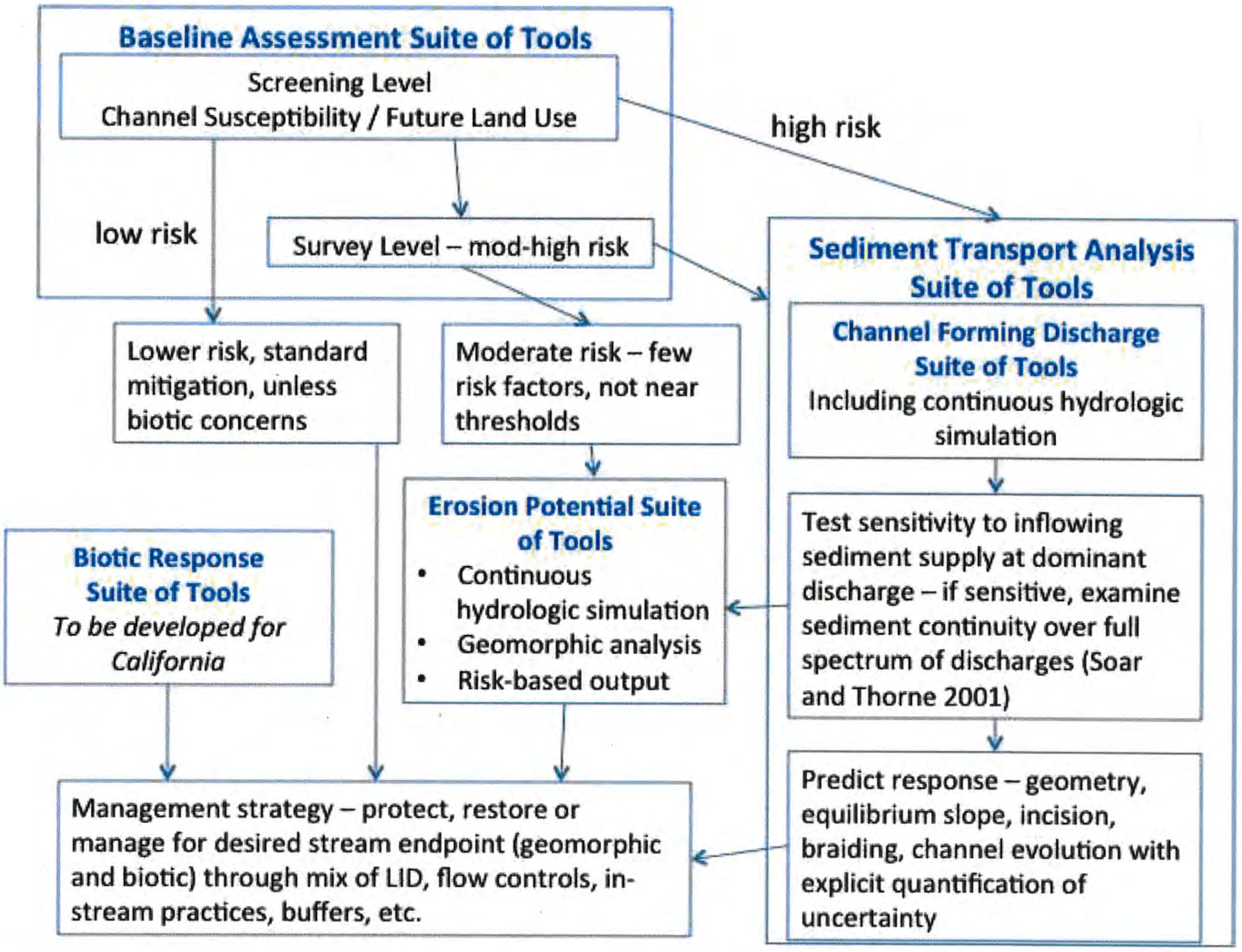

Figure B-10. Conceptual diagram showing relationships among the four suites of existing tools and biotic response tools to be developed in the future. Additional analyses will be required for engineering design.

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APPENDIX C: ADAPTIVE MANAGEMENT

WHAT IS ADAPTIVE MANAGEMENT

Adaptive management is a formalized approach for overcoming the inescapable difficulty in predicting ecological outcomes resulting from natural-resource management actions. It accomplishes this by treating all "management actions" (whether intentional or not) as experimental components within the larger structure of a monitoring program (Holling 1978, Walters 1986, Lee 1999, Ralph and Poole 2003). In other words, specific management actions that may affect ecological processes and functions are systematically evaluated, via "monitoring," to provide the data to affirm or refute the expected outcomes. To the extent that the monitoring results indicate a need to revise the scientific understanding or the management actions built on that understanding, establishing the mechanism to change management actions is a precursor, not an afterthought, of the monitoring program.

Adaptive Management was first articulated over 30 years ago (Holling, 1978) and more recently embraced through various conservation efforts worldwide. Fundamental to this approach is the integration of management and monitoring, recognizing that any management action in the context of a complex ecological system is ultimately experimental, requiring feedback to make progress.

The process of adaptive implementation is iterative and continuous; new knowledge is actively incorporated into revised experiments, a practice best described as "learning while doing" (Lee 1999). The key difference between this approach and other commonly implemented environmental management strategies is the application of scientific principles, such as hypotheses-testing,[is used] to explicitly define the relationships between policy decisions, management actions, and their measured ecological outcomes. Furthermore, this approach provides a means to understand and document these cause-and-effect relationships; it can also point to alternative actions that may produce more desirable outcomes. Uncertainty is embraced and serves as a focal point for defining ever-more specific evaluations.

Scientifically credible and relevant information can only be generated when the management "experiments" are designed with clear hypotheses about the effects of proposed actions or prescriptions. These hypotheses must be testable at multiple scales using available technology and methods (Conquest and Ralph 1998; Currens *et al.* 2000). Hypotheses that cannot be tested, are trivial (e.g., "water flows downhill"), are not credible ("water flows uphill"), or only account for site-specific conditions are not useful in considerations of the singular or cumulative effects of management actions.

In order to retain clear linkages between key questions, hypotheses, and monitoring protocols, the experimental approach must be designed before determining which goals and endpoints are appropriate (Ralph and Poole 2003) since appropriate goals should be *outcomes* of the effort, not a precondition; and the approach must explicitly tie stated hypotheses to the key ecological questions.

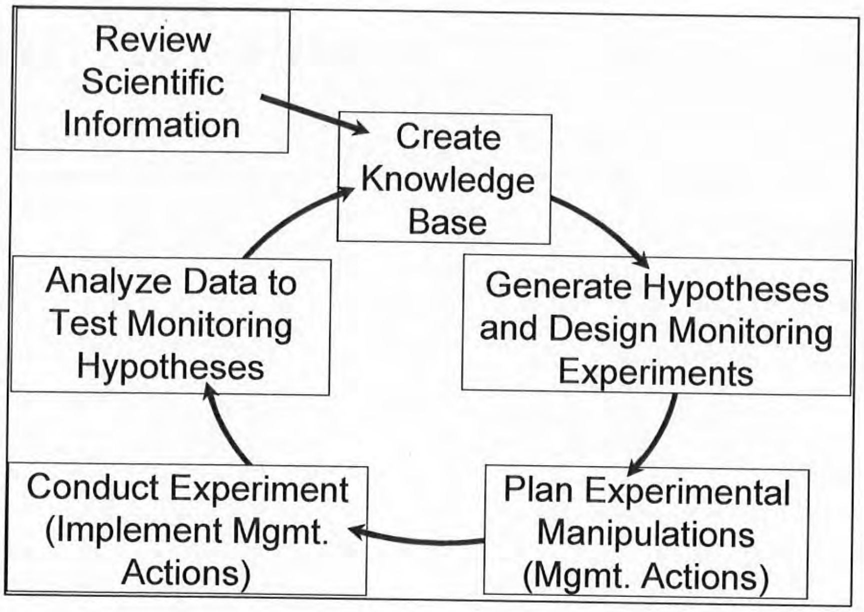

Figure A-1. Framework for an adaptive management program. The key feature of this cycle is the foundation of scientific principles and hypothesis generation; design of the management actions and the monitoring to evaluate their effects are integrated and designed to test assumptions, improve understanding, and reduce uncertainty (modified from Ralph and Poole 2003, Figure 3).

Wagner (2006) asserts that [stormwater] regulatory programs in the past often failed because they were designed in ways that ignored technological and scientific limitations. "Science-based" does not simply mean the monitoring of status and trends followed by responding to imposed benchmarks and goals, but rather that scientific principles must be the foundation of regulatory program design, and that these programs must rely on scientific methods to demonstrate results. Wagner suggests that regulations can still be designed despite incomplete or developing knowledge, but that gaps and limitations must be acknowledged and used to inform ongoing investigations. His argument clearly echoes those of scientists who insist that monitoring experiments and testable hypotheses must frame management decisions and land-use objectives.

WHAT IS *NOT* ADAPTIVE MANAGEMENT, AND WHY IS IT SO PROBLEMATIC?

Unlike the experimental approach embodied by adaptive management, an alternative process traditionally dominates in natural resource management: (1) a problem is identified, but a cause is simultaneously presumed (e.g., "increased sediment inputs into a stream are negatively impacting salmonid survival"); (2) a solution or set of solutions is proposed (e.g., timber harvest is restricted and riparian buffer width is increased), but the prescription is not translated into a testable hypothesis associated with the problem or question; and (3) if the problem is not solved within an arbitrarily reasonable period of time (e.g., a few years) then a different solution is proposed (e.g., "augmented upland and riparian restoration must be implemented"). Although simplified, this outline displays its divergence from adaptive management and from the basic principles of the scientific process—the resulting process is perpetually reactive.

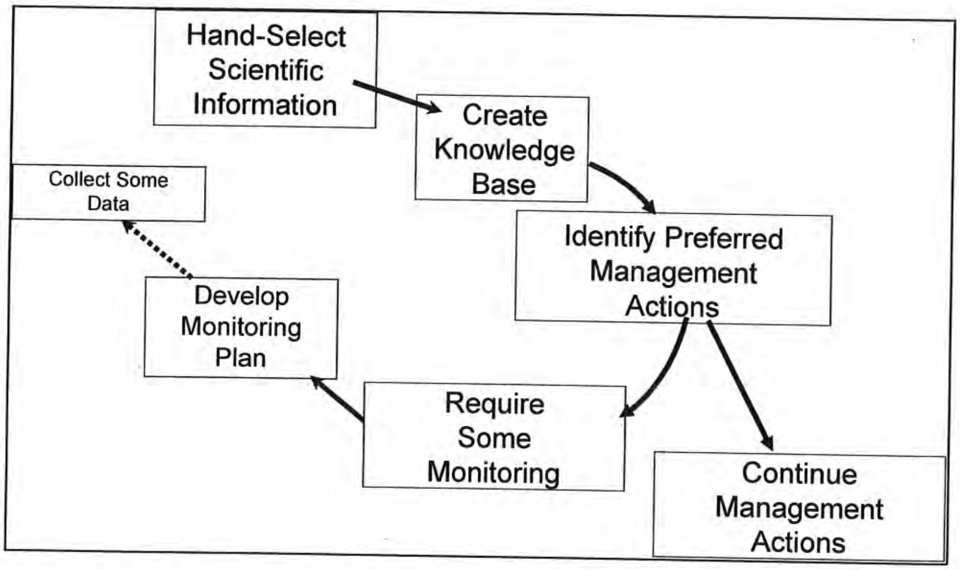

Figure A-2. Common framework for monitoring outside of an adaptive management structure. Management actions are chosen with a presumptive effect on ecological systems, and monitoring is conducted without any feedback to future actions. Even where monitoring is intended to "inform" future management actions, the absence of an explicit experimental design normally limits the utility of any monitoring data to provide meaningful insights.

In its best form, this paradigm has been termed passive adaptive management:

> Restoration planners' current management approach has been described as a "passive" adaptive management approach: science is used to

develop best-guess predictive models, make policies according to these models, and revise them as data become available. The National Academies advise that every effort be made to take a more "active" adaptive management approach by developing alternative hypotheses for the expected consequences of a particular project and then design the project so the hypotheses can be experimentally tested" (from the summary to *Adaptive Monitoring and Assessment for the Comprehensive Everglades Restoration Plan*, 2003, National Academies Press, 122 pp.).

Ralph and Poole (2003) have aptly named this approach "socio-political adaptive management" (i.e., SPAM).

BARRIERS TO IMPLEMENTING "ACTIVE" ADAPTIVE MANAGEMENT

Although the virtues of active adaptive management are readily articulated, the framework is surprisingly rare in practice. Some of these barriers are practical or logistical, and they include such issues as:

- Longevity and long-term institutionalization of monitoring;
- Effective data management systems that allow managers to readily access data;
- Ability to differentiate effects from natural variability and events, such as flood and fire;
- Cost and technical limitations of necessary data collection.

The most severe impediments, however, are not scientific but social: "We suggest that watershed-scale adaptive management must be recognized as a radical departure from established ways of managing natural resources if it is to achieve its promise... Adaptive management encourages scrutiny of prevailing social and organizational norms and this is unlikely to occur without a change in the culture of natural resource management and research" (Allan et al. 2008).

While science can provide defensible and replicable insights regarding the ecological outcomes of management prescriptions, it cannot offer absolute certainty. Policy can be and should be informed by science but is ultimately based on a variety of considerations that are not always amenable to the spatial, temporal, and technological limitations of the scientific process (Van Cleave et al. 2004). This is an uncomfortable truth for agency managers and elected officials to acknowledge, and it commonly results in funding decisions and public pronouncements using the "language" of science but not its substance.

Although efforts to build large, collaborative programs are commonly characterized by increasing stakeholder involvement and outreach, greater participation does not necessarily mean that true adaptive management is occurring, or that scientific principals are being applied to either the choice of management actions or their evaluation. These efforts, however, do reflect a movement to extend natural resource management decision-making processes beyond just technical experts in order to reflect evolving social values (Pahl-Wostl *et al.* 2007). If they are successful, this approach can open a path to achieving the best of both realms, namely scientific rigor with a broad base of community support.

ATTRIBUTES OF USEFUL HYPOTHESES FOR AN ADAPTIVE MANAGEMENT PROGRAM

A key element of any adaptive management approach is the set of hypotheses that guide both the management actions and their associated monitoring. Because these management actions are recognized as "experimental" (because in a complex system most outcome(s) cannot be predicted with absolute certainty), their selection must be guided by assumptions about what *might happen,* or what is *expected* to happen. This defines the first attribute of a useful hypothesis: it is **credible**, typically because it is based on prior knowledge or scientific understanding of the system. Indeed, some hypotheses may already be so well evaluated and understood (e.g., "Stormwater runoff from freeways carries measurably elevated concentrations of toxic pollutants") that there is little point in framing them in this structure at all—as new monitoring programs to address such hypotheses are highly unlikely to result in new information or knowledge and might be perceived as an unwise expenditure of scarce monitoring resources.

The second attribute of a useful hypothesis stems from the scientific reality that any experiment, whether conducted in the laboratory or across the landscape, provides value only insofar as its outcomes are measured and the effects are distinguishable from the influence of other, unrelated factors. Thus, the hypothesis that guides the experiment should not only be credible but also **testable**. Otherwise, why bother making measurements at all?

Lastly, these actions and measurements and analyses do not occur in a vacuum. Thus, the final guiding principle for any hypothesis in an adaptive management approach is that it be **actionable**, or that different outcomes, as revealed by monitoring, can (and will) result in different management responses. If no difference occurs, then clearly there is no reason to have made the effort in the first place.

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Experience From Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection?

C.R. MacRae[1]

Abstract

The increase in runoff rate and volume associated with urbanization has been related to accelerated rates of geomorphic activity often resulting in the destabilization and adjustment of the stream channel. Stormwater Management ponds have been constructed to control instream erosion potential based on the 1:2 year frequency post- to pre-development peak flow shaving concept. An alluvial channel downstream of such a facility was monitored for flow and assessed using a geomorphic survey. The hours of exceedance of geomorphically significant mid-bankfull flows increased by 4.2 times after 34% of the basin had been urbanized. The channel is in adjustment and it has enlarged by as much as 3 times pre-development bankfull cross-sectional area. Theoretical analyses of the magnitude and transverse distribution of excess boundary shear stress indicated that despite operation of the facility, erosion potential in the mid-bed increased by 2.4 pre-development values under existing land use conditions. These data are supported by observations from 7 streams downstream of similar facilities in Surrey, British Columbia. The need for a multi-criterion concept based on discharge and boundary material characteristics and a 2-dimensional approach is evident. An alternate design criteria based on a zero net change in the transverse distribution of shear stress about a channel perimeter using an erosion index method is proposed.

[1]Senior Technical Specialist, Aquafor Beech Limited, 132 Ontario Street, Kingston Ontario, K7L 2Y4

Introduction

Urbanization can lead to an increase in both r
can be translated into an increase in instream erosion
adjustment in channel form (Leopold, 1968; Hammer,
Narramore, 1985; Neller, 1988; Booth, 1990). To n
Stormwater Management (SWM) policies have been d
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In this study, the effectiveness of an existing
urbanizing area on Morningside Tributary in Markham,
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Urbanization And Channel Morphology

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Introduction

Urbanization can lead to an increase in both runoff volume and rate which can be translated into an increase in instream erosion potential and a concomitant adjustment in channel form (Leopold, 1968; Hammer, 1972; Graf, 1975; Allen and Narramore, 1985; Neller, 1988; Booth, 1990). To mitigate against this impact, Stormwater Management (SWM) policies have been developed based on control of the post-development peak flow rate of the 1:2 year frequency design storm event to pre-development conditions. This is achieved through the design of facilities with sufficient storage volume and control of the outflow rate to provide the required degree of attenuation. This approach is referred to as the Zero Runoff Increase (ZRI) criteria (control does not apply to runoff volume).

In Canada, millions of dollars have been spent and thousands of SWM ponds have been built to control instream erosion potential based on the ZRI concept. While the incorporation of erosion control measures into SWM policy represents a significant step forward in the management of urban water resources, the ZRI criteria has meet with limited success and may actually aggravate erosion hazard (McCuen, 1979, McCuen and Moglen, 1988; Lorant, 1983 and 1988; MacRae, 1993). The lack of success of this approach has been attributed to the use of peak flow rate in a single criterion design approach (Whipple et al., 1981; McCuen and Moglen, 1988) and the lack of consideration of the frequency and duration of flows and boundary material sensitivity to scour (McCuen and Moglen, 1988; MacRae and Rowney, 1992).

In this study, the effectiveness of an existing ZRI facility located in an urbanizing area on Morningside Tributary in Markham, Ontario is assessed in terms of the change in instream erosion potential and the stability of the receiving channel. Alteration in channel morphology is explained using a theoretical analysis of instream erosion potential based on a 2-dimensional erosion index approach (MacRae, 1991). Results from this case study are compared to survey results fo stream channels located downstream of similar peak flow shaving facilities in Surrey, British Columbia.

Urbanization And Channel Morphology

The effect of land use alteration, such as the urbanization of a basin, on the flow regime may be generalized as a change in the natural storage of a catchment (McCuen, 1979). This alteration may lead to an increase in both runoff volume and rate with an associated increase in erosion potential. Although Hollis and Luckett (1976) and Leopold (1973) reported studies to the contrary, most case studies have shown that channels tend to enlarge following urbanization (Savini and Krammerer, 1961; Hammer, 1972; Allen and Narramore, 1985; Lee and Ham, 1988; MacRae et al., 1994). Morisawa and LaFlure (1979) observed that channel cross-sectional form begins to enlarge after 20 to 25% of the basin achieve more then 5% impervious cover with channel enlargement increasing rapidly to 5 to 7 times pre-

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development channel cross-sectional area after complete development of the basin. Similarly, Booth and Reinelt (1993) reported that bank de-stabilization began after about a 10% increase in average basin imperviousness. Schueler (1995) noted that these findings were supported by fisheries habitat studies. The demarcation between stable and unstable channels after an increase in basin imperviousness of approximately 10%, indicates that a threshold may exist after which morphological change in cross-section and planimetric form will occur in the receiver. This threshold also appears to be relatively low, indicating that most streams channel systems are highly sensitive to a perturbation in the prevailing sediment-flow regime.

The Importance of Bank Materials and Mid-Bankfull Flows

Sediment transport and erosion potential increase in a non-uniform, but directly proportional manner with flow depth and hence flow rate (Leopold et al., 1964; Vanoni, 1975). Using the product of the flow frequency and sediment transport rate functions, Leopold et al., (1964) generated an effective work curve with a maximum value corresponding to a bankfull stage which recurs on average once every year to once every two years. They noted, however, that the range of geomorphically significant flows lie between the lower limit of competence and an upper limit established as those flows which are no longer contained within the active channel. A compilation of studies by Hollis (1975) showed that the increase in runoff rate due to urbanization is non-uniform such that the increase in flood frequency diminishes with return period. MacRae and Rowney (1992) demonstrated that this non-uniformity causes the maximum point on the effective work curve to shift toward the mid-bankfull events - those events that occur less then once in every year, but are above the level of competence. Consequently, mid-bankfull events are the events which do the most work in urban streams and an erosion control philosophy which does not adequately address this shift in the effective work curve may not satisfactorily meet the intended purpose.

In addition, channel banks are often composed of stratified, heterogeneous materials with the basal stratigraphic unit typically being the least resistant to scour (Klimek, 1974; Andrews, 1982; and, Thorne and Lewin, 1982). Maintenance of a stable channel form, consequently, is strongly related to the sensitivity of the basal layer to a disturbance in the flow regime (Thorne and Tovey, 1981; Harvey et al., 1979; Knighton, 1987; MacRae and Rowney, 1992). Consequently, a 1-dimensional analyses based on average flow rate may be less indicative of the streams ability to do work in terms of the erosion of intact boundary materials than a 2-dimensional approach (MacRae, 1991), and stream power (τv: the product of shear stress (τ) and mean flow velocity (v)), may be more significant than discharge alone (Knighton, 1987).

Basis For The 1:2 Year Erosion Control Approa

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Surrey, British Columbia Data

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Basis For The 1:2 Year Erosion Control Approach

Urban Stormwater Management (SWM) consists of a set of Best Management Practices (BMPs) which are applied, primarily in new urban developments, as a means to 'protect' the environment from detrimental impacts which have been associated with traditional urban forms and drainage practices. Leopold (1968) noted that the increase in the magnitude and frequency of flows due to urbanization could be compensated through storage controls such that the flows experienced by the channel downstream of the facility could be maintained within the range of flows experienced prior to development of the tributary area. It was also observed that a stream channel will develop a form sufficient to convey, without overflow, a discharge with a recurrence interval of 1.5 to 2 years and that this flow is in accord with the bankfull stage. This work was influential in developing the ZRI concept which was adopted as the basis for instream erosion control in Ontario and many other jurisdictions across Canada.

The ZRI concept, however, is a generic rather then case specific design procedure (the same criteria apply to all watersheds and stream channels regardless of size and boundary material composition), with flow as the single criterion for design based on a single flow rate (1:2 year event). Further, it does not address the increase in the frequency of mid-bankfull to bankfull flows, the increase in duration of high flow rates caused by attenuation within the storage facility or the sensitivity of the boundary materials in the receiving channel to erosion (McCuen, 1979; Lorant, 1983; McCuen and Moglen 1988; MacRae, 1994). The increase in flow frequency and duration was shown to result in an increase in sediment transport potential by McCuen and Moglen (1988) and Lorant (1988), who noted that this was sufficient to cause enlargement of the channel. Despite these concerns, numerous erosion control facilities continue to be constructed based on this hydrologic criteria.

Surrey, British Columbia Data

Lee and Ham, (1988) surveyed 30 reaches totalling 6.6 km of channel through both urban and rural streams (with and without ZRI control) in the District of Surrey, British Columbia. Using the rural streams to represent a stable, pre-development baseline condition, they concluded that stream channel width increased on average by 1.7 times the pre-development value for urbanized watersheds without erosion control facilities. They also concluded that channel widening, although reduced, still occurred in those streams urbanized with erosion control facilities in place.

Seven of the subwatersheds from the 1985 study were re-surveyed in 1988 along reaches immediately downstream of ZRI facilities to determine boundary material characteristics and sensitivity to scour. These observations indicate that these facilities maintained pre-development channel width in one case (Enver Creek), with various degrees of success for the remain 6 channels. The ratio of

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post- to pre-development channel width was found to range from $1.63 \leq (W_R) \leq 3.8$ (the average value exceeds the value reported above for urban streams without erosion controls). The parameter, W_R was found to be correlated with the strength of the least resistant, bank toe stratigraphic unit (MacRae and Rowney, 1992). These results imply that additional storage control is required as the sensitivity of the basal unit to scour increases and that erosion control criteria should include a measure of sensitivity of channel boundary materials to an increase in erosion potential. The District is currently undertaking a review of their drainage policy with respect to their erosion control criteria (Paul Ham, 1996 pres. comm.).

Morningside Creek Case Study

Morningside Tributary, drainage area 21.4 km^2, is a subwatershed of the Rouge River, a valuable cold water fishery within the Greater Toronto Area. The lower portion of the Tributary basin is fully developed and the headwater portion, drainage area 10 km^2, is currently 34% developed. The remaining 66% of the headwater area is planned for development under a mix of residential, light industrial and commercial land uses. Stormwater Management for the existing development within the headwater area, which is primarily medium to high density residential, consists of a 2 centralized, detention facilities (the North and South Ponds: Figure 1). These facilities were designed for flood and erosion control with the later based on the ZRI approach.

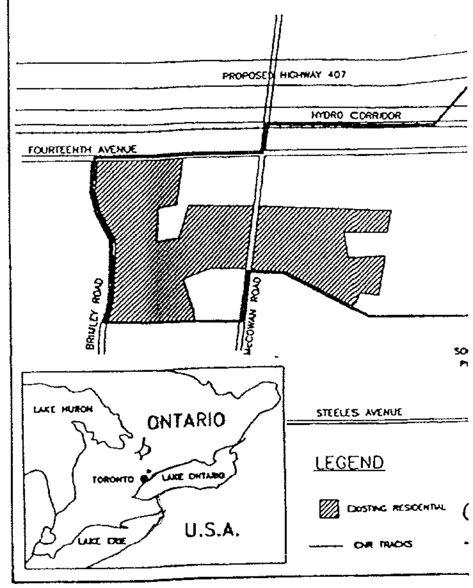
Erosion problems within the headwater area of the Tributary, which sustained a resident population of brook trout prior to urbanization, lead to concern with regard to the stability of the channel and its impact on the Rouge River. Two of the primary objectives of this study were to: gain insight into the sensitivity of the system to an alteration in the mechanisms controlling channel form; and, evaluate the success of the ZRI facility in terms of controlling instream erosion.

The Study Area

The watershed occupies areas of the Peel Plain and South Slopes physiographic regions characterized by the silty sand deposits of the Leaside Till overlaying inter-bedded lacustrine sands and silty clays (Chapman and Putnam, 1984). Approximately 80% of the soils consist of the Millikan and Woburn loams (Hoffman and Richards, 1955), which have imperfect to good drainage characteristics, respectively. The balance of the area is covered with Peel Clay soils. The topography is characterized as gently rolling upland plain.

Upper Morningside Tributary is a misfit stream which is moderately entrenched in the Leaside Till. Prior to development, tributaries upstream of the North Pond consisted of rills and gullies leading to an intermittent channel which ended at the farmer's ford approximately 0.6 km downstream of the North Pond (Figure 1). Upstream of the North Pond these tributaries are now sewered or

FIGURE 1. UPPER MORNINGSIDE TRIBUTARY EXISTING LAND USE



channelized and the channel between the No
flows perennially. Downstream of the ford, b
year by groundwater inputs with two springs
The channel from the North Pond to Steels
length, is referred to as the upper Morningside
defines the limits of the study area (Figure 1)

A silty sand alluvial soil covers the
layers of silt, cross-bedded sand and fine
bedding structure) exists beneath the recent all
was observed at the farmer's ford. Vegetation
bottomland forest which generally increase i
disturbance downvalley. Currently sediment
majority of the tributary area is limited due to
the pond. Silt, clay and detritus is prevalent fo
control facility indicating that a supply of fine
and into the study reach. Sediments, primarily
within the valley through erosion of the
where the active channel is in contact with th

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annel width was found to range from $1.63 \leq (W_R) \leq 3.8$ the value reported above for urban streams without neter, W_R was found to be correlated with the strength toe stratigraphic unit (MacRae and Rowney, 1992). litional storage control is required as the sensitivity of eases and that erosion control criteria should include a hannel boundary materials to an increase in erosion rrently undertaking a review of their drainage policy n control criteria (Paul Ham, 1996 pres. comm.).

udy

ry, drainage area 21.4 km^2, is a subwatershed of the ld water fishery within the Greater Toronto Area. The ry basin is fully developed and the headwater portion, currently 34% developed. The remaining 66% of the for development under a mix of residential, light land uses. Stormwater Management for the existing dwater area, which is primarily medium to high density centralized, detention facilities (the North and South ilities were designed for flood and erosion control with approach.

within the headwater area of the Tributary, which ion of brook trout prior to urbanization, lead to concern of the channel and its impact on the Rouge River. Two f this study were to: gain insight into the sensitivity of n in the mechanisms controlling channel form; and, ZRI facility in terms of controlling instream erosion.

cupies areas of the Peel Plain and South Slopes acterized by the silty sand deposits of the Leaside Till custrine sands and silty clays (Chapman and Putnam, % of the soils consist of the Millikan and Woburn loams 1955), which have imperfect to good drainage y. The balance of the area is covered with Peel Clay soils. rized as gently rolling upland plain.

e Tributary is a misfit stream which is moderately Till. Prior to development, tributaries upstream of the lls and gullies leading to an intermittent channel which approximately 0.6 km downstream of the North Pond he North Pond these tributaries are now sewered or

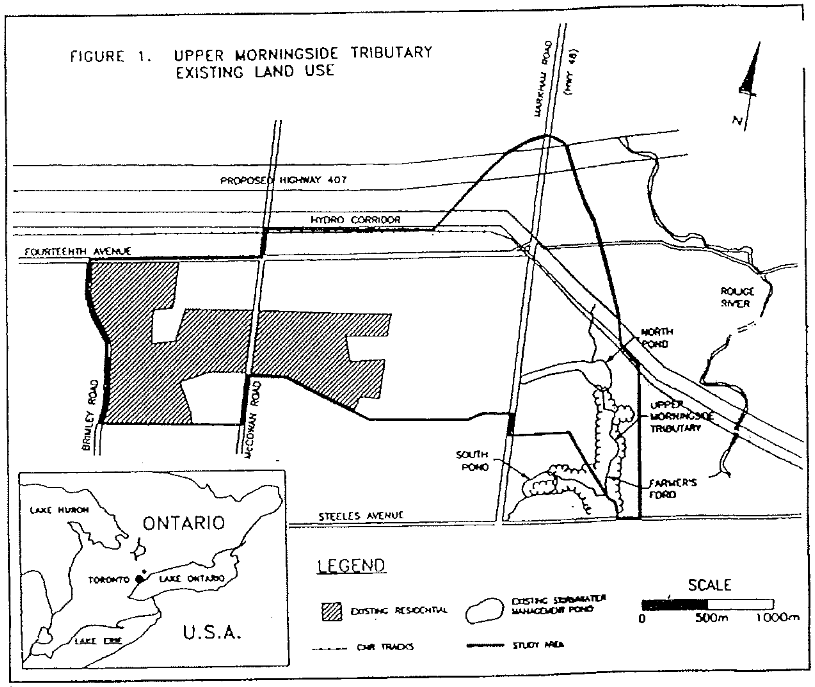

FIGURE 1. UPPER MORNINGSIDE TRIBUTARY EXISTING LAND USE

channelized and the channel between the North Pond and the farmer's ford now flows perennially. Downstream of the ford, baseflow is maintained throughout the year by groundwater inputs with two springs located at the west side of the ford. The channel from the North Pond to Steels Avenue, approximately 1.3 km in length, is referred to as the upper Morningside Tributary and this length of channel defines the limits of the study area (Figure 1).

A silty sand alluvial soil covers the valley bottom which is underlain by layers of silt, cross-bedded sand and fine gravel. A deposit of sand (massive bedding structure) exists beneath the recent alluvium and a layer of grey stoney clay was observed at the farmer's ford. Vegetation within the valley consists of slope and bottomland forest which generally increase in density and decrease in degree of disturbance downvalley. Currently sediment supply to the study reach from the majority of the tributary area is limited due to the settling of coarse particulates in the pond. Silt, clay and detritus is prevalent for a 100 m stretch downstream of the control facility indicating that a supply of fine sediment is passing through the pond and into the study reach. Sediments, primarily in the sand size fraction, are supplied within the valley through erosion of the active channel and the floodplain banks where the active channel is in contact with the valley wall.

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Study Methodology

Geomorphic surveys were conducted in the summers of 1993 and 1994 and a flow monitoring station was established at the pond outlet and operated continuously over the above 2 year period. The study reach was divided into 5 Response Segments (RSs) based on their sediment transport potential, the nature of local sediment sources, and 'like' morphological characteristics and processes (Figure 2).

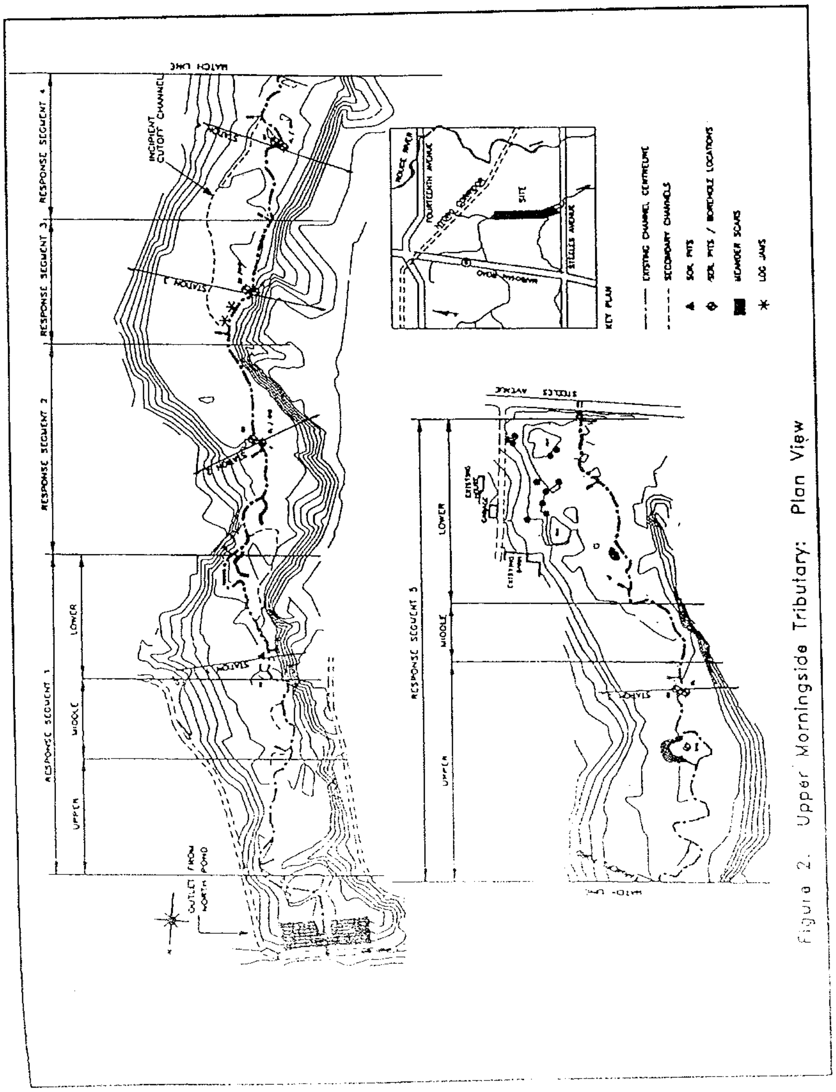

Figure 2. Upper Morningside Tributary: Plan View

Within each RS, channel form variable representative reach to characterize: planimetric for amplitude, pool-riffle sequence, and bar forms), lc geometry (channel and valley cross-sections alon; between meander bends); hydrologic characteristic: roughness coefficient, primary flow velocity); bounda stratification and material composition, critical shear substrate composition (particle size analyses of bar for alluvium) and substratum composition (particle size c materials or bed armour beneath the loose alluvia accounts of riparian vegetation. Rates of geomorphi fluvial forms, such as transient bars, paleofluvial meander features, comparison of historic longit photographs, erosion pin data, and empirical relatio Collective consideration of these data provided insig of the system given a change in the driving mechani

Baseline Geomorphic State

The interpretation of observed morphologica unstable channel environment, differ between RSs due the hydraulic affect of Large Organic Debris (LOD) j of coarse sediment, niche points, pre-development relative erodability of the bed and bank materials. . processes and morphological response are presented i collectively, however, morphological evidence sugge: upper Morningside Tributary is currently unstable an in form or adjustment is pending.

Erosion pins (1.0 m in length) were installed mid-bank locations at two sites, E2 (RS 1) and E3 (Figure 3). Results from the monitoring of these si reported in Table II. High rates of bed and bank eros where a niche point, which is migrating upstream h: pin locations. A moderate rate of downcutting and a reported at site E3. The lower rate of downcutting is flow resistance due to LODs within the channel an coarse sediment originating in RS 3. The high rate of increase in shear stress at the bank toe due to greater flows against the banks by LODs accumulating with of the channel in April 1995 noted that enlargement the complete removal of all six pins.

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vere conducted in the summers of 1993 and 1994 and was established at the pond outlet and operated 2 year period. The study reach was divided into 5 ed on their sediment transport potential, the nature of 'like' morphological characteristics and processes

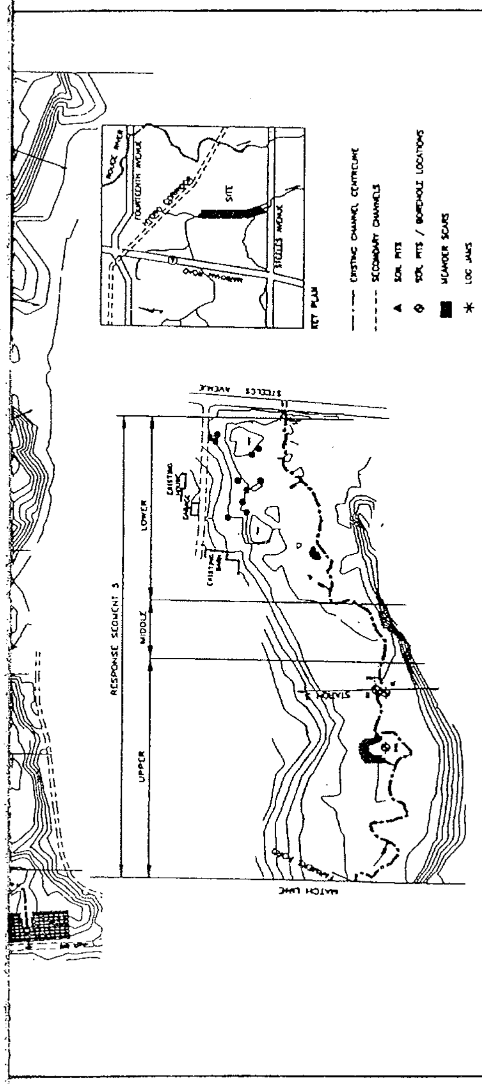

Figure 2. Upper Morningside Tributary: Plan View

Within each RS, channel form variables were collected along representative reach to characterize: planimetric form (meander wavelength a amplitude, pool-riffle sequence, and bar forms), longitudinal profile; hydraulic geometry (channel and valley cross-sections along straight channel segments between meander bends); hydrologic characteristics (discharge rate, Manning's roughness coefficient, primary flow velocity); boundary material composition (bank stratification and material composition, critical shear stress (by stratigraphic unit), substrate composition (particle size analyses of bar forms and non-descriptive, loose alluvium) and substratum composition (particle size characteristics of the intact bed materials or bed armour beneath the loose alluvial deposits); and, descriptive accounts of riparian vegetation. Rates of geomorphic activity were inferred from fluvial forms, such as transient bars, paleofluvial investigations of abandoned meander features, comparison of historic longitudinal profiles and oblique photographs, erosion pin data, and empirical relations published in the literature. Collective consideration of these data provided insight into the evolutionary path of the system given a change in the driving mechanisms.

Baseline Geomorphic State

The interpretation of observed morphological features, which indicate an unstable channel environment, differ between RSs due to changes in valley gradient, the hydraulic affect of Large Organic Debris (LOD) jams, significant local sources of coarse sediment, niche points, pre-development hydraulic geometry, and the relative erodability of the bed and bank materials. A summary of the dominant processes and morphological response are presented in Table I for each RS. Taken collectively, however, morphological evidence suggest that the entire length of the upper Morningside Tributary is currently unstable and either undergoing a change in form or adjustment is pending.

Erosion pins (1.0 m in length) were installed in the mid-bed, bank toe and mid-bank locations at two sites, E2 (RS 1) and E3 (RS 5) in the spring of 199 (Figure 3). Results from the monitoring of these sites over a 1 year period are reported in Table II. High rates of bed and bank erosion were observed at site E2 where a niche point, which is migrating upstream has come to within 5 m of the pin locations. A moderate rate of downcutting and a high rate of basal scour were reported at site E3. The lower rate of downcutting is attributed to: the increase in flow resistance due to LODs within the channel and an increase in the influx of coarse sediment originating in RS 3. The high rate of basal scour is attributed to an increase in shear stress at the bank toe due to greater flow depths and deflection of flows against the banks by LODs accumulating within the channel. An inspection of the channel in April, 1995 noted that enlargement of the channel had resulted in the complete removal of all six pins.

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Table I Summary of Morphological Erosion Index Analyses

REACH/ STATION	COMMENT	EROSION PIN EXPOSURE (cm)
RS 1 (E2)	Entrenched due to the upstream migration of niche point - rate of downcutting decreasing - high influx of coarse sediment - banks have widened due to basal scour - geomorphic activity declining	BED = 13 TOE = 14 BNK = 29
RS 2	Aggrading due to backwater from LOD jam in RS 3 - banks saturated and failing through mass wasting and basal scour - cutoff channel forming at LOD jam - moderate rate of geomorphic activity	
RS 3	Cutoff at u/s end has isolated RS 3 from flow increase - this is balanced by a low sediment load immediately d/s of the LOD - channel temporarily stable - influx of sand in middle segment from erosion of valley wall causing aggradation.	
RS 4	Flow energy reduced by cutoff at LOD jam in RS 3 - sediment supply from RS 3 has created aggrading condition - low rate of geomorphic activity but high rates pending failure of LOD	
RS 5 (E3)	Entrenched - rate of downcutting diminishing due to a high sediment load and the hydraulic effect of local LODs - high rate of basal scour causing bank failure through oversteepened -aggravated by deflection of flows against banks by LOD jams	BED = 3 TOE = 16 BNK = -1

RS = Response Segment; E2 & E3 are erosion pin stations; BED, TOE and BNK refer to the mid-bed region and the basal and mid-bank stratigraphic units respectively.

Changes in longitudinal profile between 1993 and 1994 also indicate that the channel is in a period of adjustment (Figure 3). Due to differences in survey protocol between the two years, only elevation differences over successive riffle sections can be interpreted as morphologic change. These data indicate that degradation is actively occurring in RS 1 between Stations 200 and 240 due to the upstream migration of a niche point and valley formation. Aggradation is also occurring in RS 2 between Stations 480 and 590 due to the backwater affect of the LOD jam. Aggradation is also occurring in RS 3 (Stations 640 to 700) due to the bypass of high flows through the cutoff at the LOD jam and a significant influx of coarse sediment from basal erosion of the valley wall. Aggradation observed in RS 4

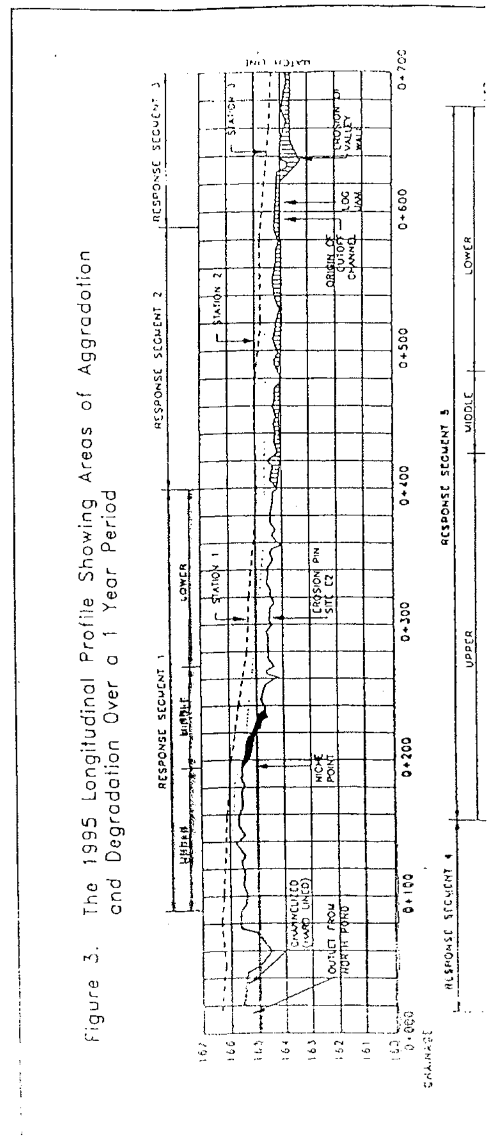

Figure 3. The 1995 Longitudinal Profile Showing Areas of Aggradation and Degradation Over a 1 Year Period

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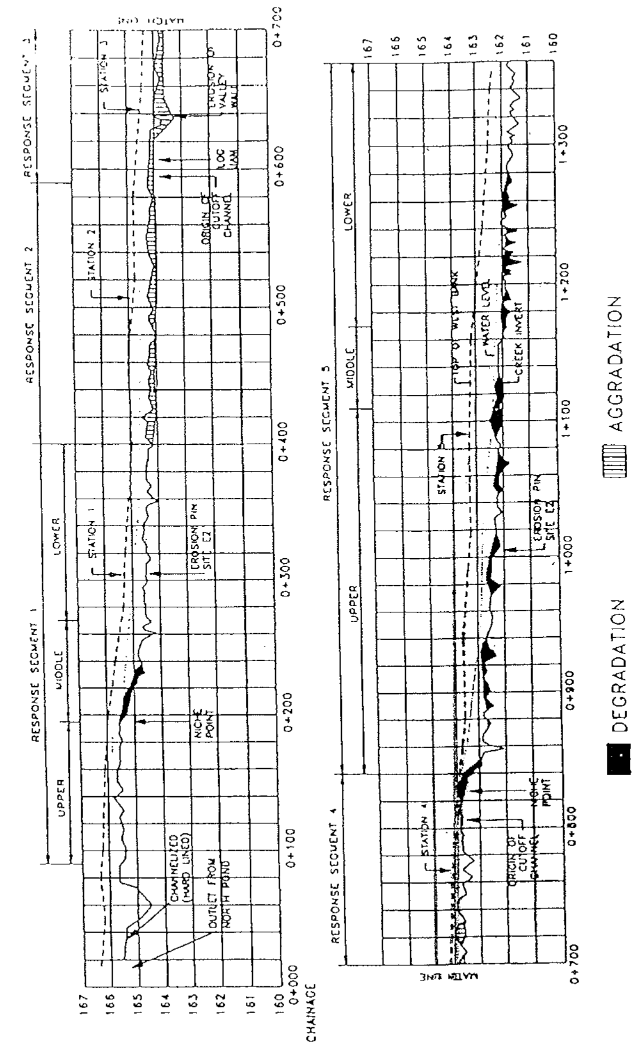
phological Erosion Index Analyses

COMMENT	EROSION PIN EXPOSURE (cm)
due to the upstream migration of niche f downcutting decreasing - high influx of nent - banks have widened due to basal - geomorphic activity declining	BED = 13 TOE = 14 BNK = 29
e to backwater from LOD jam in RS 3 - ed and failing through mass wasting and - cutoff channel forming at LOD jam - erate rate of geomorphic activity	
end has isolated RS 3 from flow increase iced by a low sediment load immediately D - channel temporarily stable - influx of dle segment from erosion of valley wall causing aggradation.	
reduced by cutoff at LOD jam in RS 3 - upply from RS 3 has created aggrading ow rate of geomorphic activity but high rates pending failure of LOD	
rate of downcutting diminishing due to a nt load and the hydraulic effect of local n rate of basal scour causing bank failure rsteepened -aggravated by deflection of ws against banks by LOD jams	BED = 3 TOE = 16 BNK = -1

& E3 are erosion pin stations; BED, TOE and BNK refer to the basal and mid-bank stratigraphic units respectively.

nal profile between 1993 and 1994 also indicate that the adjustment (Figure 3). Due to differences in survey years, only elevation differences over successive riffle d as morphologic change. These data indicate that rring in RS 1 between Stations 200 and 240 due to the he point and valley formation. Aggradation is occurring 30 and 590 due to the backwater affect of the LOD jam. ng in RS 3 (Stations 640 to 700) due to the bypass of off at the LOD jam and a significant influx of coarse n of the valley wall. Aggradation observed in RS 4

Figure 3. The 1995 Longitudinal Profile Showing Areas of Aggradation and Degradation Over a 1 Year Period



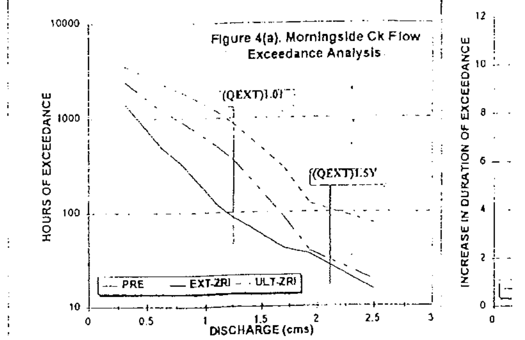
RB-AR35374

Table II Summary of Morphological Erosion Index Analyses

REACH/ STATION	COMMENT	EROSION PIN EXPOSURE (cm)
RS 1 (E2)	Entrenched due to the upstream migration of niche point - rate of downcutting decreasing - high influx of coarse sediment - banks have widened due to basal scour - geomorphic activity declining	BED = 13 TOE = 14 BNK = 29
RS 2	Aggrading due to backwater from LOD jam in RS 3 - banks saturated and failing through mass wasting and basal scour - cutoff channel forming at LOD jam - moderate rate of geomorphic activity	
RS 3	Cutoff at u/s end has isolated RS 3 from flow increase - this is balanced by a low sediment load immediately d/s of the LOD - channel temporarily stable - influx of sand in middle segment from erosion of valley wall causing aggradation.	
RS 4	Flow energy reduced by cutoff at LOD jam in RS 3 - sediment supply from RS 3 has created aggrading condition - low rate of geomorphic activity but high rates pending failure of LOD	
RS 5 (E3)	Entrenched - rate of downcutting diminishing due to a high sediment load and the hydraulic effect of local LODs - high rate of basal scour causing bank failure through oversteepened -aggravated by deflection of flows against banks by LOD jams	BED = 3 TOE = 16 BNK = -1

RS = Response Segment; E2 & E3 are erosion pin stations; BED, TOE and BNK refer to the mid-bed region and the basal and mid-bank stratigraphic units respectively.

(Stations 700 to 790) is associated with the lower energy environment created by the diversion of flows, as noted above, and the movement of the sediment wave from RS 3 through this reach. The behaviour of RS 5 is as noted above for site E3. While the behaviour of the five RSs appears to be highly variable, aggradation in RS 2, 3, and 4 is a temporary phenomena linked to the life expectancy of the LOD jam in RS 3. Failure of the LOD, headcutting of the cutoff channel or upstream migration of the niche point in RS 5 will eventually result in the degradation of these reaches. Consequently, the overriding process within all segments is characteristic of valley formation. The complex response of the channel system also serves to illustrate the need for a geomorphic interpretation of the fluvial forms and processes operating within the channel system.



Exceedance Analyses

QUALHYMO (Rowney and MacRae, [illegible] simulation model developed for the planning leve[illegible] in urbanizing watersheds, was setup and calibrat[illegible] 1994) at the pond outlet. The model was used to [illegible] a one hour time step based on Atmospheric Envir[illegible] temperature records reported for L.B. Pearson Inte[illegible] the time step of one hour were considered appro[illegible] watersheds being modelled and the amount of fl[illegible] The fit between predicted and observed flow ra[illegible] Flows under ultimate development conditions [illegible] fraction of impervious area in the model. All oth[illegible] same.

An exceedance analyses of the 5 year per[illegible] change in the duration of time in which the flow [illegible] flow rates. This exercise was applied to pre-develo[illegible] land use characteristics with the existing ZRI faci[illegible] ultimate land use scenario with the ZRI pond (UL[illegible] of events in the mid-bankfull ((Q_{EXT})[illegible]=1.24 m[illegible] 10 times pre-development levels for existing [illegible] respectively (Table III; Figure 4(B)). A smaller in[illegible] for bankfull flow ($(Q_{EXT})_{5Y}$=2.[illegible] m[illegible]s) was [illegible] significant alterat[illegible] in the flow regime has [illegible] flows in the mid-bankfull flow range. This [illegible] current classification of the channel system as [illegible] aggravated under [illegible] land use [illegible].

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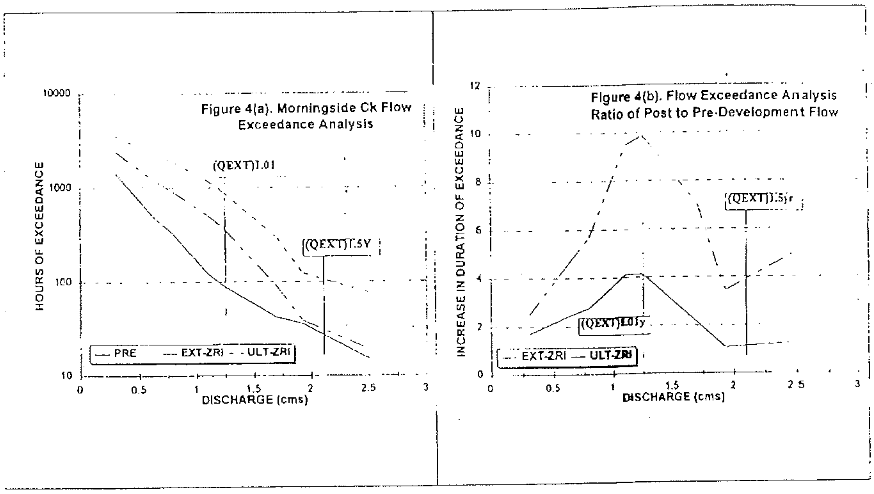
phological Erosion Index Analyses

COMMENT	EROSION PIN EXPOSURE (cm)
ue to the upstream migration of niche downcutting decreasing - high influx of nt - banks have widened due to basal geomorphic activity declining	BED = 13 TOE = 14 BNK = 29
to backwater from LOD jam in RS 3 - l and failing through mass wasting and cutoff channel forming at LOD jam - ate rate of geomorphic activity	
d has isolated RS 3 from flow increase ed by a low sediment load immediately - channel temporarily stable - influx of e segment from erosion of valley wall causing aggradation.	
duced by cutoff at LOD jam in RS 3 - ply from RS 3 has created aggrading w rate of geomorphic activity but high es pending failure of LOD	
te of downcutting diminishing due to a load and the hydraulic effect of local ate of basal scour causing bank failure teepened -aggravated by deflection of against banks by LOD jams	BED = 3 TOE = 16 BNK = -1

E3 are erosion pin stations; BED, TOE and BNK refer to e basal and mid-bank stratigraphic units respectively.

iated with the lower energy environment created by ed above, and the movement of the sediment wave The behaviour of RS 5 is as noted above for site E3. e RSs appears to be highly variable, aggradation in phenomena linked to the life expectancy of the LOD LOD, headcutting of the cutoff channel or upstream n RS 5 will eventually result in the degradation of , the overriding process within all segments is on. The complex response of the channel system also a geomorphic interpretation of the fluvial forms and channel system.



Exceedance Analyses

QUALHYMO (Rowney and MacRae, 1991), a continuous hydrologic simulation model developed for the planning level design and evaluation of BMPs in urbanizing watersheds, was setup and calibrated to observed flows (1993 and 1994) at the pond outlet. The model was used to generate a 5 year time series at a one hour time step based on Atmospheric Environment Service precipitation and temperature records reported for L.B. Pearson International Airport. These data and the time step of one hour were considered appropriate given the size of the sub-watersheds being modelled and the amount of flow routing created by the Pond. The fit between predicted and observed flow rates was considered to be good. Flows under ultimate development conditions were obtained by adjusting the fraction of impervious area in the model. All other parameter values remained the same.

An exceedance analyses of the 5 year period was undertaken to assess the change in the duration of time in which the flow series exceeded a set of specified flow rates. This exercise was applied to pre-development conditions (PRE), existing land use characteristics with the existing ZRI facility in place (EXT-ZRI), and the ultimate land use scenario with the ZRI pond (ULT-ZRI; Figure 4(A)). The duration of events in the mid-bankfull ($(Q_{EXT})_{1.01YR}$=1.24 m^3s^{-1}) flow range increased by 4 and 10 times pre-development levels for existing and ultimate land use conditions respectively (Table III; Figure 4(B)). A smaller increase in the hours of exceedance for bankfull flow ($(Q_{EXT})_{1.5YR}$=2.1 m^3s^{-1}) was also noted. These data indicate that a significant alteration in the flow regime has occurred, particularly with respect to flows in the mid-bankfull flow range. This increase in flows is consistent with the current classification of the channel system as unstable and this state will be aggravated under future land use conditions.

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Table III Hours Of Exceedance For The $Q_{1.01YR}$ and $Q_{1.5YR}$ Flow Rates

RI (yrs)	Q_{EXT} (m^3s^{-1})	EXCEEDANCE (hours)		
		PRE	EXT-ZRI	ULT-ZRI
1.01	1.24	90	380	900
1.5	2.1	30	34	120

RI = Recurrence Interval; Q_{EXT} = Existing Flow Rate; PRE, EXT and ULT refer to pre-development, existing and ultimate land use; ZRI = 1:2 year peak flow shaving facility

Instream Erosion Potential

To assess instream erosion potential (E_S), a comparative approach was adopted wherein indices of E_S for the pre-development condition were adopted as a baseline to determine the relative impact of a land use alteration and the effectiveness of the ZRI facility. Paleofluvial techniques were used to reconstruct an historic meander scar which was used to approximate pre-development E_S channel form. This procedure assumes that the cross-section and planimetric geometry of the meander scar is in equilibrium with land use conditions and the associated flow-sediment regimes circa 1950.

An index of E_S is defined in the SHEAR1 command in QUALHYMO as:

$$(\Delta E_S)_P = \left[\int \left(f(q_S)_o - (q_S)_I\right)_{POST} dt \; - \; \int \left(f(q_S)_o - (q_S)_I\right)_{PRE} dt\right]_P$$

in which $(\Delta E_S)_P$ is the change in instream erosion potential at point P about the channel perimeter, q_S is the sediment transport potential, the subscripts I and O stand for Input and Output from the control reach and POST and PRE represent post- and pre-development land use conditions respectively (MacRae, 1994).

The SHEAR 1 command requires: data describing cross-section and planimetric geometry; and, critical shear stress (τ_{cr}) and shear stress as a function of flow depth for each boundary station. Critical shear stress was determined based on the physical properties of the material within each bank stratigraphic unit and the intact bed materials. Shear stress versus flow depth relations were based on minimizing the error between predicted and observed flow and the average boundary shear stress computed by the model for 10 stations about the channel perimeter and average boundary shear stress ($\tau = \gamma RS$). Using this approach, E_S was then determined for the meander scar and each RS at the representative cross-

sections for the PRE, EXT-ZRI, and ULT-ZRI
period. This technique allows for the assessme
for channels formed in stratified, heterogeneo
dimensional manner.

It has been established that sediment tr
of erosion potential (Vanoni, 1975; Simons
action of the sediment-water mixture is the d
al., 1964; Simons and Li, 1982; Harvey and W
of the relation for q_S were applied including th
and DuBoys bed load transport functions (Ma
relations were found to produce similar resu
defined below was adopted for this analysis,

$$(q_s)_P = \left[a(\tau_o - \tau\right.$$

in which a is a coefficient (given the compara
is the instantaneous shear stress, and ν is the

The results of the analysis are presente
stations (results are not presented for the BN
Data in Table III report the *erosion index rat*
each representative cross-section over $(E_S)_{BED}$
ULT-ZRI conditions. A value of $R_{ES(BED)}$=1 i
back to pre-development levels. Assuming the
stable, this would indicate that further enla
minimal. The ratio, however, was found to
implying that enlargement is still occurring. T
the April, 1995 inspection.

The complexity of dealing with a chan
be simplified by using the pre-development
the change in erosion potential. Flows for PRE
were used to determine E_S at the meander scar
the *erosion index ratio* wherein $R_{ES(BED)}$=2.4 for
ZRI conditions These data are consistent wi
ratio ($1.29 \le R_E \le 2.94$), which is defined as post-
cross-section area at bankfull stage (Table II
development flows also indicate that enlargem

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ance For The $Q_{1.01YR}$ and $Q_{1.5YR}$ Flow Rates

EXCEEDANCE (hours)		
PRE	EXT-ZRI	ULT-ZRI
90	380	900
30	34	120

$_{r}$ = Existing Flow Rate; PRE, EXT and ULT refer to pre-
mate land use; ZRI = 1:2 year peak flow shaving facility

rosion potential (E_S), a comparative approach was $_S$ for the pre-development condition were adopted as relative impact of a land use alteration and the ity. Paleofluvial techniques were used to reconstruct hich was used to approximate pre-development E_S re assumes that the cross-section and planimetric r is in equilibrium with land use conditions and the mes circa 1950.

ined in the SHEAR1 command in QUALHYMO as:

$$q_S)_o-(q_S)_I\big)_{POST}dt \;-\; \int\big(f(q_S)_o-(q_S)_I\big)_{PRE}dt\Big]_P$$

e in instream erosion potential at point P about the sediment transport potential, the subscripts I and O rom the control reach and POST and PRE represent nd use conditions respectively (MacRae, 1994).

mand requires: data describing cross-section and ritical shear stress (τ_{crit}) and shear stress as a function ary station. Critical shear stress was determined based the material within each bank stratigraphic unit and ar stress versus flow depth relations were based on en predicted and observed flow and the average ted by the model for 40 stations about the channel ary shear stress (τ=ρgRS). Using this approach, E_S was ander scar and each RS at the representative cross-

sections for the PRE, EXT-ZRI, and ULT-ZRI conditions for the 5 year simulation period. This technique allows for the assessment of E_S about both the bed and bar for channels formed in stratified, heterogeneous boundary materials in a pseudo -dimensional manner.

It has been established that sediment transport potential serves as a measure of erosion potential (Vanoni, 1975; Simons and Li, 1982) and that the shearing action of the sediment-water mixture is the dominant erosion process (Leopold et al., 1964; Simons and Li, 1982; Harvey and Watson, 1986). Various explicit forms of the relation for q_S were applied including the Meyer-Peter Muller, stream power, and DuBoys bed load transport functions (MacRae, 1991). In this application these relations were found to produce similar results, consequently, stream power as defined below was adopted for this analysis,

$$(q_s)_P = \left[a(\tau_o-\tau_{crit})\bar{v}\right]_P$$

in which *a* is a coefficient (given the comparative approach *a* was set to unity), τ_o is the instantaneous shear stress, and v is the average primary flow velocity.

The results of the analysis are presented in Table III for the BED and TOE stations (results are not presented for the BNK station for which $(E_S)_{BNK} \ll (E_S)_{TOE}$). Data in Table III report the *erosion index ratio* ($R_{ES(BED)}$), expressed as $(E_S)_{BED}$ for each representative cross-section over $(E_S)_{BED}$ at the meander scar for EXT-ZRI and ULT-ZRI conditions. A value of $R_{ES(BED)}$=1 indicates that (E_S) has been reduced back to pre-development levels. Assuming the pre-development channel form to be stable, this would indicate that further enlargement of the channel would be minimal. The ratio, however, was found to be $1.25 \le R_{ES(BED)} \le 2.76$ for EXT-ZRI implying that enlargement is still occurring. This prediction was confirmed during the April, 1995 inspection.

The complexity of dealing with a channel system that is in adjustment can be simplified by using the pre-development channel as a basis for comparison of the change in erosion potential. Flows for PRE, EXT-ZRI and ULT-ZRI conditions were used to determine E_S at the meander scar. Results were expressed in terms of the *erosion index ratio* wherein $R_{ES(BED)}$=2.4 for EXT-ZRI and $R_{ES(BED)}$=4.6 for ULT-ZRI conditions. These data are consistent with the magnitude of the enlargement ratio ($1.29 \le R_E \le 2.94$), which is defined as post- divided by pre-development channel cross-section area at bankfull stage (Table II). Flood frequency analysis of pre-development flows also indicate that enlargement of the channel has occurred.

Table IV. Summary of E_S And Hydraulic Geometry Data

PARAMETER		RESPONSE SEGMENT CROSS-SECTION NUMBER					
		1	2	3	4	5	SCAR
W_{BFL} (m)		6.36	5.31	4.70	3.50	6.40	4.70
D_{BFK} (m)		0.53	0.40	0.65	0.44	0.89	0.58
A_{BFL} (m^2)		3.50	5.15	2.83	2.25	5.00	1.75
Q_{BFL} (m^3/s)		2.9	3.2	2.34	1.25	6.05	1.36
R_E[1]		2.0	2.94	1.62	1.29	2.86	1.00
$R_{ES(BED)}$[2]	EXT[3]	2.25	1.57	1.25	1.57	2.76	2.41
	ULT[3]	4.38	4.10	1.67	2.41	6.10	4.58
$R_{ES(TOE)}$	EXT	0.98	1.00	2.74	1.28	10.11	1.00
	ULT	12.17	1.00	7.55	5.82	45.71	1.00

1. RE is the enlargement ratio expressed as the post- to pre-development bankfull channel area; 2. R_{ES} is the ratio of E_S at the RS cross-section to E_S at the meander scar under pre-development conditions and TOE and BED refer to the basal stratigraphic and mid-bed regions of the channel respectively; 3. EXT and ULT are the existing and ultimate land use scenarios with the 1:2 year peak flow shaving facility in place.

Bankfull flow, which ranges from $3 \leq RI \leq 10$ years, exceeds that reported by Leopold et al., (1964) and Leopold (1968) for natural, stable channels. The exception was RS 4 (RI=1.6 years), where isolation from the increase in high flows due to the cutoff channel in RS 3, small cross-section profile and broad, flat floodplain along with high boundary material resistance to scour have combined to minimize the degree of impact on this RS. Under ULT-ZRI conditions the enlargement ratio, $1.67 \leq R_{ES(BED)} \leq 6.10$, indicates that further enlargement will occur despite operation of the ZRI facility.

Alternate Erosion Control Design Criteria

The change in E_S, the comparison of longitudinal profiles, an exceedance analysis of frequent flow events, a geomorphic survey and erosion pin data were used to demonstrate that progressive enlargement of Upper Morningside Tributary is occurring despite the presence of a ZRI facility. Secondly, the degree of enlargement is consistent with streams which have no stormwater controls. These data support similar observations from Surrey B.C., qualitative observations reported by many municipalities and other studies reported in the literature which conclude

that the ZRI concept has not satisfied the intent
methods must be considered. Whipple et al., (1
be made so that the aggregate erosional effec
greater than that prescribed to a known stable s
be achieved through provision of additional de
required for flood control. This concept, referre
was demonstrated using a 1-dimensional di
transport capacity by McCuen and Moglen (198
pond was reduced until the computed post-de
approached the pre-development level. In
represented an 85% reduction in post-developme
1:2 year peak flow rate. Balancing pre- and
based on average hydraulic parameters may n
because of the heterogeneous and stratified na
It is important to understand, consequently, ho
resistance to disruption are distributed about t
Rowney, 1992).

Based on the importance of flow rate an
Moglen (1988) proposed a policy which stat
cannot exceed the pre-development amount for
flow event (assuming the pre-development c
Erosion, however, is an on-going although hig
structure is an important consideration in the c
to a disturbance. MacRae (1991) proposed an e
(1988) design criteria wherein channel erosion
transverse distribution of erosion potential abou
constant with pre-development values, over the
the channel is just able to move the dominant
criteria resulted in the development of an approa
Control (DRC; MacRae, 1994). A form of this
the preferred methodology for erosion contr
Environment and Energy (P'ng, 1994).

Conclusions

High rates of geomorphic activity, elev
bank erosion, and channel enlargement of up to
were documented in a channel after a 34% urb
was correlated with an increase in erosion p
regions of up to 6 and 10 times amounts
conditions respectively. An exceedance
indicated that geomorphically significant
by [illegible] times. These impacts, which are
Stormwater Management program, were locat
a ZRI facility. Channel instability is predicted

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d Hydraulic Geometry Data

ESPONSE SEGMENT CROSS-SECTION NUMBER					
	2	3	4	5	SCAR
6	5.31	4.70	3.50	6.40	4.70
3	0.40	0.65	0.44	0.89	0.58
0	5.15	2.83	2.25	5.00	1.75
9	3.2	2.34	1.25	6.05	1.36
0	2.94	1.62	1.29	2.86	1.00
5	1.57	1.25	1.57	2.76	2.41
8	4.10	1.67	2.41	6.10	4.58
8	1.00	2.74	1.28	10.11	1.00
17	1.00	7.55	5.82	45.71	1.00

expressed as the post- to pre-development bankfull channel t the RS cross-section to E_S at the meander scar under pre- TOE and BED refer to the basal stratigraphic and mid-bed ely; 3. EXT and ULT are the existing and ultimate land use e 1:2 year peak flow shaving facility in place.

from 3≤RI≤10 years, exceeds that reported by Leopold 968) for natural, stable channels. The exception was isolation from the increase in high flows due to the cross-section profile and broad, flat floodplain along resistance to scour have combined to minimize the 5. Under ULT-ZRI conditions the enlargement ratio, that further enlargement will occur despite operation

esign Criteria

e comparison of longitudinal profiles, an exceedance ents, a geomorphic survey and erosion pin data were gressive enlargement of Upper Morningside Tributary esence of a ZRI facility. Secondly, the degree of th streams which have no stormwater controls. These ons from Surrey B.C., qualitative observations reported other studies reported in the literature which conclude

that the ZRI concept has not satisfied the intent of erosion control and that alternate methods must be considered. Whipple et al., (1981) concluded that provision mu be made so that the aggregate erosional effect of a series of storms will not . greater than that prescribed to a known stable state. They rationalized that this may be achieved through provision of additional detention storage over and above that required for flood control. This concept, referred to as 'Extended Detention Control', was demonstrated using a 1-dimensional discrete event analysis of sediment transport capacity by McCuen and Moglen (1988). Peak outflow rate from a control pond was reduced until the computed post-development sediment transport rate, approached the pre-development level. In their particular case study, this represented an 85% reduction in post-development flows below the pre-development 1:2 year peak flow rate. Balancing pre- and post-development erosion potential based on average hydraulic parameters may not, however, be adequate by itself because of the heterogeneous and stratified nature of channel boundary materials. It is important to understand, consequently, how the potential for erosion and the resistance to disruption are distributed about the channel perimeter (MacRae and Rowney, 1992).

Based on the importance of flow rate and bed load movement, McCuen and Moglen (1988) proposed a policy which states the post-development bed load cannot exceed the pre-development amount for the 1:2 year recurrence interval (RI) flow event (assuming the pre-development channel to represent a stable state). Erosion, however, is an on-going although highly discontinuous process and bank structure is an important consideration in the determination of channel sensitivity to a disturbance. MacRae (1991) proposed an expansion of McCuen and Moglen's (1988) design criteria wherein channel erosion is minimized if the alteration in the transverse distribution of erosion potential about a channel perimeter is maintained constant with pre-development values, over the range of available flows, such that the channel is just able to move the dominant particle size of its bed load. This criteria resulted in the development of an approach referred to as Distributed Runoff Control (DRC; MacRae, 1994). A form of this approach was recently adopted a the preferred methodology for erosion control by the Ontario Ministry of t Environment and Energy (P'ng, 1994).

Conclusions

High rates of geomorphic activity, elevated sediment yields from bed and bank erosion, and channel enlargement of up to 3 times pre-development conditions were documented in a channel after a 34% urbanization of the basin. This activity was correlated with an increase in erosion potential in the mid-bed and bank toe regions of up to 6 and 10 times amounts determined under pre-development conditions respectively. An exceedance analysis of a 5 year flow series also indicated that geomorphically significant mid-bankfull flows increased in duration by 4.6 times. These impacts, which are similar to streams which have no Stormwater Management program, were documented fora channel downstream of a ZRI facility. Channel instability is predicted to increasefurther under the ultimate

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development scenario resulting in additional adjustment of the channel system. These results, which are supported by findings from 7 stream systems in Surrey, British Columbia, indicate that the ZRI approach fails to meet the intent of Stormwater Management. It also points to the need for a multi-criterion concept which considers both discharge and boundary material characteristics. An alternate multi-criterion design approach is proposed based on a zero net change in the transverse distribution of shear stress about a channel perimeter using an erosion index method.

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RB-AR35382

Effects of Urban Growth

Douglas T. Sove
Percy M. Washing

Abstract

The general impacts of urbanization on stre
professionals responsible for stream habitat
attempts to reconstruct damaged streams fo
to pre-urban conditions or on stream modif
characteristics of the stream as it currently
approaches are subject to higher failure rat
Because the changes brought by urban grov
concepts of how the stream is adjusting to
understood before effective stream remedia
do not adapt to constantly changing enviro
instability is often the dominant limiting fa
streams.

This paper presents a logical picture for str
including the hydraulic relationships to hab
response is understood, a "new urban strea
the effects of increased runoff from urban

[1]Director of Engineering Services,
306th Street, Federal Way, Washington 98

[2]President, Gaia Northwest ...
Seattle, Washington 98125

RB-AR35383

State of California
CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
LOS ANGELES REGION

Resolution No. 98-08

APPROVING BEST MANAGEMENT PRACTICES FOR MUNICIPAL STORM WATER AND URBAN RUNOFF MANAGEMENT PROGRAMS IN LOS ANGELES COUNTY

(NPDES NO. CAS614001)

WHEREAS, THE CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD, LOS ANGELES REGION FINDS:

1. Pursuant to the requirements of Order No. 96-054, Waste Discharge Requirements for Municipal Storm Water and Urban Runoff Discharges Within the County of Los Angeles (Permit), the Principal Permittee, in consultation with Permittees, has developed a model program for Industrial/Commercial Education. This program must include Best Management Practices (BMPs) to control/minimize the discharge of pollutants to receiving waters.

2. The Permit required the City of Los Angeles to conduct a study on pollutants entering storm drains from street and sidewalk washing operation by: (i) characterizing municipal street washing and sidewalk washing; (ii) assessing the impacts of such activities; and (iii) recommending appropriate BMPs to control any adverse impact. Accordingly, the City of Los Angeles has completed and submitted a final report entitled *A Study of Pollutants Entering Storm Drains from Street and Sidewalk Washing Operations in Los Angeles, California* that includes recommended BMPs for said activities.

3. The Permit also requires that the BMPs be approved by the Regional Board before the Permittees incorporate them into their regulatory programs.

4. The BMPs have been evaluated and are considered appropriate for the respective program/activity.

THEREFORE BE IT RESOLVED THAT:

1. The Best Management Practices contained in the following Attachments are approved:

   a. Attachment 1 -- Industrial/Commercial Program (Site Visit); and

   b. Attachment 2 -- Sidewalk and Street Washing.

2. Permittees consider these BMPs in their regulatory programs in accordance with the provisions of Order No. 96-054.

I, Dennis Dickerson, Executive Officer, do hereby certify that the foregoing is a full, true and correct copy of a Resolution adopted by the California Regional Water Quality Control Board, Los Angeles Region, on April 13, 1998.

DENNIS A. DICKERSON
Executive Officer

BMP List Index

Table 1 is an index to all BMP lists and their SIC codes.

Table 1 Index of BMP Lists for Industrial/Commercial Facilities		
Attachment 1		
Page Section	*SIC Codes (exceptions in parentheses)*	*Industry Types*
A	24 (2434)	Timber Products Facilities
B	26	Paper and Allied Products Mfg Facilities
C	28 (283)	Chemicals and Allied Products Mfg Facilities
D	29	Asphalt Paving and Roofing Materials Manufacturers and Lubricant Manufacturers
E	32	Glass, Clay, Concrete, and Gypsum Product Facilities
F	33	Primary Metals Facilities
G	10	Metal Mining Facilities
H	12	Coal Mines and Coal Mining-Related Facilities
I	13	Oil & Gas Extraction Facilities
J	14	Mineral Mining and Processing Facilities
K	4953	Hazardous Waste Treatment, Storage or Disposal Facilities
L	4953	Landfills and Land Application Sites
M	5015	Automobile Salvage Yards
N	5093	Scrap & Waste Recycling
O	4911	Steam Electric Power Generating Facilities
P	40 41 42 43 5171	Vehicle and Equipment Maintenance Areas at Land Transportation Facilities
Q	44	Vehicle and Equipment Maintenance Areas at Water Transportation Facilities
R	373	Ship & Boat Building or Repairing Yards
S	45	Vehicle and Equipment Maintenance and Deicing Areas at Air Transportation Facilities
T	4952	Treatment Works

Page Section Refers to the Best Management Practices List for the Industrial/Commercial Education Site Visit Program (January 5, 1998) 4/13/98

Table 1 Index of BMP Lists for Industrial/Commercial Facilities		
Attachment 1		
Page Section	*SIC Codes (exceptions in parentheses)*	*Industry Types*
U	20 21	Food and Kindred Products Facilities
V	22 23	Textile Mills, Apparel, and Other Fabric Product Manufacturing Facilities
W	2434 25	Wood and Metal Furniture and Fixture Manufacturing Facilities
X	27	Printing and Publishing Facilities
Y	30 39	Rubber, Miscellaneous Plastic Products, and Miscellaneous Manufacturing Industries
Z	31	Leather Tanning and Finishing Facilities
AA	34	Fabricated Metal Products Industry
AB	35 (357) 37 (373)	Facilities that Manufacture Transportation Equip., Industrial, or Commercial Machinery
AC	357 38 36	Manufacturers of Electronic and Electrical Equipment
Attachment 2		
Page Section	*SIC Codes (exceptions in parentheses)*	*Commercial Types*
AD	5013 5014 7532-7534 7536-7539	Vehicle Service Facilities
AE	5541	Gasoline Stations
AF	5812	Restaurants

Page Section Refers to the Best Management Practices List for the Industrial/Commercial Education Site Visit Program (January 5, 1998)

Resolution No. 98-08

ATTACHMENT 2

Recommended Best Management Practices
for
Municipal Sidewalk and Street Washing Operations

TYPE OF DISCHARGE	RECOMMENDED BMPS
SIDEWALK WASH WATER	1. Remove trash, debris, and free standing oil/grease spills/leaks (use absorbent material, if necessary) from the area before washing; and 2. Use high-pressure, low volume spray washing using only potable water with no cleaning agents at an average usage of 0.006 gallon per square feet of sidewalk area.
STREET/ALLEY WASH WATER FROM AREAS WITH UNSANITARY CONDITIONS*	Collect and divert wash water to the sanitary sewer - publicly-owned treatment works (POTW). Note: POTW approval may be needed.

* This BMP is only to be applied in areas impacted by transient populations. Each Permittee is required to apply this BMP in areas where the congregation of transient populations can reasonably be expected to result in a significant threat to water quality.

4/13/98
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Linda S. Adams
Secretary for Environmental Protection

State Water Resources Control Board

Arnold Schwarzenegger
Governor

Division of Water Quality
1001 I Street • Sacramento, California 95814 • (916) 341-5455
Mailing Address: P.O. Box 100 • Sacramento, California • 95812-0100
Fax (916) 341-5463 • http://www.waterboards.ca.gov

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES)
GENERAL PERMIT FOR
STORM WATER DISCHARGES
ASSOCIATED WITH CONSTRUCTION AND LAND DISTURBANCE
ACTIVITIES

ORDER NO. 2009-0009-DWQ
NPDES NO**. CAS000002**

This Order was adopted by the State Water Resources Control Board on:	**September 2, 2009**
This Order shall become effective on:	**July 1, 2010**
This Order shall expire on:	**September 2, 2014**

IT IS HEREBY ORDERED, that this Order supersedes Order No. 99-08-DWQ [as amended by Order No. 2010-0014-DWQ] except for enforcement purposes. The Discharger shall comply with the requirements in this Order to meet the provisions contained in Division 7 of the California Water Code (commencing with section 13000) and regulations adopted thereunder, and the provisions of the federal Clean Water Act and regulations and guidelines adopted thereunder.

I, Jeanine Townsend, Clerk to the Board, do hereby certify that this Order with all attachments is a full, true, and correct copy of an Order adopted by the State Water Resources Control Board, on September 2, 2009.

AYE: Vice Chair Frances Spivy-Weber
Board Member Arthur G. Baggett, Jr.
Board Member Tam M. Doduc

NAY: Chairman Charles R. Hoppin

ABSENT: None

ABSTAIN: None

Jeanine Townsend

Jeanine Townsend
Clerk to the Board

Linda S. Adams
Secretary for Environmental Protection

State Water Resources Control Board

Arnold Schwarzenegger
Governor

Division of Water Quality
1001 I Street • Sacramento, California 95814 • (916) 341-5455
Mailing Address: P.O. Box 100 • Sacramento, California • 95812-0100
Fax (916) 341-5463 • http://www.waterboards.ca.gov

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) GENERAL PERMIT FOR STORM WATER DISCHARGES ASSOCIATED WITH CONSTRUCTION AND LAND DISTURBANCE ACTIVITIES

ORDER NO. 2010-0014-DWQ
NPDES NO. CAS000002

Order No. 2009-0009-DWQ was adopted by the State Water Resources Control Board on:	**September 2, 2009**
Order No. 2009-0009-DWQ became effective on:	**July 1, 2010**
Order No. 2009-0009-DWQ shall expire on:	**September 2, 2014**
This Order, which amends Order No. 2009-0009-DWQ, was adopted by the State Water Resources Control Board on:	**November 16, 2010**
This Order shall become effective on:	**February 14, 2011**

IT IS HEREBY ORDERED that this Order amends Order No. 2009-0009-DWQ. Additions to Order No. 2009-0009-DWQ are reflected in blue-underline text and deletions are reflected in red-strikeout text.

IT IS FURTHER ORDERED that staff are directed to prepare and post a conformed copy of Order No. 2009-0009-DWQ incorporating the revisions made by this Order.

I, Jeanine Townsend, Clerk to the Board, do hereby certify that this Order with all attachments is a full, true, and correct copy of an Order adopted by the State Water Resources Control Board, on **November 16, 2010.**

AYE: Chairman Charles R. Hoppin
Vice Chair Frances Spivy-Weber
Board Member Arthur G. Baggett, Jr.
Board Member Tam M. Doduc

NAY: None

ABSENT: None

ABSTAIN: None

Jeanine Townsend
Jeanine Townsend
Clerk to the Board

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STATE WATER RESOURCES CONTROL BOARD
ORDER NO. 2009-0009-DWQ
[AS AMENDED BY ORDER NO. 2010-0014-DWQ]
NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM
GENERAL PERMIT NO. CAS000002

WASTE DISCHARGE REQUIREMENTS
FOR
DISCHARGES OF STORM WATER RUNOFF ASSOCIATED WITH CONSTRUCTION AND LAND DISTURBANCE ACTIVITIES

I. FINDINGS

A. General Findings

The State Water Resources Control Board (State Water Board) finds that:

1. The federal Clean Water Act (CWA) prohibits certain discharges of storm water containing pollutants except in compliance with a National Pollutant Discharge Elimination System (NPDES) permit (Title 33 United States Code (U.S.C.) §§ 1311 and 1342(p); also referred to as Clean Water Act (CWA) §§ 301 and 402(p)). The U.S. Environmental Protection Agency (U.S. EPA) promulgates federal regulations to implement the CWA's mandate to control pollutants in storm water runoff discharges. (Title 40 Code of Federal Regulations (C.F.R.) Parts 122, 123, and 124). The federal statutes and regulations require discharges to surface waters comprised of storm water associated with construction activity, including demolition, clearing, grading, and excavation, and other land disturbance activities (except operations that result in disturbance of less than one acre of total land area and which are not part of a larger common plan of development or sale), to obtain coverage under an NPDES permit. The NPDES permit must require implementation of Best Available Technology Economically Achievable (BAT) and Best Conventional Pollutant Control Technology (BCT) to reduce or eliminate pollutants in storm water runoff. The NPDES permit must also include additional requirements necessary to implement applicable water quality standards.

2. This General Permit authorizes discharges of storm water associated with construction activity so long as the dischargers comply with all requirements, provisions, limitations and prohibitions in the permit. In addition, this General Permit regulates the discharges of storm water associated with construction activities from all Linear

Underground/Overhead Projects resulting in the disturbance of greater than or equal to one acre (Attachment A).

3. This General Permit regulates discharges of pollutants in storm water associated with construction activity (storm water discharges) to waters of the United States from construction sites that disturb one or more acres of land surface, or that are part of a common plan of development or sale that disturbs more than one acre of land surface.

4. This General Permit does not preempt or supersede the authority of local storm water management agencies to prohibit, restrict, or control storm water discharges to municipal separate storm sewer systems or other watercourses within their jurisdictions.

5. This action to adopt a general NPDES permit is exempt from the provisions of Chapter 3 of the California Environmental Quality Act (CEQA) (Public Resources Code Section 21100, et seq.), pursuant to Section 13389 of the California Water Code.

6. Pursuant to 40 C.F.R. § 131.12 and State Water Board Resolution No. 68-16,[1] which incorporates the requirements of § 131.12 where applicable, the State Water Board finds that discharges in compliance with this General Permit will not result in the lowering of water quality standards, and are therefore consistent with those provisions. Compliance with this General Permit will result in improvements in water quality.

7. This General Permit serves as an NPDES permit in compliance with CWA § 402 and will take effect on July 1, 2010 by the State Water Board provided the Regional Administrator of the U.S. EPA has no objection. If the U.S. EPA Regional Administrator objects to its issuance, the General Permit will not become effective until such objection is withdrawn.

8. Following adoption and upon the effective date of this General Permit, the Regional Water Quality Control Boards (Regional Water Boards) shall enforce the provisions herein.

9. Regional Water Boards establish water quality standards in Basin Plans. The State Water Board establishes water quality standards in various statewide plans, including the California Ocean Plan. U.S. EPA establishes water quality standards in the National Toxic Rule (NTR) and the California Toxic Rule (CTR).

[1] Resolution No. 68-16 generally requires that existing water quality be maintained unless degradation is justified based on specific findings.

10. This General Permit does not authorize discharges of fill or dredged material regulated by the U.S. Army Corps of Engineers under CWA § 404 and does not constitute a waiver of water quality certification under CWA § 401.

11. The primary storm water pollutant at construction sites is excess sediment. Excess sediment can cloud the water, which reduces the amount of sunlight reaching aquatic plants, clog fish gills, smother aquatic habitat and spawning areas, and impede navigation in our waterways. Sediment also transports other pollutants such as nutrients, metals, and oils and greases.

12. Construction activities can impact a construction site's runoff sediment supply and transport characteristics. These modifications, which can occur both during and after the construction phase, are a significant cause of degradation of the beneficial uses established for water bodies in California. Dischargers can avoid these effects through better construction site design and activity practices.

13. This General Permit recognizes four distinct phases of construction activities. The phases are Grading and Land Development Phase, Streets and Utilities Phase, Vertical Construction Phase, and Final Landscaping and Site Stabilization Phase. Each phase has activities that can result in different water quality effects from different water quality pollutants. This General Permit also recognizes inactive construction as a category of construction site type.

14. Compliance with any specific limits or requirements contained in this General Permit does not constitute compliance with any other applicable requirements.

15. Following public notice in accordance with State and Federal laws and regulations, the State Water Board heard and considered all comments and testimony in a public hearing on 06/03/2009. The State Water Board has prepared written responses to all significant comments.

16. Construction activities obtaining coverage under the General Permit may have multiple discharges subject to requirements that are specific to general, linear, and/or active treatment system discharge types.

17. The State Water Board may reopen the permit if the U.S. EPA adopts a final effluent limitation guideline for construction activities.

B. Activities Covered Under the General Permit

18. Any construction or demolition activity, including, but not limited to, clearing, grading, grubbing, or excavation, or any other activity that results in a land disturbance of equal to or greater than one acre.

19. Construction activity that results in land surface disturbances of less than one acre if the construction activity is part of a larger common plan of development or the sale of one or more acres of disturbed land surface.

20. Construction activity related to residential, commercial, or industrial development on lands currently used for agriculture including, but not limited to, the construction of buildings related to agriculture that are considered industrial pursuant to U.S. EPA regulations, such as dairy barns or food processing facilities.

21. Construction activity associated with Linear Underground/Overhead Utility Projects (LUPs) including, but not limited to, those activities necessary for the installation of underground and overhead linear facilities (e.g., conduits, substructures, pipelines, towers, poles, cables, wires, connectors, switching, regulating and transforming equipment and associated ancillary facilities) and include, but are not limited to, underground utility mark-out, potholing, concrete and asphalt cutting and removal, trenching, excavation, boring and drilling, access road and pole/tower pad and cable/wire pull station, substation construction, substructure installation, construction of tower footings and/or foundations, pole and tower installations, pipeline installations, welding, concrete and/or pavement repair or replacement, and stockpile/borrow locations.

22. Discharges of sediment from construction activities associated with oil and gas exploration, production, processing, or treatment operations or transmission facilities.[2]

23. Storm water discharges from dredge spoil placement that occur outside of U.S. Army Corps of Engineers jurisdiction (upland sites) and that disturb one or more acres of land surface from construction activity are covered by this General Permit. Construction sites that intend to disturb one or more acres of land within the jurisdictional boundaries of

[2] Pursuant to the Ninth Circuit Court of Appeals' decision in *NRDC v. EPA* (9th Cir. 2008) 526 F.3d 591, and subsequent denial of the U.S. EPA's petition for reconsideration in November 2008, oil and gas construction activities discharging storm water contaminated only with sediment are no longer exempt from the NPDES program.

a CWA § 404 permit should contact the appropriate Regional Water Board to determine whether this permit applies to the site.

C. Activities Not Covered Under the General Permit

24. Routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of the facility.

25. Disturbances to land surfaces solely related to agricultural operations such as disking, harrowing, terracing and leveling, and soil preparation.

26. Discharges of storm water from areas on tribal lands; construction on tribal lands is regulated by a federal permit.

27. Construction activity and land disturbance involving discharges of storm water within the Lake Tahoe Hydrologic Unit. The Lahontan Regional Water Board has adopted its own permit to regulate storm water discharges from construction activity in the Lake Tahoe Hydrologic Unit (Regional Water Board 6SLT). Owners of construction sites in this watershed must apply for the Lahontan Regional Water Board permit rather than the statewide Construction General Permit.

28. Construction activity that disturbs less than one acre of land surface, and that is not part of a larger common plan of development or the sale of one or more acres of disturbed land surface.

29. Construction activity covered by an individual NPDES Permit for storm water discharges.

30. Discharges from small (1 to 5 acre) construction activities with an approved Rainfall Erosivity Waiver authorized by U.S. EPA Phase II regulations certifying to the State Board that small construction activity will occur only when the Rainfall Erosivity Factor is less than 5 (“R” in the Revised Universal Soil Loss Equation).

31. Landfill construction activity that is subject to the Industrial General Permit.

32. Construction activity that discharges to Combined Sewer Systems.

33. Conveyances that discharge storm water runoff combined with municipal sewage.

34. Discharges of storm water identified in CWA § 402(*l*)(2), 33 U.S.C. § 1342(*l*)(2).

35. Discharges occurring in basins that are not tributary or hydrologically connected to waters of the United States (for more information contact your Regional Water Board).

D. Obtaining and Modifying General Permit Coverage

36. This General Permit requires all dischargers to electronically file all Permit Registration Documents (PRDs), Notices of Termination (NOT), changes of information, annual reporting, and other compliance documents required by this General Permit through the State Water Board's Storm water Multi-Application and Report Tracking System (SMARTS) website.

37. Any information provided to the Regional Water Board shall comply with the Homeland Security Act and any other federal law that concerns security in the United States; any information that does not comply should not be submitted.

38. This General Permit grants an exception from the Risk Determination requirements for existing sites covered under Water Quality Orders No. 99-08-DWQ, and No. 2003-0007-DWQ. For certain sites, adding additional requirements may not be cost effective. Construction sites covered under Water Quality Order No. 99-08-DWQ shall obtain permit coverage at the Risk Level 1. LUPs covered under Water Quality Order No. 2003-0007-DWQ shall obtain permit coverage as a Type 1 LUP. The Regional Water Boards have the authority to require Risk Determination to be performed on sites currently covered under Water Quality Orders No. 99-08-DWQ and No. 2003-0007-DWQ where they deem it necessary. The State Water Board finds that there are two circumstances when it may be appropriate for the Regional Water Boards to require a discharger that had filed an NOI under State Water Board Order No. 99-08-DWQ to recalculate the site's risk level. These circumstances are: (1) when the discharger has a demonstrated history of noncompliance with State Water Board Order No. 99-08-DWQ or; (2) when the discharger's site poses a significant risk of causing or contributing to an exceedance of a water quality standard without the implementation of the additional Risk Level 2 or 3 requirements.

E. Prohibitions

39. All discharges are prohibited except for the storm water and non-storm water discharges specifically authorized by this General Permit or another NPDES permit. Non-storm water discharges include a wide variety of sources, including improper dumping, spills, or leakage from storage tanks or transfer areas. Non-storm water discharges may

contribute significant pollutant loads to receiving waters. Measures to control spills, leakage, and dumping, and to prevent illicit connections during construction must be addressed through structural as well as non-structural Best Management Practices (BMPs)[3]. The State Water Board recognizes, however, that certain non-storm water discharges may be necessary for the completion of construction.

40. This General Permit prohibits all discharges which contain a hazardous substance in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

41. This General Permit incorporates discharge prohibitions contained in water quality control plans, as implemented by the State Water Board and the nine Regional Water Boards.

42. Pursuant to the Ocean Plan, discharges to Areas of Special Biological Significance (ASBS) are prohibited unless covered by an exception that the State Water Board has approved.

43. This General Permit prohibits the discharge of any debris[4] from construction sites. Plastic and other trash materials can cause negative impacts to receiving water beneficial uses. The State Water Board encourages the use of more environmentally safe, biodegradable materials on construction sites to minimize the potential risk to water quality.

F. Training

44. In order to improve compliance with and to maintain consistent enforcement of this General Permit, all dischargers are required to appoint two positions - the Qualified SWPPP Developer (QSD) and the Qualified SWPPP Practitioner (QSP) - who must obtain appropriate training. Together with the key stakeholders, the State and Regional Water Boards are leading the development of this curriculum through a collaborative organization called The Construction General Permit (CGP) Training Team.

45. The Professional Engineers Act (Bus. & Prof. Code section 6700, et seq.) requires that all engineering work must be performed by a California licensed engineer.

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[3] BMPs are scheduling of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants to waters of the United States. BMPs also include treatment requirements, operating procedures, and practice to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

[4] Litter, rubble, discarded refuse, and remains of destroyed inorganic anthropogenic waste.

G. Determining and Reducing Risk

46. The risk of accelerated erosion and sedimentation from wind and water depends on a number of factors, including proximity to receiving water bodies, climate, topography, and soil type.

47. This General Permit requires dischargers to assess the risk level of a site based on both sediment transport and receiving water risk. This General Permit contains requirements for Risk Levels 1, 2 and 3, and LUP Risk Type 1, 2, and 3 (Attachment A). Risk levels are established by determining two factors: first, calculating the site's sediment risk; and second, receiving water risk during periods of soil exposure (i.e. grading and site stabilization). Both factors are used to determine the site-specific Risk Level(s). LUPs can be determined to be Type 1 based on the flowchart in Attachment A.1.

48. Although this General Permit does not mandate specific setback distances, dischargers are encouraged to set back their construction activities from streams and wetlands whenever feasible to reduce the risk of impacting water quality (e.g., natural stream stability and habitat function). Because there is a reduced risk to receiving waters when setbacks are used, this General Permit gives credit to setbacks in the risk determination and post-construction storm water performance standards. The risk calculation and runoff reduction mechanisms in this General Permit are expected to facilitate compliance with any Regional Water Board and local agency setback requirements, and to encourage voluntary setbacks wherever practicable.

49. Rain events can occur at any time of the year in California. Therefore, a Rain Event Action Plan (REAP) is necessary for Risk Level 2 and 3 traditional construction projects (LUPs exempt) to ensure that active construction sites have adequate erosion and sediment controls implemented prior to the onset of a storm event, even if construction is planned only during the dry season.

50. Soil particles smaller than 0.02 millimeters (mm) (i.e., finer than medium silt) do not settle easily using conventional measures for sediment control (i.e., sediment basins). Given their long settling time, dislodging these soils results in a significant risk that fine particles will be released into surface waters and cause unacceptable downstream impacts. If operated correctly, an Active Treatment System (ATS[5]) can prevent or reduce the release of fine particles from construction sites.

[5] An ATS is a treatment system that employs chemical coagulation, chemical flocculation, or electro coagulation in order to reduce turbidity caused by fine suspended sediment.

Use of an ATS can effectively reduce a site's risk of impacting receiving waters.

51. Dischargers located in a watershed area where a Total Maximum Daily Load (TMDL) has been adopted or approved by the Regional Water Board or U.S. EPA may be required by a separate Regional Water Board action to implement additional BMPs, conduct additional monitoring activities, and/or comply with an applicable waste load allocation and implementation schedule. Such dischargers may also be required to obtain an individual Regional Water Board permit specific to the area.

H. Effluent Standards

52. The State Water Board convened a blue ribbon panel of storm water experts that submitted a report entitled, “The Feasibility of Numeric Effluent Limits Applicable to Discharges of Storm Water Associated with Municipal, Industrial and Construction Activities,” dated June 19, 2006. The panel concluded that numeric limits or action levels are technically feasible to control construction storm water discharges, provided that certain conditions are considered. The panel also concluded that numeric effluent limitations (NELs) are feasible for discharges from construction sites that utilize an ATS. The State Water Board has incorporated the expert panel’s suggestions into this General Permit, which includes both numeric action levels (NALs) and NELs for pH and turbidity, and special numeric limits for ATS discharges.

Numeric Effluent Limitations

53. Discharges of storm water from construction activities may become contaminated from alkaline construction materials resulting in high pH (greater than pH 7). Alkaline construction materials include, but are not limited to, hydrated lime, concrete, mortar, cement kiln dust (CKD), Portland cement treated base (CTB), fly ash, recycled concrete, and masonry work. This General Permit includes an NEL for pH (6.0-9.0) that applies only at sites that exhibit a "high risk of high pH discharge." A "high risk of high pH discharge" can occur during the complete utilities phase, the complete vertical build phase, and any portion of any phase where significant amounts of materials are placed directly on the land at the site in a manner that could result in significant alterations to the background pH of any discharges.

54. For Risk Level 3 discharges, this General Permit establishes technology-based, numeric effluent limitations (NELs) for turbidity of 500 NTU. Exceedances of the turbidity NEL constitutes a violation of this General Permit.

55. This General Permit establishes a 5 year, 24 hour (expressed in inches of rainfall) Compliance Storm Event exemption from the technology-based NELs for Risk Level 3 dischargers.

Determining Compliance with Numeric Limitations

56. This General Permit sets a pH NAL of 6.5 to 8.5, and a turbidity NAL of 250 NTU. The purpose of the NAL and its associated monitoring requirement is to provide operational information regarding the performance of the measures used at the site to minimize the discharge of pollutants and to protect beneficial uses and receiving waters from the adverse effects of construction-related storm water discharges. The NALs in this General Permit for pH and turbidity are not directly enforceable and do not constitute NELs.

57. This General Permit requires dischargers with NAL exceedances to immediately implement additional BMPs and revise their Storm Water Pollution Prevention Plans (SWPPPs) accordingly to either prevent pollutants and authorized non-storm water discharges from contaminating storm water, or to substantially reduce the pollutants to levels consistently below the NALs. NAL exceedances are reported in the State Water Boards SMARTS system, and the discharger is required to provide an NAL Exceedance Report when requested by a Regional Water Board.

58. If run-on is caused by a forest fire or any other natural disaster, then NELs do not apply.

59. Exceedances of the NELs are a violation of this Permit. This General Permit requires dischargers with NEL exceedances to implement additional monitoring, BMPs, and revise their SWPPPs accordingly. Dischargers are required to notify the State and Regional Water Boards of the violation through the State Water Boards SMARTs system, and provide an NEL Violation Report sharing additional information concerning the NEL exceedance.

I. Receiving Water Limitations

60. This General Permit requires all enrolled dischargers to determine the receiving waters potentially affected by their discharges and to comply with all applicable water quality standards, including any more stringent standards applicable to a water body.

J. Sampling, Monitoring, Reporting and Record Keeping

61. Visual monitoring of storm water and non-storm water discharges is required for all sites subject to this General Permit.

62. Records of all visual monitoring inspections are required to remain on-site during the construction period and for a minimum of three years.

63. For all Risk Level 3 and Risk Level 2 sites, this General Permit requires effluent monitoring for pH and turbidity. Sampling, analysis and monitoring requirements for effluent monitoring for pH and turbidity are contained in this General Permit.

64. Risk Level 3 sites in violation of the Numeric Effluent Limitations contained in this General Permit and with direct discharges to receiving water are required to conduct receiving water monitoring.

65. For Risk Level 3 sites larger than 30 acres and with direct discharges to receiving waters, this General Permit requires bioassessment sampling before and after site completion to determine if significant degradation to the receiving water's biota has occurred. Bioassessment sampling guidelines are contained in this General Permit.

66. A summary and evaluation of the sampling and analysis results will be submitted in the Annual Reports.

67. This General Permit contains sampling, analysis and monitoring requirements for non-visible pollutants at all sites subject to this General Permit.

68. Compliance with the General Permit relies upon dischargers to electronically self-report any discharge violations and to comply with any Regional Water Board enforcement actions.

69. This General Permit requires that all dischargers maintain a paper or electronic copy of all required records for three years from the date generated or date submitted, whichever is last. These records must be available at the construction site until construction is completed. For LUPs, these documents may be retained in a crew member's vehicle and made available upon request.

K. Active Treatment System (ATS) Requirements

70. Active treatment systems add chemicals to facilitate flocculation, coagulation and filtration of suspended sediment particles. The uncontrolled release of these chemicals to the environment can negatively affect the beneficial uses of receiving waters and/or degrade water quality (e.g., acute and chronic toxicity). Additionally, the batch storage and treatment of storm water through an ATS' can potentially

cause physical impacts on receiving waters if storage volume is inadequate or due to sudden releases of the ATS batches and improperly designed outfalls.

71. If designed, operated and maintained properly an ATS can achieve very high removal rates of suspended sediment (measured as turbidity), albeit at sometimes significantly higher costs than traditional erosion/sediment control practices. As a result, this General Permit establishes NELs consistent with the expected level of typical ATS performance.

72. This General Permit requires discharges of storm water associated with construction activity that undergo active treatment to comply with special operational and effluent limitations to ensure that these discharges do not adversely affect the beneficial uses of the receiving waters or cause degradation of their water quality.

73. For ATS discharges, this General Permit establishes technology-based NELs for turbidity.

74. This General Permit establishes a 10 year, 24 hour (expressed in inches of rainfall) Compliance Storm Event exemption from the technology-based numeric effluent limitations for ATS discharges. Exceedances of the ATS turbidity NEL constitutes a violation of this General Permit.

L. Post-Construction Requirements

75. This General Permit includes performance standards for post-construction that are consistent with State Water Board Resolution No. 2005-0006, "Resolution Adopting the Concept of Sustainability as a Core Value for State Water Board Programs and Directing Its Incorporation," and 2008-0030, “Requiring Sustainable Water Resources Management.“ The requirement for all construction sites to match pre-project hydrology will help ensure that the physical and biological integrity of aquatic ecosystems are sustained. This “runoff reduction” approach is analogous in principle to Low Impact Development (LID) and will serve to protect related watersheds and waterbodies from both hydrologic-based and pollution impacts associated with the post-construction landscape.

76. LUP projects are not subject to post-construction requirements due to the nature of their construction to return project sites to pre-construction conditions.

M. Storm Water Pollution Prevention Plan Requirements

77. This General Permit requires the development of a site-specific SWPPP. The SWPPP must include the information needed to demonstrate compliance with all requirements of this General Permit, and must be kept on the construction site and be available for review. The discharger shall ensure that a QSD develops the SWPPP.

78. To ensure proper site oversight, this General Permit requires a Qualified SWPPP Practitioner to oversee implementation of the BMPs required to comply with this General Permit.

N. Regional Water Board Authorities

79. Regional Water Boards are responsible for implementation and enforcement of this General Permit. A general approach to permitting is not always suitable for every construction site and environmental circumstances. Therefore, this General Permit recognizes that Regional Water Boards must have some flexibility and authority to alter, approve, exempt, or rescind permit authority granted under this General Permit in order to protect the beneficial uses of our receiving waters and prevent degradation of water quality.

IT IS HEREBY ORDERED that all dischargers subject to this General Permit shall comply with the following conditions and requirements (including all conditions and requirements as set forth in Attachments A, B, C, D, E and F)[6]:

II. CONDITIONS FOR PERMIT COVERAGE

A. Linear Underground/Overhead Projects (LUPs)

1. Linear Underground/Overhead Projects (LUPs) include, but are not limited to, any conveyance, pipe, or pipeline for the transportation of any gaseous, liquid (including water and wastewater for domestic municipal services), liquescent, or slurry substance; any cable line or wire for the transmission of electrical energy; any cable line or wire for communications (e.g. telephone, telegraph, radio or television messages); and associated ancillary facilities. Construction activities associated with LUPs include, but are not limited to, (a) those activities necessary for the installation of underground and overhead linear facilities (e.g., conduits, substructures, pipelines, towers, poles, cables, wires, connectors, switching, regulating and transforming equipment, and associated ancillary facilities); and include, but are not limited to, (b) underground utility mark-out, potholing, concrete and asphalt cutting and removal, trenching, excavation, boring and drilling, access road and pole/tower pad and cable/wire pull station, substation construction, substructure installation, construction of tower footings and/or foundations, pole and tower installations, pipeline installations, welding, concrete and/ or pavement repair or replacement, and stockpile/borrow locations.

2. The Legally Responsible Person is responsible for obtaining coverage under the General Permit where the construction of pipelines, utility lines, fiber-optic cables, or other linear underground/overhead projects will occur across several properties unless the LUP construction activities are covered under another construction storm water permit.

3. Only LUPs shall comply with the conditions and requirements in Attachment A, A.1 & A.2 of this Order. The balance of this Order is not applicable to LUPs except as indicated in Attachment A.

[6] These attachments are part of the General Permit itself and are not separate documents that are capable of being updated independently by the State Water Board.

B. Obtaining Permit Coverage Traditional Construction Sites

1. The Legally Responsible Person (LRP) (see Special Provisions, Electronic Signature and Certification Requirements, Section IV.I.1) must obtain coverage under this General Permit.

2. To obtain coverage, the LRP must electronically file Permit Registration Documents (PRDs) prior to the commencement of construction activity. Failure to obtain coverage under this General Permit for storm water discharges to waters of the United States is a violation of the CWA and the California Water Code.

3. PRDs shall consist of:

   a. Notice of Intent (NOI)
   b. Risk Assessment (Section VIII)
   c. Site Map
   d. Storm Water Pollution Prevention Plan (Section XIV)
   e. Annual Fee
   f. Signed Certification Statement

   Any information provided to the Regional Water Board shall comply with the Homeland Security Act and any other federal law that concerns security in the United States; any information that does not comply should not be submitted.

   Attachment B contains additional PRD information. Dischargers must electronically file the PRDs, and mail the appropriate annual fee to the State Water Board.

4. This permit is effective on July 1, 2010.

   a. **Dischargers Obtaining Coverage On or After July 1, 2010:** All dischargers requiring coverage on or after July 1, 2010, shall electronically file their PRDs prior to the commencement of construction activities, and mail the appropriate annual fee no later than seven days prior to the commencement of construction activities. Permit coverage shall not commence until the PRDs and the annual fee are received by the State Water Board, and a WDID number is assigned and sent by SMARTS.

   b. **Dischargers Covered Under 99-08-DWQ and 2003-0007-DWQ:** Existing dischargers subject to State Water Board Order No. 99-08-DWQ (existing dischargers) will continue coverage under 99-08-DWQ until July 1, 2010. After July 1, 2010, all NOIs subject to State Water Board Order No. 99-08-DWQ will be terminated.

Existing dischargers shall electronically file their PRDs no later than July 1, 2010. If an existing discharger's site acreage subject to the annual fee has changed, it shall mail a revised annual fee no less than seven days after receiving the revised annual fee notification, **or else lose permit coverage**. All existing dischargers shall be exempt from the risk determination requirements in Section VIII of this General Permit until two years after permit adoption. All existing dischargers are therefore subject to Risk Level 1 requirements regardless of their site's sediment and receiving water risks. However, a Regional Board retains the authority to require an existing discharger to comply with the Section VIII risk determination requirements.

5. The discharger is only considered covered by this General Permit upon receipt of a Waste Discharger Identification (WDID) number assigned and sent by the State Water Board Storm water Multi-Application and Report Tracking System (SMARTS). In order to demonstrate compliance with this General Permit, the discharger must obtain a WDID number and must present documentation of a valid WDID upon demand.

6. During the period this permit is subject to review by the U.S. EPA, the prior permit (State Water Board Order No. 99-08-DWQ) remains in effect. Existing dischargers under the prior permit will continue to have coverage under State Water Board Order No. 99-08-DWQ until this General Permit takes effect on July 1, 2010. Dischargers who complete their projects and electronically file an NOT prior to July 1, 2010, are not required to obtain coverage under this General Permit.

7. Small Construction Rainfall Erosivity Waiver

   EPA's Small Construction Erosivity Waiver applies to sites between one and five acres demonstrating that there are no adverse water quality impacts.

   Dischargers eligible for a Rainfall Erosivity Waiver based on low erosivity potential shall complete the electronic Notice of Intent (NOI) and Sediment Risk form through the State Water Board's SMARTS system, certifying that the construction activity will take place during a period when the value of the rainfall erosivity factor is less than five. Where the LRP changes or another LRP is added during construction, the new LRP must also submit a waiver certification through the SMARTS system.

   If a small construction site continues beyond the projected completion date given on the waiver certification, the LRP shall recalculate the rainfall erosivity factor for the new project duration and submit this information through the SMARTS system. If the new R factor is below five (5), the discharger shall update through SMARTS all applicable information on the waiver certification and retain a copy of the revised waiver onsite. The LRP shall submit the new waiver certification 30 days prior to the projected completion date listed on the original waiver form to assure exemption from permitting requirements is uninterrupted. If the new R factor is five (5) or above, the LRP shall be required to apply for coverage under this Order.

8. In the case of a public emergency that requires immediate construction activities, a discharger shall submit a brief description of the emergency construction activity within five days of the onset of construction, and then shall submit all PRDs within thirty days.

C. Revising Permit Coverage for Change of Acreage or New Ownership

1. The discharger may reduce or increase the total acreage covered under this General Permit when a portion of the site is complete and/or conditions for termination of coverage have been met (See Section II.D Conditions for Termination of Coverage); when ownership of a portion of the site is sold to a different entity; or when new acreage, subject to this General Permit, is added to the site.

2. Within 30 days of a reduction or increase in total disturbed acreage, the discharger shall electronically file revisions to the PRDs that include:

   a. A revised NOI indicating the new project size;

   b. A revised site map showing the acreage of the site completed, acreage currently under construction, acreage sold/transferred or added, and acreage currently stabilized in accordance with the Conditions for Termination of Coverage in Section II.D below.

   c. SWPPP revisions, as appropriate; and

   d. Certification that any new landowners have been notified of applicable requirements to obtain General Permit coverage. The certification shall include the name, address, telephone number, and e-mail address of the new landowner.

   e. If the project acreage has increased, dischargers shall mail payment of revised annual fees within 14 days of receiving the revised annual fee notification.

3. The discharger shall continue coverage under the General Permit for any parcel that has not achieved “Final Stabilization” as defined in Section II.D.

4. When an LRP with active General Permit coverage transfers its LRP status to another person or entity that qualifies as an LRP, the existing LRP shall inform the new LRP of the General Permit’s requirements. In order for the new LRP to continue the construction activity on its parcel of property, the new LRP, or the new LRP’s approved signatory, must submit PRDs in accordance with this General Permit’s requirements.

D. Conditions for Termination of Coverage

1. Within 90 days of when construction is complete or ownership has been transferred, the discharger shall electronically file a Notice of Termination (NOT), a final site map, and photos through the State Water Boards SMARTS system. Filing a NOT certifies that all General Permit requirements have been met. The Regional Water Board will consider a construction site complete only when all portions of the site have been transferred to a new owner, or all of the following conditions have been met:

    a. For purposes of “final stabilization,” the site will not pose any additional sediment discharge risk than it did prior to the commencement of construction activity;

    b. There is no potential for construction-related storm water pollutants to be discharged into site runoff;

    c. Final stabilization has been reached;

    d. Construction materials and wastes have been disposed of properly;

    e. Compliance with the Post-Construction Standards in Section XIII of this General Permit has been demonstrated;

    f. Post-construction storm water management measures have been installed and a long-term maintenance plan[7] has been established; and

    g. All construction-related equipment, materials and any temporary BMPs no longer needed are removed from the site.

[7] For the purposes of this requirement a long-term maintenance plan will be designed for a minimum of five years, and will describe the procedures to ensure that the post-construction storm water management measures are adequately maintained.

2. The discharger shall certify that final stabilization conditions are satisfied in their NOT. Failure to certify shall result in continuation of permit coverage and annual billing.

3. The NOT must demonstrate through photos, RUSLE or RUSLE2, or results of testing and analysis that the site meets all of the conditions above (Section II.D.1) and the final stabilization condition (Section II.D.1.a) is attained by one of the following methods:

   a. “70% final cover method,” no computational proof required

      OR:

   b. “RUSLE or RUSLE2 method,” computational proof required

      OR:

   c. “Custom method”, the discharger shall demonstrate in some other manner than a or b, above, that the site complies with the “final stabilization” requirement in Section II.D.1.a.

III. DISCHARGE PROHIBITIONS

A. Dischargers shall not violate any discharge prohibitions contained in applicable Basin Plans or statewide water quality control plans. Waste discharges to Areas of Special Biological Significance (ASBS) are prohibited by the California Ocean Plan, unless granted an exception issued by the State Water Board.

B. All discharges are prohibited except for the storm water and non-storm water discharges specifically authorized by this General Permit or another NPDES permit.

C. Authorized non-storm water discharges may include those from de-chlorinated potable water sources such as: fire hydrant flushing, irrigation of vegetative erosion control measures, pipe flushing and testing, water to control dust, uncontaminated ground water from dewatering, and other discharges not subject to a separate general NPDES permit adopted by a Regional Water Board. The discharge of non-storm water is authorized under the following conditions:

1. The discharge does not cause or contribute to a violation of any water quality standard;

2. The discharge does not violate any other provision of this General Permit;

3. The discharge is not prohibited by the applicable Basin Plan;

4. The discharger has included and implemented specific BMPs required by this General Permit to prevent or reduce the contact of the non-storm water discharge with construction materials or equipment.

5. The discharge does not contain toxic constituents in toxic amounts or (other) significant quantities of pollutants;

6. The discharge is monitored and meets the applicable NALs and NELs; and

7. The discharger reports the sampling information in the Annual Report.

If any of the above conditions are not satisfied, the discharge is not authorized by this General Permit. The discharger shall notify the Regional Water Board of any anticipated non-storm water discharges not already authorized by this General Permit or another NPDES permit, to determine whether a separate NPDES permit is necessary.

D. Debris resulting from construction activities are prohibited from being discharged from construction sites.

E. When soil contamination is found or suspected and a responsible party is not identified, or the responsible party fails to promptly take the appropriate action, the discharger shall have those soils sampled and tested to ensure proper handling and public safety measures are implemented. The discharger shall notify the appropriate local, State, and federal agency(ies) when contaminated soil is found at a construction site, and will notify the appropriate Regional Water Board.

IV. SPECIAL PROVISIONS

A. Duty to Comply

1. The discharger shall comply with all of the conditions of this General Permit. Any permit noncompliance constitutes a violation of the Clean Water Act (CWA) and the Porter-Cologne Water Quality Control Act and is grounds for enforcement action and/or removal from General Permit coverage.

2. The discharger shall comply with effluent standards or prohibitions established under Section 307(a) of the CWA for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if this General Permit has not yet been modified to incorporate the requirement.

B. General Permit Actions

1. This General Permit may be modified, revoked and reissued, or terminated for cause. The filing of a request by the discharger for a General Permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance does not annul any General Permit condition.

2. If any toxic effluent standard or prohibition (including any schedule of compliance specified in such effluent standard or prohibition) is promulgated under Section 307(a) of the CWA for a toxic pollutant which is present in the discharge and that standard or prohibition is more stringent than any limitation on the pollutant in this General Permit, this General Permit shall be modified or revoked and reissued to conform to the toxic effluent standard or prohibition and the dischargers so notified.

C. Need to Halt or Reduce Activity Not a Defense

It shall not be a defense for a discharger in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this General Permit.

D. Duty to Mitigate

The discharger shall take all responsible steps to minimize or prevent any discharge in violation of this General Permit, which has a reasonable likelihood of adversely affecting human health or the environment.

E. Proper Operation and Maintenance

The discharger shall at all times properly operate and maintain any facilities and systems of treatment and control (and related appurtenances) which are installed or used by the discharger to achieve compliance with the conditions of this General Permit. Proper operation and maintenance also includes adequate laboratory controls and appropriate quality assurance procedures. Proper operation and maintenance may require the operation of backup or auxiliary facilities or similar systems installed by a discharger when necessary to achieve compliance with the conditions of this General Permit.

F. Property Rights

This General Permit does not convey any property rights of any sort or any exclusive privileges, nor does it authorize any injury to private property or any invasion of personal rights, nor does it authorize any infringement of Federal, State, or local laws or regulations.

G. Duty to Maintain Records and Provide Information

1. The discharger shall maintain a paper or electronic copy of all required records, including a copy of this General Permit, for three years from the date generated or date submitted, whichever is last. These records shall be available at the construction site until construction is completed.

2. The discharger shall furnish the Regional Water Board, State Water Board, or U.S. EPA, within a reasonable time, any requested information to determine compliance with this General Permit. The discharger shall also furnish, upon request, copies of records that are required to be kept by this General Permit.

H. Inspection and Entry

The discharger shall allow the Regional Water Board, State Water Board, U.S. EPA, and/or, in the case of construction sites which discharge through a municipal separate storm sewer, an authorized representative of the municipal operator of the separate storm sewer system receiving the discharge, upon the presentation of credentials and other documents as may be required by law, to:

1. Enter upon the discharger's premises at reasonable times where a regulated construction activity is being conducted or where records must be kept under the conditions of this General Permit;

2. Access and copy at reasonable times any records that must be kept under the conditions of this General Permit;

3. Inspect at reasonable times the complete construction site, including any off-site staging areas or material storage areas, and the erosion/sediment controls; and

4. Sample or monitor at reasonable times for the purpose of ensuring General Permit compliance.

I. Electronic Signature and Certification Requirements

1. All Permit Registration Documents (PRDs) and Notices of Termination (NOTs) shall be electronically signed, certified, and submitted via SMARTS to the State Water Board. Either the Legally Responsible Person (LRP), as defined in Appendix 5 – Glossary, or a person legally authorized to sign and certify PRDs and NOTs on behalf of the LRP (the LRP's Approved Signatory, as defined in Appendix 5 - Glossary) must submit all information electronically via SMARTS.

2. Changes to Authorization. If an Approved Signatory's authorization is no longer accurate, a new authorization satisfying the requirements of paragraph (a) of this section must be submitted via SMARTS prior to or together with any reports, information or applications to be signed by an Approved Signatory.

3. All Annual Reports, or other information required by the General Permit (other than PRDs and NOTs) or requested by the Regional Water Board, State Water Board, U.S. EPA, or local storm water management agency shall be certified and submitted by the LRP or the LRP's Approved Signatory.

J. Certification

Any person signing documents under Section IV.I above, shall make the following certification:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, to the best of my knowledge and belief, the information submitted is, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

K. Anticipated Noncompliance

The discharger shall give advance notice to the Regional Water Board and local storm water management agency of any planned changes in the construction activity, which may result in noncompliance with General Permit requirements.

L. Bypass

Bypass[8] is prohibited. The Regional Water Board may take enforcement action against the discharger for bypass unless:

1. Bypass was unavoidable to prevent loss of life, personal injury or severe property damage;[9]

2. There were no feasible alternatives to bypass, such as the use of auxiliary treatment facilities, retention of untreated waste, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass that could occur during normal periods of equipment downtime or preventative maintenance;

3. The discharger submitted a notice at least ten days in advance of the need for a bypass to the Regional Water Board; or

4. The discharger may allow a bypass to occur that does not cause effluent limitations to be exceeded, but only if it is for essential maintenance to assure efficient operation. In such a case, the above bypass conditions are not applicable. The discharger shall submit notice of an unanticipated bypass as required.

M. Upset

1. A discharger that wishes to establish the affirmative defense of an upset[10] in an action brought for noncompliance shall demonstrate,

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[8] The intentional diversion of waste streams from any portion of a treatment facility

[9] Severe property damage means substantial physical damage to property, damage to the treatment facilities that causes them to become inoperable, or substantial and permanent loss of natural resources that can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

[10] An exceptional incident in which there is unintentional and temporary noncompliance the technology based numeric effluent limitations because of factors beyond the reasonable control of the discharger. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventative maintenance, or careless or improper operation.

through properly signed, contemporaneous operating logs, or other relevant evidence that:

a. An upset occurred and that the discharger can identify the cause(s) of the upset

b. The treatment facility was being properly operated by the time of the upset

c. The discharger submitted notice of the upset as required; and

d. The discharger complied with any remedial measures required

2. No determination made before an action of noncompliance occurs, such as during administrative review of claims that noncompliance was caused by an upset, is final administrative action subject to judicial review.

3. In any enforcement proceeding, the discharger seeking to establish the occurrence of an upset has the burden of proof

N. Penalties for Falsification of Reports

Section 309(c)(4) of the CWA provides that any person who knowingly makes any false material statement, representation, or certification in any record or other document submitted or required to be maintained under this General Permit, including reports of compliance or noncompliance shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than two years or by both.

O. Oil and Hazardous Substance Liability

Nothing in this General Permit shall be construed to preclude the institution of any legal action or relieve the discharger from any responsibilities, liabilities, or penalties to which the discharger is or may be subject to under Section 311 of the CWA.

P. Severability

The provisions of this General Permit are severable; and, if any provision of this General Permit or the application of any provision of this General Permit to any circumstance is held invalid, the application of such provision to other circumstances and the remainder of this General Permit shall not be affected thereby.

Q. Reopener Clause

This General Permit may be modified, revoked and reissued, or terminated for cause due to promulgation of amended regulations, receipt of U.S. EPA guidance concerning regulated activities, judicial decision, or in accordance with 40 Code of Federal Regulations (CFR) 122.62, 122.63, 122.64, and 124.5.

R. Penalties for Violations of Permit Conditions

1. Section 309 of the CWA provides significant penalties for any person who violates a permit condition implementing Sections 301, 302, 306, 307, 308, 318, or 405 of the CWA or any permit condition or limitation implementing any such section in a permit issued under Section 402. Any person who violates any permit condition of this General Permit is subject to a civil penalty not to exceed $37,500[11] per calendar day of such violation, as well as any other appropriate sanction provided by Section 309 of the CWA.

2. The Porter-Cologne Water Quality Control Act also provides for civil and criminal penalties, which in some cases are greater than those under the CWA.

S. Transfers

This General Permit is not transferable.

T. Continuation of Expired Permit

This General Permit continues in force and effect until a new General Permit is issued or the SWRCB rescinds this General Permit. Only those dischargers authorized to discharge under the expiring General Permit are covered by the continued General Permit.

[11] May be further adjusted in accordance with the Federal Civil Penalties Inflation Adjustment Act.

V. EFFLUENT STANDARDS

A. Narrative Effluent Limitations

1. Storm water discharges and authorized non-storm water discharges regulated by this General Permit shall not contain a hazardous substance equal to or in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

2. Dischargers shall minimize or prevent pollutants in storm water discharges and authorized non-storm water discharges through the use of controls, structures, and management practices that achieve BAT for toxic and non-conventional pollutants and BCT for conventional pollutants.

B. Numeric Effluent Limitations (NELs)

Table 1- Numeric Effluent Limitations, Numeric Action Levels, Test Methods, Detection Limits, and Reporting Units

Parameter	Test Method	Discharge Type	Min. Detection Limit	Units	Numeric Action Level	Numeric Effluent Limitation
pH	Field test with calibrated portable instrument	Risk Level 2	0.2	pH units	lower NAL = 6.5 upper NAL = 8.5	N/A
		Risk Level 3			lower NAL = 6.5 upper NAL = 8.5	lower NEL = 6.0 upper NEL = 9.0
Turbidity	EPA 0180.1 and/or field test with calibrated portable instrument	Risk Level 2	1	NTU	250 NTU	N/A
		Risk Level 3			250 NTU	500 NTU

1. Numeric Effluent Limitations (NELs):

   a. **Storm Event, Daily Average pH Limits –** For Risk Level 3 dischargers, the pH of storm water and non-storm water discharges shall be within the ranges specified in Table 1 during any site phase where there is a "high risk of pH discharge."[12]

b. **Storm Event Daily Average Turbidity Limit –** For Risk Level 3 dischargers, the turbidity of storm water and non-storm water discharges shall not exceed 500 NTU.

2. If daily average sampling results are outside the range of pH NELs (i.e., is below the lower NEL for pH or exceeds the upper NEL for pH) or exceeds the turbidity NEL (as listed in Table 1), the discharger is in violation of this General Permit and shall electronically file monitoring results in violation within 5 business days of obtaining the results.

3. **Compliance Storm Event**:

   Discharges of storm water from Risk Level 3 sites shall comply with applicable NELs (above) unless the storm event causing the discharges is determined after the fact to be equal to or larger than the Compliance Storm Event (expressed in inches of rainfall). The Compliance Storm Event for Risk Level 3 discharges is the 5 year, 24 hour storm (expressed in tenths of an inch of rainfall), as determined by using these maps:

   http://www.wrcc.dri.edu/pcpnfreq/nca5y24.gif
   http://www.wrcc.dri.edu/pcpnfreq/sca5y24.gif

   Compliance storm event verification shall be done by reporting on-site rain gauge readings as well as nearby governmental rain gauge readings.

4. Dischargers shall not be required to comply with NELs if the site receives run-on from a forest fire or any other natural disaster.

C. Numeric Action Levels (NALs)

1. For Risk Level 2 and 3 dischargers, the lower storm event average NAL for pH is 6.5 pH units and the upper storm event average NAL for pH is 8.5 pH units. The discharger shall take actions as described below if the discharge is outside of this range of pH values.

[12] A period of high risk of pH discharge is defined as a project's complete utilities phase, complete vertical build phase, and any portion of any phase where significant amounts of materials are placed directly on the land at the site in a manner that could result in significant alterations of the background pH of the discharges.

2. For Risk Level 2 and 3 dischargers, the NAL storm event daily average for turbidity is 250 NTU. The discharger shall take actions as described below if the discharge is outside of this range of turbidity values.

3. Whenever the results from a storm event daily average indicate that the discharge is below the lower NAL for pH, exceeds the upper NAL for pH, or exceeds the turbidity NAL (as listed in Table 1), the discharger shall conduct a construction site and run-on evaluation to determine whether pollutant source(s) associated with the site's construction activity may have caused or contributed to the NAL exceedance and shall immediately implement corrective actions if they are needed.

4. The site evaluation shall be documented in the SWPPP and specifically address whether the source(s) of the pollutants causing the exceedance of the NAL:

   a. Are related to the construction activities and whether additional BMPs are required to (1) meet BAT/BCT requirements; (2) reduce or prevent pollutants in storm water discharges from causing exceedances of receiving water objectives; and (3) determine what corrective action(s) were taken or will be taken and with a description of the schedule for completion.

      AND/OR:

   b. Are related to the run-on associated with the construction site location and whether additional BMPs measures are required to (1) meet BAT/BCT requirements; (2) reduce or prevent pollutants in storm water discharges from causing exceedances of receiving water objectives; and (3) what corrective action(s) were taken or will be taken with a description of the schedule for completion.

VI. RECEIVING WATER LIMITATIONS

A. The discharger shall ensure that storm water discharges and authorized non-storm water discharges to any surface or ground water will not adversely affect human health or the environment.

B. The discharger shall ensure that storm water discharges and authorized non-storm water discharges will not contain pollutants in quantities that threaten to cause pollution or a public nuisance.

C. The discharger shall ensure that storm water discharges and authorized non-storm water discharges will not contain pollutants that cause or contribute to an exceedance of any applicable water quality objectives or water quality standards (collectively, WQS) contained in a Statewide Water Quality Control Plan, the California Toxics Rule, the National Toxics Rule, or the applicable Regional Water Board's Water Quality Control Plan (Basin Plan).

D. Dischargers located within the watershed of a CWA § 303(d) impaired water body, for which a TMDL has been approved by the U.S. EPA, shall comply with the approved TMDL if it identifies "construction activity" or land disturbance as a source of the pollution.

VII. TRAINING QUALIFICATIONS AND CERTIFICATION REQUIREMENTS

A. General

The discharger shall ensure that all persons responsible for implementing requirements of this General Permit shall be appropriately trained in accordance with this Section. Training should be both formal and informal, occur on an ongoing basis, and should include training offered by recognized governmental agencies or professional organizations. Those responsible for preparing and amending SWPPPs shall comply with the requirements in this Section VII.

The discharger shall provide documentation of all training for persons responsible for implementing the requirements of this General Permit in the Annual Reports.

B. SWPPP Certification Requirements

1. **Qualified SWPPP Developer:** The discharger shall ensure that SWPPPs are written, amended and certified by a Qualified SWPPP Developer (QSD). A QSD shall have one of the following registrations or certifications, and appropriate experience, as required for:

   a. A California registered professional civil engineer;

   b. A California registered professional geologist or engineering geologist;

   c. A California registered landscape architect;

   d. A professional hydrologist registered through the American Institute of Hydrology;

   e. A Certified Professional in Erosion and Sediment Control (CPESC) ™ registered through Enviro Cert International, Inc.;

   f. A Certified Professional in Storm Water Quality (CPSWQ) ™ registered through Enviro Cert International, Inc.; or

   g. A professional in erosion and sediment control registered through the National Institute for Certification in Engineering Technologies (NICET).

Effective two years after the adoption date of this General Permit, a QSD shall have attended a State Water Board-sponsored or approved QSD training course.

2. The discharger shall list the name and telephone number of the currently designated Qualified SWPPP Developer(s) in the SWPPP.

3. **Qualified SWPPP Practitioner:** The discharger shall ensure that all BMPs required by this General Permit are implemented by a Qualified SWPPP Practitioner (QSP). A QSP is a person responsible for non-storm water and storm water visual observations, sampling and analysis. Effective two years from the date of adoption of this General Permit, a QSP shall be either a QSD or have one of the following certifications:

   a. A certified erosion, sediment and storm water inspector registered through Enviro Cert International, Inc.; or

   b. A certified inspector of sediment and erosion control registered through Certified Inspector of Sediment and Erosion Control, Inc.

   Effective two years after the adoption date of this General Permit, a QSP shall have attended a State Water Board-sponsored or approved QSP training course.

4. The LRP shall list in the SWPPP, the name of any Approved Signatory, and provide a copy of the written agreement or other mechanism that provides this authority from the LRP in the SWPPP.

5. The discharger shall include, in the SWPPP, a list of names of all contractors, subcontractors, and individuals who will be directed by the Qualified SWPPP Practitioner. This list shall include telephone numbers and work addresses. Specific areas of responsibility of each subcontractor and emergency contact numbers shall also be included.

6. The discharger shall ensure that the SWPPP and each amendment will be signed by the Qualified SWPPP Developer. The discharger shall include a listing of the date of initial preparation and the date of each amendment in the SWPPP.

VIII. RISK DETERMINATION

The discharger shall calculate the site's sediment risk and receiving water risk during periods of soil exposure (i.e. grading and site stabilization) and use the calculated risks to determine a Risk Level(s) using the methodology in

Appendix 1. For any site that spans two or more planning watersheds,[13] the discharger shall calculate a separate Risk Level for each planning watershed. The discharger shall notify the State Water Board of the site's Risk Level determination(s) and shall include this determination as a part of submitting the PRDs. If a discharger ends up with more than one Risk Level determination, the Regional Water Board may choose to break the project into separate levels of implementation.

IX. RISK LEVEL 1 REQUIREMENTS

Risk Level 1 Dischargers shall comply with the requirements included in Attachment C of this General Permit.

X. RISK LEVEL 2 REQUIREMENTS

Risk Level 2 Dischargers shall comply with the requirements included in Attachment D of this General Permit.

XI. RISK LEVEL 3 REQUIREMENTS

Risk Level 3 Dischargers shall comply with the requirements included in Attachment E of this General Permit.

XII. ACTIVE TREATMENT SYSTEMS (ATS)

Dischargers choosing to implement an ATS on their site shall comply with all of the requirements in Attachment F of this General Permit.

[13] Planning watershed: defined by the Calwater Watershed documents as a watershed that ranges in size from approximately 3,000 to 10,000 acres http://cain.ice.ucdavis.edu/calwater/calwfaq.html, http://gis.ca.gov/catalog/BrowseRecord.epl?id=22175 .

XIII. POST-CONSTRUCTION STANDARDS

A. All dischargers shall comply with the following runoff reduction requirements unless they are located within an area subject to post-construction standards of an active Phase I or II municipal separate storm sewer system (MS4) permit that has an approved Storm Water Management Plan.

1. This provision shall take effect three years from the adoption date of this permit, or later at the discretion of the Executive Officer of the Regional Board.

2. The discharger shall demonstrate compliance with the requirements of this section by submitting with their NOI a map and worksheets in accordance with the instructions in Appendix 2. The discharger shall use non-structural controls unless the discharger demonstrates that non-structural controls are infeasible or that structural controls will produce greater reduction in water quality impacts.

3. The discharger shall, through the use of non-structural and structural measures as described in Appendix 2, replicate the pre-project water balance (for this permit, defined as the volume of rainfall that ends up as runoff) for the smallest storms up to the 85th percentile storm event (or the smallest storm event that generates runoff, whichever is larger). Dischargers shall inform Regional Water Board staff at least 30 days prior to the use of any structural control measure used to comply with this requirement. Volume that cannot be addressed using non-structural practices shall be captured in structural practices and approved by the Regional Water Board. When seeking Regional Board approval for the use of structural practices, dischargers shall document the infeasibility of using non-structural practices on the project site, or document that there will be fewer water quality impacts through the use of structural practices.

4. For sites whose disturbed area exceeds two acres, the discharger shall preserve the pre-construction drainage density (miles of stream length per square mile of drainage area) for all drainage areas within the area serving a first order stream[14] or larger stream and ensure that post-project time of runoff concentration is equal or greater than pre-project time of concentration.

[14] A first order stream is defined as a stream with no tributaries.

B. All dischargers shall implement BMPs to reduce pollutants in storm water discharges that are reasonably foreseeable after all construction phases have been completed at the site (Post-construction BMPs).

XIV. SWPPP REQUIREMENTS

A. The discharger shall ensure that the Storm Water Pollution Prevention Plans (SWPPPs) for all traditional project sites are developed and amended or revised by a QSD. The SWPPP shall be designed to address the following objectives:

1. All pollutants and their sources, including sources of sediment associated with construction, construction site erosion and all other activities associated with construction activity are controlled;

2. Where not otherwise required to be under a Regional Water Board permit, all non-storm water discharges are identified and either eliminated, controlled, or treated;

3. Site BMPs are effective and result in the reduction or elimination of pollutants in storm water discharges and authorized non-storm water discharges from construction activity to the BAT/BCT standard;

4. Calculations and design details as well as BMP controls for site run-on are complete and correct, and

5. Stabilization BMPs installed to reduce or eliminate pollutants after construction are completed.

B. To demonstrate compliance with requirements of this General Permit, the QSD shall include information in the SWPPP that supports the conclusions, selections, use, and maintenance of BMPs.

C. The discharger shall make the SWPPP available at the construction site during working hours while construction is occurring and shall be made available upon request by a State or Municipal inspector. When the original SWPPP is retained by a crewmember in a construction vehicle and is not currently at the construction site, current copies of the BMPs and map/drawing will be left with the field crew and the original SWPPP shall be made available via a request by radio/telephone.

XV. REGIONAL WATER BOARD AUTHORITIES

A. In the case where the Regional Water Board does not agree with the discharger's self-reported risk level (e.g., they determine themselves to be a Level 1 Risk when they are actually a Level 2 Risk site), Regional Water Boards may either direct the discharger to reevaluate the Risk Level(s) for their site or terminate coverage under this General Permit.

B. Regional Water Boards may terminate coverage under this General Permit for dischargers who fail to comply with its requirements or where they determine that an individual NPDES permit is appropriate.

C. Regional Water Boards may require dischargers to submit a Report of Waste Discharge / NPDES permit application for Regional Water Board consideration of individual requirements.

D. Regional Water Boards may require additional Monitoring and Reporting Program Requirements, including sampling and analysis of discharges to sediment-impaired water bodies.

E. Regional Water Boards may require dischargers to retain records for more than the three years required by this General Permit.

XVI. ANNUAL REPORTING REQUIREMENTS

A. All dischargers shall prepare and electronically submit an Annual Report no later than September 1 of each year.

B. The discharger shall certify each Annual Report in accordance with the Special Provisions.

C. The discharger shall retain an electronic or paper copy of each Annual Report for a minimum of three years after the date the annual report is filed.

D. The discharger shall include storm water monitoring information in the Annual Report consisting of:

1. a summary and evaluation of all sampling and analysis results, including copies of laboratory reports;

2. the analytical method(s), method reporting unit(s), and method detection limit(s) of each analytical parameter (analytical results that are less than the method detection limit shall be reported as "less than the method detection limit");

3. a summary of all corrective actions taken during the compliance year;

4. identification of any compliance activities or corrective actions that were not implemented;

5. a summary of all violations of the General Permit;

6. the names of individual(s) who performed the facility inspections, sampling, visual observation (inspections), and/or measurements;

7. the date, place, time of facility inspections, sampling, visual observation (inspections), and/or measurements, including precipitation (rain gauge); and

8. the visual observation and sample collection exception records and reports specified in Attachments C, D, and E.

E. The discharger shall provide training information in the Annual Report consisting of:

1. documentation of all training for individuals responsible for all activities associated with compliance with this General Permit;

2. documentation of all training for individuals responsible for BMP installation, inspection, maintenance, and repair; and

3. documentation of all training for individuals responsible for overseeing, revising, and amending the SWPPP.

CALIFORNIA Water Boards

Edmund G. Brown Jr.
Governor

Matthew Rodriquez
Secretary for Environmental Protection

State Water Resources Control Board

CONSTRUCTION GENERAL PERMIT POST-CONSTRUCTION REQUIREMENT NOTIFICATION

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) GENERAL PERMIT FOR STORM WATER DISCHARGES ASSOCIATED WITH CONSTRUCTION AND LAND DISTURBANCE ACTIVITIES

Dischargers covered under the National Pollutant Discharge Elimination System General Permit for Storm Water Discharges Associated with Construction and Land Disturbance Activity, State Water Resources Control Board Order No. 2009-0009-DWQ as amended by 2010-0014-DWQ (CGP) on or after September 2, 2012, are required to comply with the run-off reduction requirements in Section XIII(A).

Exemption for Dischargers Located in Municipal Separate Storm Sewer Systems (MS4s)
Dischargers with construction sites that are located within a municipality permitted by a Phase I or II municipal separate storm sewer system (MS4) permit with an approved Storm Water Management Plan (SWMP) containing post construction standards are not subject to this provision. However, Dischargers must notify the Water Boards that they qualify for this exemption by submitting and certifying information to support this exemption via the State Water Board's Stormwater Multi-Application, Reporting and Tracking System (SMARTS).

Dischargers Covered on September 2, 2012 (Existing Dischargers)
CGP Section XIII(A)(2) requires Dischargers to submit via SMARTS a map and worksheet in accordance with the instructions of Appendix 2 of the CGP for **all portions of the construction site** by September 2, 2012. In other words, complete the screens in SMARTS for post construction prior to September 2, 2012, for all areas of the site that will be covered on or after September 2, 2012.

CGP Sections XIII(A)(3) and (4) of the CGP require the Discharger to comply with performance-based elements, which will most likely be evaluated for compliance at the point of termination of coverage (either partial or complete) under the CGP. Dischargers may amend the worksheet as often as needed prior to submitting a Notice of Termination (NOT) or Change of Information (COI) that reduces the area of coverage.

To demonstrate compliance with these requirements, all Existing Dischargers must:

1) Log into SMARTS at: https://smarts.waterboards.ca.gov
2) Click "Approved/Terminated NOIs"
3) Select the appropriate Application ID number
4) Reductions in acreage should be completed through the "COI" tab
5) Select the "Post-Construction" tab to complete the Run-off reduction worksheet screens[1]

[1] Construction sites located within a municipality permitted by a Phase I or II MS4 permit with an approved SWMP containing post construction standards must only answer "yes" to the first question in the "Post-Construction" tab.

New Dischargers Covered After September 2, 2012 (New Dischargers)
CGP Section XIII(A)(2) requires all new Dischargers seeking permit coverage on or after September 2, 2012, to submit via SMARTS a map and worksheet in accordance with the instructions of Appendix 2 of the CGP for **all portions of the construction site**. In other words, a site seeking CGP coverage on or after September 2, 2012, must complete the screens in SMARTS for post construction as part of their permit registration documents (PRDs).

CGP Sections XIII(A)(3) and (4) of the CGP require the Discharger to comply with performance-based elements, which will most likely be evaluated for compliance at the point of termination (either partial or complete) of coverage under the CGP. Dischargers may amend the worksheet as often as needed prior to submitting a Notice of Termination (NOT) or Change of Information (COI) that reduces the area of coverage.

To demonstrate compliance with these requirements, all New Dischargers must:

1) Log into SMARTS at: https://smarts.waterboards.ca.gov
2) Click “Apply for New Notice of Intent (NOI)”
3) Select the Construction Storm Water General Permit permit type
4) Complete the process to start an NOI for the new facility
5) Select the “Post-Construction” tab to complete the Run-off reduction worksheet screens[1]

Please note that failure to comply with any of the requirements in the CGP, including these run-off reduction-related requirements effective September 2, 2012, may result in administrative enforcement by the Water Boards, including, but not limited to, administrative civil liabilities (penalties) up to $10,000 per day of violation. Failure to comply with the CGP may also result in the potential for enforcement by other entities.

The CGP is available on the State Water Resources Control Board’s website at:
http://www.waterboards.ca.gov/water_issues/programs/stormwater/constpermits.shtml

Please contact the Storm Water Help Desk if you have any questions. 1-866-563-3107 or stormwater@waterboards.ca.gov

APPENDIX 2:
Post-Construction Water Balance Performance Standard Spreadsheet

The discharger shall submit with their Notice of Intent (NOI) the following information to demonstrate compliance with the New and Re-Development Water Balance Performance Standard.

Map Instructions

The discharger must submit a small-scale topographic map of the site to show the existing contour elevations, pre- and post-construction drainage divides, and the total length of stream in each watershed area. Recommended scales include 1 in. = 20 ft., 1 in. = 30 ft., 1 in. = 40 ft., or 1 in = 50 ft. The suggested contour interval is usually 1 to 5 feet, depending upon the slope of the terrain. The contour interval may be increased on steep slopes. Other contour intervals and scales may be appropriate given the magnitude of land disturbance.

Spreadsheet Instructions

The intent of the spreadsheet is to help dischargers calculate the project-related increase in runoff volume and select impervious area and runoff reduction credits to reduce the project-related increase in runoff volume to pre-project levels.

The discharger has the option of using the spreadsheet (**Appendix 2.1)** or a more sophisticated, watershed process-based model (e.g. Storm Water Management Model, Hydrological Simulation Program Fortran) to determine the project-related increase in runoff volume.

In* Appendix 4.1**, ***you must complete the worksheet for each land use/soil type combination for each project sub-watershed.

Steps 1 through 9 pertain specifically to the Runoff Volume Calculator:

Step 1: Enter the county where the project is located in cell H3.

Step 2: Enter the soil type in cell H6.

Step 3: Enter the existing pervious (dominant) land use type in cell H7.

Step 4: Enter the proposed pervious (dominant) land use type in cell H8.

Step 5: Enter the total project site area in cell H11 or J11.

Step 6: Enter the sub-watershed area in cell H12 or J12.

Step 7: Enter the existing rooftop area in cell H17 or J17, the existing non-rooftop impervious area in cell H18 or J18, the proposed rooftop area in cell H19 or J19, and the proposed non-rooftop impervious area in cell H20 or J20

Step 8: Work through each of the impervious area reduction credits and claim credits where applicable. Volume that cannot be addressed using non-structural practices must be captured in structural practices and approved by the Regional Water Board.

Step 9: Work through each of the impervious volume reduction credits and claim credits where applicable. Volume that cannot be addressed using non-structural practices must be captured in structural practices and approved by the Regional Water Board.

Non-structural Practices Available for Crediting

- ***Porous Pavement***
- ***Tree Planting***
- ***Downspout Disconnection***
- ***Impervious Area Disconnection***
- ***Green Roof***
- ***Stream Buffer***
- ***Vegetated Swales***
- ***Rain Barrels and Cisterns***
- ***Landscaping Soil Quality***

ATTACHMENT A
Linear Underground/ Overhead Requirements

All Linear Underground/Overhead project dischargers who submit permit registration documents (PRDs) indicating their intention to be regulated under the provisions of this General Permit shall comply with the following:

A. DEFINITION OF LINEAR UNDERGROUND/OVERHEAD PROJECTS

1. Linear Underground/Overhead Projects (LUPs) include, but are not limited to, any conveyance, pipe, or pipeline for the transportation of any gaseous, liquid (including water and wastewater for domestic municipal services), liquiescent, or slurry substance; any cable line or wire for the transmission of electrical energy; any cable line or wire for communications (e.g., telephone, telegraph, radio, or television messages); and associated ancillary facilities. Construction activities associated with LUPs include, but are not limited to, (a) those activities necessary for the installation of underground and overhead linear facilities (e.g., conduits, substructures, pipelines, towers, poles, cables, wires, connectors, switching, regulating and transforming equipment, and associated ancillary facilities); and include, but are not limited to, (b) underground utility mark-out, potholing, concrete and asphalt cutting and removal, trenching, excavation, boring and drilling, access road and pole/tower pad and cable/wire pull station, substation construction, substructure installation, construction of tower footings and/or foundations, pole and tower installations, pipeline installations, welding, concrete and/ or pavement repair or replacement, and stockpile/borrow locations.

2. LUP evaluation shall consist of two tasks:

a. Confirm that the project or project section(s) qualifies as an LUP. The State Water Board website contains a project determination guidance flowchart. http://www.waterboards.ca.gov/water_issues/programs/stormwater/constpermits.shtml

b. Identify which Type(s) (1, 2 or 3 described in Section I below) are applicable to the project or project sections based on project sediment and receiving water risk. (See Attachment A.1)

3. A Legally Responsible Person (LRP) for a Linear Underground/Overhead project is required to obtain CGP coverage under one or more permit registration document (PRD) electronic submittals to the State Water Board's Storm Water Multi-Application and Report Tracking (SMARTs) system. Attachment A.1 contains a flow chart to be used when determining if a linear project qualifies for coverage and to determine LUP Types. Since a LUP may be constructed within both developed and undeveloped locations and portions of LUPs may be constructed by different contractors, LUPs may be broken into logical permit sections. Sections may be determined based on portions of a project conducted by one contractor. Other situations may also occur, such as the time period in which the sections of a project will be constructed (e.g. project phases), for which separate permit coverage is possible. For projects that are broken into separate sections, a description of how each section relates to the overall project and the definition of the boundaries between sections shall be clearly stated.

4. Where construction activities transverse or enter into different Regional Water Board jurisdictions, LRPs shall obtain permit coverage for each Regional Water Board area involved prior to the commencement of construction activities.

5. Small Construction Rainfall Erosivity Waiver

EPA's Small Construction Erosivity Waiver applies to sites between one and five acres demonstrating that there are no adverse water quality impacts.

Dischargers eligible for a Rainfall Erosivity Waiver based on low erosivity potential shall complete the electronic Notice of Intent (NOI) and Sediment Risk form through the State Water Board's SMARTS system, certifying that the construction activity will take place during a period when the value of the rainfall erosivity factor is less than five. Where the LRP changes or another LRP is added during construction, the new LRP must also submit a waiver certification through the SMARTS system.

If a small linear construction site continues beyond the projected completion date given on the waiver certification, the LRP shall recalculate the rainfall erosivity factor for the new project duration and submit this information through the SMARTS system. If the new R factor is below five (5), the discharger shall update through SMARTS all applicable information on the waiver certification and retain a copy of the revised waiver onsite. The LRP shall submit the new waiver certification 30 days prior to the projected completion date listed on the original waiver form to assure exemption from permitting requirements is uninterrupted. If the new R factor is five (5) or above, the LRP shall be required to apply for coverage under this Order.

B. LINEAR PROJECT PERMIT REGISTRATION DOCUMENTS (PRDs)

Any information provided to the Regional Water Board shall comply with the Homeland Security Act and any other federal law that concerns security in the United States; any information that does not comply should not be submitted. PRDs shall consist of the following:

1. Notice of Intent (NOI)

Prior to construction activities, the LRP of a proposed linear underground/overhead project shall utilize the processes and methods provided in Attachment A.2, Permit Registration Documents (PRDs) – General Instructions for Linear Underground/Overhead Projects to comply with the Construction General Permit.

2. Site Maps

LRPs submitting PRDs shall include at least 3 maps. The first map will be a zoomed[1] 1000-1500 ft vicinity map that shows the starting point of the project. The second will be a zoomed map of 1000-1500 ft showing the ending location of the project. The third will be a larger view vicinity map, 1000 ft to 2000 ft, displaying the entire project location depending on the project size, and indicating the LUP type (1, 2 or 3) areas within the total project footprint.

3. Drawings

LRPs submitting PRDs shall include a construction drawing(s) or other appropriate drawing(s) or map(s) that shows the locations of storm drain

[1] An image with a close-up/enhanced detailed view of site features that show minute details such as streets and neighboring structures.
Or: An image with a close-up/enhanced detailed view of the site's surrounding infrastructure.
Or: An image with a close up detailed view of the project and its surroundings.

inlets and waterbodies[2] that may receive discharges from the construction activities and that shows the locations of BMPs to be installed for all those BMPs that can be illustrated on the revisable drawing(s) or map(s). If storm drain inlets, waterbodies, and/or BMPs cannot be adequately shown on the drawing(s) or map(s) they should be described in detail within the SWPPP.

4. Storm Water Pollution Prevention Plan (SWPPP)

LUP dischargers shall comply with the SWPPP Preparation, Implementation, and Oversight requirements in Section K of this Attachment.

5. Contact information

LUP dischargers shall include contact information for all contractors (or subcontractors) responsible for each area of an LUP project. This should include the names, telephone numbers, and addresses of contact personnel. Specific areas of responsibility of each contact, and emergency contact numbers should also be included.

6. In the case of a public emergency that requires immediate construction activities, a discharger shall submit a brief description of the emergency construction activity within five days of the onset of construction, and then shall submit all PRDs within thirty days.

C. LINEAR PROJECT TERMINATION OF COVERAGE REQUIREMENTS

The LRP may terminate coverage of an LUP when construction activities are completed by submitting an electronic notice of termination (NOT) through the State Water Board's SMARTS system. Termination requirements are different depending on the complexity of the LUP. An LUP is considered complete when: (a) there is no potential for construction-related storm water pollution; (b) all elements of the SWPPP have been completed; (c) construction materials and waste have been disposed of properly; (d) the site is in compliance with all local storm water management requirements; and (e) the LRP submits a notice of termination (NOT) and has received approval for termination from the appropriate Regional Water Board office.

1. LUP Stabilization Requirements

The LUP discharger shall ensure that all disturbed areas of the construction site are stabilized prior to termination of coverage under this General Permit. Final stabilization for the purposes of submitting an NOT

[2] Includes basin(s) that the MS4 storm sewer systems may drain to for Hydromodification or Hydrological Conditional of Concerns under the MS4 permits.

is satisfied when all soil disturbing activities are completed and one of the following criteria is met:

a. In disturbed areas that were vegetated prior to construction activities of the LUP, the area disturbed must be re-established to a uniform vegetative cover equivalent to 70 percent coverage of the preconstruction vegetative conditions. Where preconstruction vegetation covers less than 100 percent of the surface, such as in arid areas, the 70 percent coverage criteria is adjusted as follows: if the preconstruction vegetation covers 50 percent of the ground surface, 70 percent of 50 percent (.70 X .50=.35) would require 35 percent total uniform surface coverage; or

b. Where no vegetation is present prior to construction, the site is returned to its original line and grade and/or compacted to achieve stabilization; or

c. Equivalent stabilization measures have been employed. These measures include, but are not limited to, the use of such BMPs as blankets, reinforced channel liners, soil cement, fiber matrices, geotextiles, or other erosion resistant soil coverings or treatments.

2. LUP Termination of Coverage Requirements

The LRP shall file an NOT through the State Water Board's SMARTS system. By submitting an NOT, the LRP is certifying that construction activities for an LUP are complete and that the project is in full compliance with requirements of this General Permit and that it is now compliant with soil stabilization requirements where appropriate. Upon approval by the appropriate Regional Water Board office, permit coverage will be terminated.

3. Revising Coverage for Change of Acreage

When the LRP of a portion of an LUP construction project changes, or when a phase within a multi-phase project is completed, the LRP may reduce the total acreage covered by this General Permit. In reducing the acreage covered by this General Permit, the LRP shall electronically file revisions to the PRDs that include:

a. a revised NOI indicating the new project size;

b. a revised site map showing the acreage of the project completed, acreage currently under construction, acreage sold, transferred or added, and acreage currently stabilized.

c. SWPPP revisions, as appropriate; and

d. certification that any new LRPs have been notified of applicable requirements to obtain General Permit coverage. The certification shall include the name, address, telephone number, and e-mail address (if known) of the new LRP.

If the project acreage has increased, dischargers shall mail payment of revised annual fees within 14 days of receiving the revised annual fee notification.

D. DISCHARGE PROHIBITIONS

1. LUP dischargers shall not violate any discharge prohibitions contained in applicable Basin Plans or statewide water quality control plans. Waste discharges to Areas of Special Biological Significance (ASBS) are prohibited by the California Ocean Plan, unless granted an exception issued by the State Water Board.

2. LUP dischargers are prohibited from discharging non-storm water that is not otherwise authorized by this General Permit. Non-storm water discharges authorized by this General Permit[3] may include, fire hydrant flushing, irrigation of vegetative erosion control measures, pipe flushing and testing, water to control dust, street cleaning, dewatering,[4] uncontaminated groundwater from dewatering, and other discharges not subject to a separate general NPDES permit adopted by a Regional Water Board. Such discharges are allowed by this General Permit provided they are not relied upon to clean up failed or inadequate construction or post-construction BMPs designed to keep materials on site. These authorized non-storm water discharges:

[3] Dischargers must identify all authorized non-storm water discharges in the LUP's SWPPP and identify BMPs that will be implemented to either eliminate or reduce pollutants in non-storm water discharges. Regional Water Boards may direct the discharger to discontinue discharging such non-storm water discharges if determined that such discharges discharge significant pollutants or threaten water quality.

[4] Dewatering activities may be prohibited or need coverage under a separate permit issued by the Regional Water Boards. Dischargers shall check with the appropriate Regional Water Boards for any required permit or basin plan conditions prior to initial dewatering activities to land, storm drains, or waterbodies.

a. Shall not cause or contribute to a violation of any water quality standard;

b. Shall not violate any other provision of this General Permit;

c. Shall not violate any applicable Basin Plan;

d. Shall comply with BMPs as described in the SWPPP;

e. Shall not contain toxic constituents in toxic amounts or (other) significant quantities of pollutants;

f. Shall be monitored and meets the applicable NALs and NELs; and

g. Shall be reported by the discharger in the Annual Report.

If any of the above conditions are not satisfied, the discharge is not authorized by this General Permit. The discharger shall notify the Regional Water Board of any anticipated non-storm water discharges not authorized by this General Permit to determine the need for a separate NPDES permit.

Additionally, some LUP dischargers may be required to obtain a separate permit if the applicable Regional Water Board has adopted a General Permit for dewatering discharges. Wherever feasible, alternatives, that do not result in the discharge of non-storm water, shall be implemented in accordance with this Attachment's Section K.2 - SWPPP Implementation Schedule.

3. LUP dischargers shall ensure that trench spoils or any other soils disturbed during construction activities that are contaminated[5] are not discharged with storm water or non-storm water discharges into any storm drain or water body except pursuant to an NPDES permit.

When soil contamination is found or suspected and a responsible party is not identified, or the responsible party fails to promptly take the appropriate action, the LUP discharger shall have those soils sampled and tested to ensure that proper handling and public safety measures are

[5] Contaminated soil contains pollutants in concentrations that exceed the appropriate thresholds that various regulatory agencies set for those substances. Preliminary testing of potentially contaminated soils will be based on odor, soil discoloration, or prior history of the site's chemical use and storage and other similar factors. When soil contamination is found or suspected and a responsible party is not identified, or the responsible party fails to promptly take the appropriate action, the discharger shall have those soils sampled and tested to ensure proper handling and public safety measures are implemented. The legally responsible person will notify the appropriate local, State, or federal agency(ies) when contaminated soil is found at a construction site, and will notify the Regional Water Board by submitting an NOT at the completion of the project.

implemented. The LUP discharger shall notify the appropriate local, State, and federal agency(ies) when contaminated soil is found at a construction site, and will notify the appropriate Regional Water Board.

4. Discharging any pollutant-laden water that will cause or contribute to an exceedance of the applicable Regional Water Board's Basin Plan from a dewatering site or sediment basin into any receiving water or storm drain is prohibited.

5. Debris[6] resulting from construction activities are prohibited from being discharged from construction project sites.

E. SPECIAL PROVISIONS

1. Duty to Comply

a. The LUP discharger must comply with all of the conditions of this General Permit. Any permit noncompliance constitutes a violation of the Clean Water Act (CWA) and the Porter-Cologne Water Quality Control Act and is grounds for enforcement action and/or removal from General Permit coverage.

b. The LUP discharger shall comply with effluent standards or prohibitions established under Section 307(a) of the CWA for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if this General Permit has not yet been modified to incorporate the requirement.

2. General Permit Actions

a. This General Permit may be modified, revoked and reissued, or terminated for cause. The filing of a request by the discharger for a General Permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance does not annul any General Permit condition.

[6] Litter, rubble, discarded refuse, and remains of something destroyed.

b. If any toxic effluent standard or prohibition (including any schedule of compliance specified in such effluent standard or prohibition) is promulgated under Section 307(a) of the CWA for a toxic pollutant which is present in the discharge and that standard or prohibition is more stringent than any limitation on the pollutant in this General Permit, this General Permit shall be modified or revoked and reissued to conform to the toxic effluent standard or prohibition and the dischargers so notified.

3. Need to Halt or Reduce Activity Not a Defense

It shall not be a defense for an LUP discharger in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this General Permit.

4. Duty to Mitigate

The LUP discharger shall take all responsible steps to minimize or prevent any discharge in violation of this General Permit, which has a reasonable likelihood of adversely affecting human health or the environment.

5. Proper Operation and Maintenance

The LUP discharger shall at all times properly operate and maintain any facilities and systems of treatment and control (and related appurtenances) which are installed or used by the discharger to achieve compliance with the conditions of this General Permit and with the requirements of the Storm Water Pollution Prevention Plan (SWPPP). Proper operation and maintenance also includes adequate laboratory controls and appropriate quality assurance procedures. Proper operation and maintenance may require the operation of backup or auxiliary facilities or similar systems installed by a discharger when necessary to achieve compliance with the conditions of this General Permit.

6. Property Rights

This General Permit does not convey any property rights of any sort or any exclusive privileges, nor does it authorize any injury to private property or any invasion of personal rights, nor does it authorize any infringement of Federal, State, or local laws or regulations.

7. Duty to Maintain Records and Provide Information

a. The LUP discharger shall maintain a paper or electronic copy of all required records, including a copy of this General Permit, for three years from the date generated or date submitted, whichever is last. These records shall be kept at the construction site or in a crew member's vehicle until construction is completed, and shall be made available upon request.

b. The LUP discharger shall furnish the Regional Water Board, State Water Board, or USEPA, within a reasonable time, any requested information to determine compliance with this General Permit. The LUP discharger shall also furnish, upon request, copies of records that are required to be kept by this General Permit.

8. Inspection and Entry

The LUP discharger shall allow the Regional Water Board, State Water Board, USEPA, and/or, in the case of construction sites which discharge through a municipal separate storm sewer, an authorized representative of the municipal operator of the separate storm sewer system receiving the discharge, upon the presentation of credentials and other documents as may be required by law, to:

a. Enter upon the discharger's premises at reasonable times where a regulated construction activity is being conducted or where records must be kept under the conditions of this General Permit;

b. Access and copy at reasonable times any records that must be kept under the conditions of this General Permit;

c. Inspect at reasonable times the complete construction site, including any off-site staging areas or material storage areas, and the erosion/sediment controls; and

d. Sample or monitor at reasonable times for the purpose of ensuring General Permit compliance.

9. Electronic Signature and Certification Requirements

a. All Permit Registration Documents (PRDs) and Notices of Termination (NOTs) shall be electronically signed, certified, and submitted via SMARTS to the State Water Board. Either the Legally Responsible Person (LRP), as defined in Appendix 5 – Glossary, or a person legally authorized to sign and certify PRDs and NOTs on behalf of the LRP (the LRP's Approved Signatory, as defined in Appendix 5 - Glossary) must submit all information electronically via SMARTS.

b. Changes to Authorization. If an Approved Signatory's authorization is no longer accurate, a new authorization satisfying the requirements of paragraph (a) of this section must be submitted via SMARTS prior to or together with any reports, information or applications to be signed by an Approved Signatory.

c. All SWPPP revisions, annual reports, or other information required by the General Permit (other than PRDs and NOTs) or requested by the Regional Water Board, State Water Board, USEPA, or local storm water management agency shall be certified and submitted by the LRP or the LRP's Approved Signatory.

10. Certification

Any person signing documents under Section E.9 above, shall make the following certification:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system or those persons directly responsible for gathering the information, to the best of my knowledge and belief, the information submitted is, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

11. Anticipated Noncompliance

The LUP discharger shall give advance notice to the Regional Water Board and local storm water management agency of any planned changes in the construction activity, which may result in noncompliance with General Permit requirements.

12. Penalties for Falsification of Reports

Section 309(c)(4) of the CWA provides that any person who knowingly makes any false material statement, representation, or certification in any record or other document submitted or required to be maintained under this General Permit, including reports of compliance or noncompliance shall upon conviction, be punished by a fine of not more than $10,000 or by imprisonment for not more than two years or by both.

13. Oil and Hazardous Substance Liability

Nothing in this General Permit shall be construed to preclude the institution of any legal action or relieve the discharger from any responsibilities, liabilities, or penalties to which the LUP discharger is or may be subject to under Section 311 of the CWA.

14. Severability

The provisions of this General Permit are severable; and, if any provision of this General Permit or the application of any provision of this General Permit to any circumstance is held invalid, the application of such provision to other circumstances and the remainder of this General Permit shall not be affected thereby.

15. Reopener Clause

This General Permit may be modified, revoked and reissued, or terminated for cause due to promulgation of amended regulations, receipt of USEPA guidance concerning regulated activities, judicial decision, or in accordance with 40 Code of Federal Regulations (CFR) 122.62, 122.63, 122.64, and 124.5.

16. Penalties for Violations of Permit Conditions

a. Section 309 of the CWA provides significant penalties for any person who violates a permit condition implementing Sections 301, 302, 306, 307, 308, 318, or 405 of the CWA or any permit condition or limitation implementing any such section in a permit issued under Section 402. Any person who violates any permit condition of this General Permit is subject to a civil penalty not to exceed $37,500[7] per calendar day of such violation, as well as any other appropriate sanction provided by Section 309 of the CWA.

b. The Porter-Cologne Water Quality Control Act also provides for civil and criminal penalties, which in some cases are greater than those under the CWA.

17. Transfers

This General Permit is not transferable. A new LRP of an ongoing construction activity must submit PRDs in accordance with the requirements of this General Permit to be authorized to discharge under this General Permit. An LRP who is a property owner with active General Permit coverage who sells a fraction or all the land shall inform the new property owner(s) of the requirements of this General Permit.

18. Continuation of Expired Permit

This General Permit continues in force and effect until a new General Permit is issued or the SWRCB rescinds this General Permit. Only those

[7] May be further adjusted in accordance with the Federal Civil Penalties Inflation Adjustment Act

dischargers authorized to discharge under the expiring General Permit are covered by the continued General Permit.

F. EFFLUENT STANDARDS

1. Narrative Effluent Limitations

a. LUP dischargers shall ensure that storm water discharges and authorized non-storm water discharges regulated by this General Permit do not contain a hazardous substance equal to or in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

b. LUP dischargers shall minimize or prevent pollutants in storm water discharges and authorized non-storm water discharges through the use of structural or non-structural controls, structures, and management practices that achieve BAT for toxic and non-conventional pollutants and BCT for conventional pollutants.

2. Numeric Effluent Limitations (NELs)

Table 1. Numeric Effluent Limitations, Numeric Action Levels, Test Methods, Detection Limits, and Reporting Units

Parameter	Test Method	Discharge Type	Min. Detection Limit	Units	Numeric Action Level	Numeric Effluent Limitation
pH	Field test with calibrated portable instrument	LUP Type 2	0.2	pH units	lower NAL = 6.5 upper NAL = 8.5	N/A
		LUP Type 3			lower NAL = 6.5 upper NAL = 8.5	lower NEL = 6.0 upper NEL = 9.0
Turbidity	EPA 0180.1 and/or field test with calibrated portable instrument	LUP Type 2	1	NTU	250 NTU	N/A
		LUP Type 3			250 NTU	500 NTU

a. Numeric Effluent Limitations (NELs):

i **Storm Event, Daily Average pH Limits –** For LUP Type 3 dischargers, the daily average pH of storm water and non-storm water discharges shall be within the ranges specified in Table 1 during any project phase where there is a "high risk of pH discharge."[8]

ii **Storm Event Daily Average Turbidity Limit –** For LUP Type 3 dischargers, the daily average turbidity of storm water and non-storm water discharges shall not exceed 500 NTU.

[8] A period of high risk of pH discharge is defined as a project's complete utilities phase, complete vertical build phase, and any portion of any phase where significant amounts of materials are placed directly on the land at the site in a manner that could result in significant alterations of the background pH of the discharges.

b. If a daily average sample result is outside the range of pH NELs (i.e., is below the lower NEL for pH or exceeds the upper NEL for pH) or exceeds the turbidity NEL (as listed in Table 1), the discharger is in violation of this General Permit and shall electronically file the results in violation within 5 business days of obtaining the results.

c. Compliance Storm Event:

Discharges of storm water from LUP Type 3 sites shall comply with applicable NELs (above) unless the storm event causing the discharges is determined after the fact to be equal to or larger than the Compliance Storm Event (expressed in inches of rainfall). The Compliance Storm Event for LUP Type 3 discharges is the 5-year, 24-hour storm (expressed in tenths of an inch of rainfall), as determined by using these maps:

http://www.wrcc.dri.edu/pcpnfreq/nca5y24.gif
http://www.wrcc.dri.edu/pcpnfreq/sca5y24.gif

Compliance storm event verification shall be done by reporting on-site rain gauge readings as well as nearby governmental rain gauge readings.

d. Dischargers shall not be required to comply with NELs if the site receives run-on from a forest fire or any other natural disaster.

3. Numeric Action Levels (NALs)

a. For LUP Type 2 and 3 dischargers, the lower storm event daily average NAL for pH is 6.5 pH units and the upper storm event daily average NAL for pH is 8.5 pH units. The LUP discharger shall take actions as described below if the storm event daily average discharge is outside of this range of pH values.

b. For LUP Type 2 and 3 dischargers, the storm event daily average NAL for turbidity is 250 NTU. The discharger shall take actions as described below if the storm event daily average discharge is outside of this range of turbidity values.

c. Whenever daily average analytical effluent monitoring results indicate that the discharge is below the lower NAL for pH, exceeds the upper NAL for pH, or exceeds the turbidity NAL (as listed in Table 1), the LUP discharger shall conduct a construction site and run-on evaluation to determine whether pollutant source(s) associated with the site's construction activity may have caused or contributed to the NAL exceedance and shall immediately implement corrective actions if they are needed.

d. The site evaluation will be documented in the SWPPP and specifically address whether the source(s) of the pollutants causing the exceedance of the NAL:

i Are related to the construction activities and whether additional BMPs or SWPPP implementation measures are required to (1) meet BAT/BCT requirements; (2) reduce or prevent pollutants in storm water discharges from causing exceedances of receiving water objectives; and (3) determine what corrective action(s) were taken or will be taken and with a description of the schedule for completion.

AND/OR:

ii Are related to the run-on associated with the construction site location and whether additional BMPs or SWPPP implementation measures are required to (1) meet BAT/BCT requirements; (2) reduce or prevent pollutants in storm water discharges from causing exceedances of receiving water objectives; and (3) decide what corrective action(s) were taken or will be taken, including a description of the schedule for completion.

G. RECEIVING WATER LIMITATIONS

1. LUP dischargers shall ensure that storm water discharges and authorized non-storm water discharges to any surface or ground water will not adversely affect human health or the environment.

2. LUP dischargers shall ensure that storm water discharges and authorized non-storm water discharges will not contain pollutants in quantities that threaten to cause pollution or a public nuisance.

3. LUP dischargers shall ensure that storm water discharges and authorized non-storm water discharges will not contain pollutants that cause or contribute to an exceedance of any applicable water quality objectives or water quality standards (collectively, WQS) contained in a Statewide Water Quality Control Plan, the California Toxics Rule, the National Toxics Rule, or the applicable Regional Water Board's Water Quality Control Plan (Basin Plan).

H. TRAINING QUALIFICATIONS

1. General

All persons responsible for implementing requirements of this General Permit shall be appropriately trained. Training should be both formal and informal, occur on an ongoing basis, and should include training offered by recognized governmental agencies or professional organizations. Persons responsible for preparing, amending and certifying SWPPPs shall comply with the requirements in this Section H.

2. SWPPP Certification Requirements

a. **Qualified SWPPP Developer:** The LUP discharger shall ensure that all SWPPPs be written, amended and certified by a Qualified SWPPP Developer (QSD). A QSD shall have one of the following registrations or certifications, and appropriate experience, as required for:

i A California registered professional civil engineer;

ii A California registered professional geologist or engineering geologist;

iii A California registered landscape architect;

iv A professional hydrologist registered through the American Institute of Hydrology;

v A certified professional in erosion and sediment control (CPESC) TM registered through Enviro Cert International, Inc;

vi A certified professional in storm water quality (CPSWQ)TM registered through Enviro Cert International, Inc.; or

vii A certified professional in erosion and sediment control registered through the National Institute for Certification in Engineering Technologies (NICET).

Effective two years after the adoption date of this General Permit, a QSD shall have attended a State Water Board-sponsored or approved QSD training course.

b. The LUP discharger shall ensure that the SWPPP is written and amended, as needed, to address the specific circumstances for each construction site covered by this General Permit prior to commencement of construction activity for any stage.

c. The LUP discharger shall list the name and telephone number of the currently designated Qualified SWPPP Developer(s) in the SWPPP.

d. **Qualified SWPPP Practitioner:** The LUP discharger shall ensure that all elements of any SWPPP for each project will be implemented by a Qualified SWPPP Practitioner (QSP). A QSP is a person responsible for non-storm water and storm water visual observations, sampling and analysis, and for ensuring full compliance with the permit and implementation of all elements of the SWPPP. Effective two years from the date of adoption of this General Permit, a QSP shall be either a QSD or have one of the following certifications:

   i A certified erosion, sediment and storm water inspector registered through Certified Professional in Erosion and Sediment Control, Inc.; or

   ii A certified inspector of sediment and erosion control registered through Certified Inspector of Sediment and Erosion Control, Inc.

   Effective two years after the adoption date of this General Permit, a QSP shall have attended a State Water Board-sponsored or approved QSP training course.

e. The LUP discharger shall ensure that the SWPPP include a list of names of all contractors, subcontractors, and individuals who will be directed by the Qualified SWPPP Practitioner, and who is ultimately responsible for implementation of the SWPPP. This list shall include telephone numbers and work addresses. Specific areas of responsibility of each subcontractor and emergency contact numbers shall also be included.

f. The LUP discharger shall ensure that the SWPPP and each amendment be signed by the Qualified SWPPP Developer. The LUP discharger shall include a listing of the date of initial preparation and the dates of each amendment in the SWPPP.

I. TYPES OF LINEAR PROJECTS

This attachment establishes three types (Type 1, 2 & 3) of complexity for areas within an LUP or project section based on threat to water quality. Project area Types are determined through Attachment A.1.

The Type 1 requirements below establish the baseline requirements for all LUPs subject to this General Permit. Additional requirements for Type 2 and Type 3 LUPs are labeled.

1. **Type 1 LUPs***:*

   LUP dischargers with areas of a LUP designated as Type 1 shall comply with the requirements in this Attachment. Type 1 LUPs are:

   a. Those construction areas where 70 percent or more of the construction activity occurs on a paved surface and where areas disturbed during construction will be returned to preconstruction conditions or equivalent protection established at the end of the construction activities for the day; or

   b. Where greater than 30 percent of construction activities occur within the non-paved shoulders or land immediately adjacent to paved surfaces, or where construction occurs on unpaved improved roads, including their shoulders or land immediately adjacent to them where:

      i Areas disturbed during construction will be returned to preconstruction conditions or equivalent protection is established at the end of the construction activities for the day to minimize the potential for erosion and sediment deposition, and

      ii Areas where established vegetation was disturbed during construction will be stabilized and re-vegetated by the end of project. When required, adequate temporary stabilization BMPs will be installed and maintained until vegetation is established to meet minimum cover requirements established in this General Permit for final stabilization.

   c. Where the risk determination is as follows:

      i Low sediment risk, low receiving water risk, or

      ii Low sediment risk, medium receiving water risk, or

      iii Medium sediment risk, low receiving water risk

2. **Type 2 LUPs**:

Type 2 LUPs are determined by the Combined Risk Matrix in Attachment A.1. Type 2 LUPs have the specified combination of risk:

d. High sediment risk, low receiving water risk, or

e. Medium sediment risk, medium receiving water risk, or

f. Low sediment risk, high receiving water risk

Receiving water risk is either considered "Low" for those areas of the project that are not in close proximity to a sensitive receiving watershed, "Medium" for those areas of the project within a sensitive receiving watershed yet outside of the flood plain of a sensitive receiving water body, and "High" where the soil disturbance is within close proximity to a sensitive receiving water body. Project sediment risk is calculated based on the Risk Factor Worksheet in Attachment C of this General Permit.

3. Type 3 LUPs:

Type 3 LUPs are determined by the Combined Risk Matrix in Attachment A.1. Type 3 LUPs have the specified combination of risk:

a. High sediment risk, high receiving water risk, or

b. High sediment risk, medium receiving water risk, or

c. Medium sediment risk, high receiving water risk

Receiving water risk is either considered "Medium" for those areas of the project within a sensitive receiving watershed yet outside of the flood plain of a sensitive receiving water body, or "High" where the soil disturbance is within close proximity to a sensitive receiving water body. Project sediment risk is calculated based on the Risk Factor Worksheet in Attachment C.

J. LUP TYPE-SPECIFIC REQUIREMENTS

1. Effluent Standards

a. Narrative – LUP dischargers shall comply with the narrative effluent standards below.

   i Storm water discharges and authorized non-storm water discharges regulated by this General Permit shall not contain a hazardous substance equal to or in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

ii LUP dischargers shall minimize or prevent pollutants in storm water discharges and authorized non-storm water discharges through the use of controls, structures, and management practices that achieve BAT for toxic and non-conventional pollutants and BCT for conventional pollutants.

b. Numeric – LUP Type 1 dischargers are not subject to a numeric effluent standard

c. Numeric –LUP Type 2 dischargers are subject to a pH NAL of 6.5-8.5, and a turbidity NAL of 250 NTU.

d. Numeric – LUP Type 3 dischargers are subject to a pH NAL of 6.5-8.5, and a turbidity NAL of 250 NTU. In addition, LUP Type 3 dischargers are subject to a pH NEL of 6.0-9.0 and a turbidity NEL of 500 NTU.

2. Good Site Management "Housekeeping"

a. LUP dischargers shall implement good site management (i.e., "housekeeping") measures for construction materials that could potentially be a threat to water quality if discharged. At a minimum, the good housekeeping measures shall consist of the following:

i Identify the products used and/or expected to be used and the end products that are produced and/or expected to be produced. This does not include materials and equipment that are designed to be outdoors and exposed to environmental conditions (i.e. poles, equipment pads, cabinets, conductors, insulators, bricks, etc.).

ii Cover and berm loose stockpiled construction materials that are not actively being used (i.e. soil, spoils, aggregate, fly-ash, stucco, hydrated lime, etc.).

iii Store chemicals in watertight containers (with appropriate secondary containment to prevent any spillage or leakage) or in a storage shed (completely enclosed).

iv Minimize exposure of construction materials to precipitation (not applicable to materials designed to be outdoors and exposed to the environment).

v Implement BMPs to control the off-site tracking of loose construction and landscape materials.

b. LUP dischargers shall implement good housekeeping measures for waste management, which, at a minimum, shall consist of the following:

   i Prevent disposal of any rinse or wash waters or materials on impervious or pervious site surfaces or into the storm drain system.

   ii Ensure the containment of sanitation facilities (e.g., portable toilets) to prevent discharges of pollutants to the storm water drainage system or receiving water.

   iii Clean or replace sanitation facilities and inspecting them regularly for leaks and spills.

   iv Cover waste disposal containers at the end of every business day and during a rain event.

   v Prevent discharges from waste disposal containers to the storm water drainage system or receiving water.

   vi Contain and securely protect stockpiled waste material from wind and rain at all times unless actively being used.

   vii Implement procedures that effectively address hazardous and non-hazardous spills.

   viii Develop a spill response and implementation element of the SWPPP prior to commencement of construction activities. The SWPPP shall require that:

      (1) Equipment and materials for cleanup of spills shall be available on site and that spills and leaks shall be cleaned up immediately and disposed of properly; and

      (2) Appropriate spill response personnel are assigned and trained.

   ix Ensure the containment of concrete washout areas and other washout areas that may contain additional pollutants so there is no discharge into the underlying soil and onto the surrounding areas.

c. LUP dischargers shall implement good housekeeping for vehicle storage and maintenance, which, at a minimum, shall consist of the following:

i Prevent oil, grease, or fuel from leaking into the ground, storm drains or surface waters.

ii Implement appropriate BMPs whenever equipment or vehicles are fueled, maintained or stored.

iii Clean leaks immediately and disposing of leaked materials properly.

d. LUP dischargers shall implement good housekeeping for landscape materials, which, at a minimum, shall consist of the following:

i Contain stockpiled materials such as mulches and topsoil when they are not actively being used.

ii Contain fertilizers and other landscape materials when they are not actively being used.

iii Discontinue the application of any erodible landscape material at least 2 days before a forecasted rain event[9] or during periods of precipitation.

iv Applying erodible landscape material at quantities and application rates according to manufacture recommendations or based on written specifications by knowledgeable and experienced field personnel.

v Stacking erodible landscape material on pallets and covering or storing such materials when not being used or applied.

e. LUP dischargers shall conduct an assessment and create a list of potential pollutant sources and identify any areas of the site where additional BMPs are necessary to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges. This potential pollutant list shall be kept with the SWPPP and shall identify all non-visible pollutants which are known, or should be known, to occur on the construction site. At a minimum, when developing BMPs, LUP dischargers shall do the following:

i Consider the quantity, physical characteristics (e.g., liquid, powder, solid), and locations of each potential pollutant source handled, produced, stored, recycled, or disposed of at the site.

[9] 50% or greater chance of producing precipitation.

ii Consider the degree to which pollutants associated with those materials may be exposed to and mobilized by contact with storm water.

iii Consider the direct and indirect pathways that pollutants may be exposed to storm water or authorized non-storm water discharges. This shall include an assessment of past spills or leaks, non-storm water discharges, and discharges from adjoining areas.

iv Ensure retention of sampling, visual observation, and inspection records.

v Ensure effectiveness of existing BMPs to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges.

f. LUP dischargers shall implement good housekeeping measures on the construction site to control the air deposition of site materials and from site operations.

3. Non-Storm Water Management

a. LUP dischargers shall implement measures to control all non-storm water discharges during construction.

b. LUP dischargers shall wash vehicles in such a manner as to prevent non-storm water discharges to surface waters or MS4 drainage systems.

c. LUP dischargers shall clean streets in such a manner as to prevent unauthorized non-storm water discharges from reaching surface water or MS4 drainage systems.

4. Erosion Control

a. LUP dischargers shall implement effective wind erosion control.

b. LUP dischargers shall provide effective soil cover for inactive[10] areas and all finished slopes, and utility backfill.

[10] Areas of construction activity that have been disturbed and are not scheduled to be re-disturbed for at least 14 days

c. LUP dischargers shall limit the use of plastic materials when more sustainable, environmentally friendly alternatives exist. Where plastic materials are deemed necessary, the discharger shall consider the use of plastic materials resistant to solar degradation.

5. Sediment Controls

a. LUP dischargers shall establish and maintain effective perimeter controls as needed, and implement effective BMPs for all construction entrances and exits to sufficiently control erosion and sediment discharges from the site.

b. On sites where sediment basins are to be used, LUP dischargers shall, at minimum, design sediment basins according to the guidance provided in CASQA's Construction BMP Handbook.

c. **Additional LUP Type 2 & 3 Requirement:** LUP Type 2 & 3 dischargers shall apply linear sediment controls along the toe of the slope, face of the slope, and at the grade breaks of exposed slopes to comply with sheet flow lengths[11] in accordance with Table 2 below.

Table 2 – Critical Slope/Sheet Flow Length Combinations

Slope Percentage	Sheet flow length not to exceed
0-25%	20 feet
25-50%	15 feet
Over 50%	10 feet

d. **Additional LUP Type 2 & 3 Requirement:** LUP Type 2 & 3 dischargers shall ensure that construction activity traffic to and from the project is limited to entrances and exits that employ effective controls to prevent off-site tracking of sediment.

e. **Additional LUP Type 2 & 3 Requirement:** LUP Type 2 & 3 dischargers shall ensure that all storm drain inlets and perimeter controls, runoff control BMPs, and pollutant controls at entrances and exits (e.g. tire washoff locations) are maintained and protected from activities that reduce their effectiveness.

f. **Additional LUP Type 2 & 3 Requirement:** LUP Type 2 & 3 dischargers shall inspect all immediate access roads. At a minimum daily and prior to any rain event, the discharger shall remove any

[11] Sheet flow length is the length that shallow, low velocity flow travels across a site.

sediment or other construction activity-related materials that are deposited on the roads (by vacuuming or sweeping).

g. **Additional LUP Type 3 Requirement:** The Regional Water Board may require LUP Type 3 dischargers to implement additional site-specific sediment control requirements if the implementation of the other requirements in this section are not adequately protecting the receiving waters.

6. Run-on and Run-off Controls

a. LUP dischargers shall effectively manage all run-on, all runoff within the site and all runoff that discharges off the site. Run-on from off site-shall be directed away from all disturbed areas or shall collectively be in compliance with the effluent limitations in this Attachment.

b. Run-on and runoff controls are not required for Type 1 LUPs unless the evaluation of quantity and quality of run-on and runoff deems them necessary or visual inspections show that the site requires such controls.

7. Inspection, Maintenance and Repair

a. All inspection, maintenance repair and sampling activities at the discharger's LUP location shall be performed or supervised by a QSP representing the discharger. The QSP may delegate any or all of these activities to an employee trained to do the task(s) appropriately, but shall ensure adequate deployment.

b. LUP dischargers shall conduct visual inspections and observations daily during working hours (not recorded). At least once each 24-hour period during extended storm events, **LUP Type 2 & 3 dischargers** shall conduct visual inspections to identify and record BMPs that need maintenance to operate effectively, that have failed, or that could fail to operate as intended. Inspectors shall be the QSP or be trained by the QSP.

c. Upon identifying failures or other shortcomings, as directed by the QSP, LUP dischargers shall begin implementing repairs or design changes to BMPs within 72 hours of identification and complete the changes as soon as possible.

d. For each pre- and post-rain event inspection required, LUP dischargers shall complete an inspection checklist, using a form provided by the State Water Board or Regional Water Board or in an alternative format that includes the information described below.

e. The LUP discharger shall ensure that the checklist remains on-site or with the SWPPP. At a minimum, an inspection checklist should include:

   i Inspection date and date the inspection report was written.

   ii Weather information, including presence or absence of precipitation, estimate of beginning of qualifying storm event, duration of event, time elapsed since last storm, and approximate amount of rainfall in inches.

   iii Site information, including stage of construction, activities completed, and approximate area of the site exposed.

   iv A description of any BMPs evaluated and any deficiencies noted.

   v If the construction site is safely accessible during inclement weather, list the observations of all BMPs: erosion controls, sediment controls, chemical and waste controls, and non-storm water controls. Otherwise, list the results of visual inspections at all relevant outfalls, discharge points, downstream locations and any projected maintenance activities.

   vi Report the presence of noticeable odors or of any visible sheen on the surface of any discharges.

   vii Any corrective actions required, including any necessary changes to the SWPPP and the associated implementation dates.

   viii Photographs taken during the inspection, if any.

   ix Inspector's name, title, and signature.

K. STORM WATER POLLUTION PREVENTION PLAN (SWPPP) REQUIREMENTS

1. Objectives

SWPPPs for all LUPs shall be developed and amended or revised by a QSD. The SWPPP shall be designed to address the following objectives:

a. All pollutants and their sources, including sources of sediment, associated with construction activities associated with LUP activity are controlled;

b. All non-storm water discharges are identified and either eliminated, controlled, or treated;

c. BMPs are effective and result in the reduction or elimination of pollutants in storm water discharges and authorized non-storm water discharges from LUPs during construction; and

d. Stabilization BMPs installed to reduce or eliminate pollutants after construction is completed are effective and maintained.

2. SWPPP Implementation Schedule

a. LUPs for which PRDs have been submitted to the State Water Board shall develop a site/project location SWPPP prior to the start of land-disturbing activity in accordance with this Section and shall implement the SWPPP concurrently with commencement of soil-disturbing activities.

b. For an ongoing LUP involving a change in the LRP, the new LRP shall review the existing SWPPP and amend it, if necessary, or develop a new SWPPP within 15 calendar days to conform to the requirements set forth in this General Permit.

3. Availability

The SWPPP shall be available at the construction site during working hours while construction is occurring and shall be made available upon request by a State or Municipal inspector. When the original SWPPP is retained by a crewmember in a construction vehicle and is not currently at the construction site, copies of the BMPs and map/drawing will be left with the field crew and the original SWPPP shall be made available via a request by radio/telephone.

L. REGIONAL WATER BOARD AUTHORITIES

1. Regional Water Boards shall administer the provisions of this General Permit. Administration of this General Permit may include, but is not limited to, requesting the submittal of SWPPPs, reviewing SWPPPs, reviewing monitoring and sampling and analysis reports, conducting compliance inspections, gathering site information by any medium including sampling, photo and video documentation, and taking enforcement actions.

2. Regional Water Boards may terminate coverage under this General Permit for dischargers who fail to comply with its requirements or where they determine that an individual NPDES permit is appropriate.

3. Regional Water Boards may issue separate permits for discharges of storm water associated with construction activity to individual dischargers, categories of dischargers, or dischargers in a geographic area. Upon issuance of such permits by a Regional Water Board, dischargers subject to those permits shall no longer be regulated by this General Permit.

4. Regional Water Boards may direct the discharger to reevaluate the LUP Type(s) for the project (or elements/areas of the project) and impose the appropriate level of requirements.

5. Regional Water Boards may terminate coverage under this General Permit for dischargers who negligently or with willful intent incorrectly determine or report their LUP Type (e.g., they determine themselves to be a LUP Type 1 when they are actually a Type 2).

6. Regional Water Boards may review PRDs and reject or accept applications for permit coverage or may require dischargers to submit a Report of Waste Discharge / NPDES permit application for Regional Water Board consideration of individual requirements.

7. Regional Water Boards may impose additional requirements on dischargers to satisfy TMDL implementation requirements or to satisfy provisions in their Basin Plans.

8. Regional Water Boards may require additional Monitoring and Reporting Program Requirements, including sampling and analysis of discharges to sediment-impaired water bodies.

9. Regional Water Boards may require dischargers to retain records for more than the three years required by this General Permit.

10. Based on an LUP's threat to water quality and complexity, the Regional Water Board may determine on a case-by-case basis that an LUP, or a portion of an LUP, is not eligible for the linear project requirements contained in this Attachment, and require that the discharger comply with all standard requirements in this General Permit.

11. The Regional Water Board may require additional monitoring and reporting program requirements including sampling and analysis of discharges to CWA § 303(d)-listed water bodies. Additional requirements imposed by the Regional Water Board shall be consistent with the overall monitoring effort in the receiving waters.

M. MONITORING AND REPORTING REQUIREMENTS

Table 3. LUP Summary of Monitoring Requirements

LUP Type	Visual Inspections				Sample Collection		
	Daily Site BMP	Pre-storm Event / Baseline	Daily Storm BMP	Post Storm	Storm Water Discharge	Receiving Water	Non-Visible (when applicable)
1	X						x
2	X	X	X	X	X		x
3	X	X	X	X	X	X	x

1. Objectives

LUP dischargers shall prepare a monitoring and reporting program (M&RP) prior to the start of construction and immediately implement the program at the start of construction for LUPs. The monitoring program must be implemented at the appropriate level to protect water quality at all times throughout the life of the project. The M&RP must be a part of the SWPPP, included as an appendix or separate SWPPP chapter.

2. M&RP Implementation Schedule

a. LUP dischargers shall implement the requirements of this Section at the time of commencement of construction activity. LUP dischargers are responsible for implementing these requirements until construction activity is complete and the site is stabilized.

b. LUP dischargers shall revise the M&RP when:

i Site conditions or construction activities change such that a change in monitoring is required to comply with the requirements and intent of this General Permit.

ii The Regional Water Board requires the discharger to revise its M&RP based on its review of the document. Revisions may include, but not be limited to, conducting additional site inspections, submitting reports, and certifications. Revisions shall be submitted via postal mail or electronic e-mail.

iii The Regional Water Board may require additional monitoring and reporting program requirements including sampling and analysis of discharges to CWA § 303(d)-listed water bodies. Additional requirements imposed by the Regional Water Board shall be consistent with the overall monitoring effort in the receiving waters.

3. LUP Type 1 Monitoring and Reporting Requirements

a. LUP Type 1 Inspection Requirements

i LUP Type 1 dischargers shall ensure that all inspections are conducted by trained personnel. The name(s) and contact number(s) of the assigned inspection personnel should be listed in the SWPPP.

ii LUP Type 1 dischargers shall ensure that all visual inspections are conducted daily during working hours and in conjunction with other daily activities in areas where active construction is occurring.

iii LUP Type 1 dischargers shall ensure that photographs of the site taken before, during, and after storm events are taken during inspections, and submitted through the State Water Board's SMARTS website once every three rain events.

iv LUP Type 1 dischargers shall conduct daily visual inspections to verify that:

(1) Appropriate BMPs for storm water and non-storm water are being implemented in areas where active construction is occurring (including staging areas);

(2) Project excavations are closed, with properly protected spoils, and that road surfaces are cleaned of excavated material and construction materials such as chemicals by either removing or storing the material in protective storage containers at the end of every construction day;

(3) Land areas disturbed during construction are returned to pre-construction conditions or an equivalent protection is used at the end of each workday to eliminate or minimize erosion and the possible discharge of sediment or other pollutants during a rain event.

v Inspections may be discontinued in non-active construction areas where soil-disturbing activities are completed and final soil stabilization is achieved (e.g., paving is completed, substructures are installed, vegetation meets minimum cover requirements for final stabilization, or other stabilization requirements are met).

vi Inspection programs are required for LUP Type 1 projects where temporary and permanent stabilization BMPs are installed and are to be monitored after active construction is completed. Inspection activities shall continue until adequate permanent stabilization is established and, in areas where re-vegetation is chosen, until minimum vegetative coverage is established in accordance with Section C.1 of this Attachment.

b. LUP Type 1 Monitoring Requirements for Non-Visible Pollutants

LUP Type 1 dischargers shall implement sampling and analysis requirements to monitor non-visible pollutants associated with (1) construction sites; (2) activities producing pollutants that are not visually detectable in storm water discharges; and (3) activities which could cause or contribute to an exceedance of water quality objectives in the receiving waters.

i Sampling and analysis for non-visible pollutants is only required where the LUP Type 1 discharger believes pollutants associated with construction activities have the potential to be discharged with storm water runoff due to a spill or in the event there was a breach, malfunction, failure and/or leak of any BMP. Also, failure to implement BMPs may require sample collection.

(1) Visual observations made during the monitoring program described above will help the LUP Type 1 discharger determine when to collect samples.

(2) The LUP Type 1 discharger is not required to sample if one of the conditions described above (e.g., breach or spill) occurs and the site is cleaned of material and pollutants and/or BMPs are implemented prior to the next storm event.

ii LUP Type 1 dischargers shall collect samples down-gradient from all discharge locations where the visual observations were made triggering the monitoring, and which can be safely accessed. For sites where sampling and analysis is required, personnel trained in water quality sampling procedures shall collect storm water samples.

iii If sampling for non-visible pollutant parameters is required, LUP Type 1 dischargers shall ensure that samples be analyzed for parameters indicating the presence of pollutants identified in the pollutant source assessment required in Section J.2.a.i.

iv LUP Type 1 dischargers shall collect samples during the first two hours of discharge from rain events that occur during business hours and which generate runoff.

v LUP Type 1 dischargers shall ensure that a sufficiently large sample of storm water that has not come into contact with the disturbed soil or the materials stored or used on-site (uncontaminated sample[12]) will be collected for comparison with the discharge sample. Samples shall be collected during the first two hours of discharge from rain events that occur during daylight hours and which generate runoff.

vi LUP Type 1 dischargers shall compare the uncontaminated sample to the samples of discharge using field analysis or through laboratory analysis. Analyses may include, but are not limited to, indicator parameters such as: pH, specific conductance, dissolved oxygen, conductivity, salinity, and Total Dissolved Solids (TDS).

vii For laboratory analyses, all sampling, sample preservation, and other analyses must be conducted according to test procedures pursuant to 40 C.F.R. Part 136. LUP Type 1 dischargers shall ensure that field samples are collected and analyzed according to manufacturer specifications of the sampling devices employed. Portable meters shall be calibrated according to manufacturer's specification.

viii LUP Type 1 dischargers shall ensure that all field and/or analytical data are kept in the SWPPP document.

c. <u>LUP Type 1 Visual Observation Exceptions</u>

i LUP Type 1 dischargers shall be prepared to collect samples and conduct visual observation (inspections) to meet the minimum visual observation requirements of this Attachment. The Type 1 LUP discharger is not required to physically collect samples or conduct visual observation (inspections) under the following conditions:

(1) During dangerous weather conditions such as flooding and electrical storms;

(2) Outside of scheduled site business hours.

(3) When access to the site is unsafe due to storm events.

[12] Sample collected at a location unaffected by contruction activities.

ii If the LUP Type 1 discharger does not collect the required samples or visual observation (inspections) due to these exceptions, an explanation why the sampling or visual observation (inspections) were not conducted shall be included in both the SWPPP and the Annual Report.

d. Particle Size Analysis for Risk Justification

LUP Type 1 dischargers utilizing justifying an alternative project risk shall report a soil particle size analysis used to determine the RUSLE K-Factor. ASTM D-422 (Standard Test Method for Particle-Size Analysis of Soils), as revised, shall be used to determine the percentages of sand, very fine sand, silt, and clay on the site.

4. LUP Type 2 & 3 Monitoring and Reporting Requirements

a. LUP Type 2 & 3 Inspection Requirements

i LUP Type 2 & 3 dischargers shall ensure that all inspections are conducted by trained personnel. The name(s) and contact number(s) of the assigned inspection personnel should be listed in the SWPPP.

ii LUP Type 2 & 3 dischargers shall ensure that all visual inspections are conducted daily during working hours and in conjunction with other daily activities in areas where active construction is occurring.

iii LUP Type 2 & 3 dischargers shall ensure that photographs of the site taken before, during, and after storm events are taken during inspections, and submitted through the State Water Board's SMARTS website once every three rain events.

iv LUP Type 2 & 3 dischargers shall conduct daily visual inspections to verify that appropriate BMPs for storm water and non-storm water are being implemented and in place in areas where active construction is occurring (including staging areas).

v LUP Type 2 & 3 dischargers shall conduct inspections of the construction site prior to anticipated storm events, during extended storm events, and after actual storm events to identify areas contributing to a discharge of storm water associated with construction activity. Pre-storm inspections are to ensure that BMPs are properly installed and maintained; post-storm inspections are to assure that BMPs have functioned adequately. During extended storm events, inspections shall be required during normal working hours for each 24-hour period.

vi Inspections may be discontinued in non-active construction areas where soil-disturbing activities are completed and final soil stabilization is achieved (e.g., paving is completed, substructures are installed, vegetation meets minimum cover requirements for final stabilization, or other stabilization requirements are met).

vii LUP Type 2 & 3 dischargers shall implement a monitoring program for inspecting projects that require temporary and permanent stabilization BMPs after active construction is complete. Inspections shall ensure that the BMPs are adequate and maintained. Inspection activities shall continue until adequate permanent stabilization is established and, in vegetated areas, until minimum vegetative coverage is established in accordance with Section C.1 of this Attachment.

viii If possible, LUP Type 2 & 3 dischargers shall install a rain gauge on-site at an accessible and secure location with readings made during all storm event inspections. When readings are unavailable, data from the closest rain gauge with publically available data may be used.

ix LUP Type 2 & 3 dischargers shall Include and maintain a log of the inspections conducted in the SWPPP. The log will provide the date and time of the inspection and who conducted the inspection.

b. <u>LUP Type 2 & 3 Storm Water Effluent Monitoring Requirements</u>

Table 4. LUP Type 2 & 3 Effluent Monitoring Requirements

LUP Type	Frequency	Effluent Monitoring
2	Minimum of 3 samples per day characterizing discharges associated with construction activity from the project active areas of construction.	Turbidity, pH, and non-visible pollutant parameters (if applicable)
3	Minimum of 3 samples per day characterizing discharges associated with construction activity from the project active areas of construction.	turbidity, pH, suspended sediment concentrations (SSC)[13] (only if turbidity NEL exceeded), plus non-visible pollutant parameters (if applicable)

i LUP Type 2 & 3 dischargers shall collect storm water grab samples from sampling locations characterizing discharges associated with

[13] Suspended Sediment Concentration monitoring is required for any Type 3 area that exceeds its turbidity NEL.

activity from the LUP active areas of construction. At a minimum, 3 samples shall be collected per day of discharge.

ii LUP Type 2 & 3 dischargers shall collect samples of stored or contained storm water that is discharged subsequent to a storm event producing precipitation of ½ inch or more at the time of discharge.

iii LUP Type 2 & 3 dischargers shall ensure that storm water grab sample(s) obtained be representative of the flow and characteristics of the discharge.

iv LUP Type 2 & 3 dischargers shall analyze their effluent samples for:

(1) pH and turbidity
(2) Any additional parameter for which monitoring is required by the Regional Water Board.

v LUP Type 3 dischargers that have violated the turbidity daily average NEL shall analyze subsequent effluent samples for turbidity and SSC.

c. <u>LUP Type 2 & 3 Storm Water Effluent Sampling Locations</u>

i LUP Type 2 & 3 dischargers shall perform sampling and analysis of storm water discharges to characterize discharges associated with construction activity from the entire disturbed project or area.

ii LUP Type 2 & 3 dischargers may monitor and report run-on from surrounding areas if there is reason to believe run-on may contribute to exceedance of NALs or NELs (applicable to Type 3).

iii LUP Type 2 & 3 dischargers shall select analytical test methods from the list provided in Table 5 below.

iv LUP Type 2 & 3 dischargers shall ensure that all storm water sample collection preservation and handling shall be conducted in accordance with the “Storm Water Sample Collection and Handling Instructions” below.

d. <u>LUP Type 3 Receiving Water Monitoring Requirements</u>

i In the event that an LUP Type 3 discharger violates an applicable NEL contained in this General Permit and has a direct discharge to receiving waters, the LUP discharger shall subsequently sample Receiving Waters (RWs) for turbidity, pH (if applicable) and SSC.

ii LUP Type 3 dischargers that meet the project criteria in Appendix 3 of this General Permit and have more than 30 acres of soil disturbance in the project area or project section area designated as Type 3, shall comply with the Bioassessment requirements prior to commencement of construction activity.

iii LUP Type 3 dischargers shall obtain RW samples in accordance with the requirements of the Receiving Water Sampling Locations section (Section M.4.d of this Attachment).

e. <u>LUP Type 3 Receiving Water Sampling Locations</u>

i **Upstream/up-gradient RW samples**: LUP Type 3 dischargers shall obtain any required upstream/up-gradient receiving water samples from a representative and accessible location as close as possible to and upstream from the effluent discharge point.

ii **Downstream/down-gradient RW samples**: LUP Type 3 dischargers shall obtain any required downstream/down-gradient receiving water samples from a representative and accessible location as close as possible to and downstream from the effluent discharge point.

iii If two or more discharge locations discharge to the same receiving water, LUP Type 3 dischargers may sample the receiving water at a single upstream and downstream location.

f. <u>LUP Type 2 & 3 Monitoring Requirements for Non-Visible Pollutants</u>

LUP Type 2 & 3 dischargers shall implement sampling and analysis requirements to monitor non-visible pollutants associated with (1) construction sites; (2) activities producing pollutants that are not visually detectable in storm water discharges; and (3) activities which could cause or contribute to an exceedance of water quality objectives in the receiving waters.

i Sampling and analysis for non-visible pollutants is only required where LUP Type 2 & 3 dischargers believe pollutants associated with construction activities have the potential to be discharged with storm water runoff due to a spill or in the event there was a breach, malfunction, failure and/or leak of any BMP. Also, failure to implement BMPs may require sample collection.

(1) Visual observations made during the monitoring program described above will help LUP Type 2 & 3 dischargers determine when to collect samples.

(2) LUP Type 2 & 3 dischargers are not required to sample if one of the conditions described above (e.g., breach or spill) occurs and the site is cleaned of material and pollutants and/or BMPs are implemented prior to the next storm event.

ii LUP Type 2 & 3 dischargers shall collect samples down-gradient from the discharge locations where the visual observations were made triggering the monitoring and which can be safely accessed. For sites where sampling and analysis is required, personnel trained in water quality sampling procedures shall collect storm water samples.

iii If sampling for non-visible pollutant parameters is required, LUP Type 2 & 3 dischargers shall ensure that samples be analyzed for parameters indicating the presence of pollutants identified in the pollutant source assessment required in Section J.2.a.i.

iv LUP Type 2 & 3 dischargers shall collect samples during the first two hours of discharge from rain events that occur during business hours and which generate runoff.

v LUP Type 2 & 3 dischargers shall ensure that a sufficiently large sample of storm water that has not come into contact with the disturbed soil or the materials stored or used on-site (uncontaminated sample[14]) will be collected for comparison with the discharge sample. Samples shall be collected during the first two hours of discharge from rain events that occur during daylight hours and which generate runoff.

vi LUP Type 2 & 3 dischargers shall compare the uncontaminated sample to the samples of discharge using field analysis or through laboratory analysis. Analyses may include, but are not limited to, indicator parameters such as: pH, specific conductance, dissolved oxygen, conductivity, salinity, and Total Dissolved Solids (TDS).

vii For laboratory analyses, all sampling, sample preservation, and other analyses must be conducted according to test procedures pursuant to 40 C.F.R. Part 136. LUP Type 2 & 3 dischargers shall ensure that field samples are collected and analyzed according to manufacturer specifications of the sampling devices employed. Portable meters shall be calibrated according to manufacturer's specification.

viii LUP Type 2 & 3 dischargers shall ensure that all field and/or analytical data are kept in the SWPPP document.

[14] Sample collected at a location unaffected by construction activities

g. LUP Type 2 & 3 Visual Observation and Sample Collection Exceptions

i LUP Type 2 & 3 dischargers shall be prepared to collect samples and conduct visual observation (inspections) to meet the minimum visual observation requirements of this Attachment. Type 2 & 3 LUP dischargers are not required to physically collect samples or conduct visual observation (inspections) under the following conditions:

(1) During dangerous weather conditions such as flooding and electrical storms;

(2) Outside of scheduled site business hours.

(3) When access to the site is unsafe due to storm events.

ii If the LUP Type 2 or 3 discharger does not collect the required samples or visual observation (inspections) due to these exceptions, an explanation why the sampling or visual observation (inspections) were not conducted shall be included in both the SWPPP and the Annual Report.

h. LUP Type 2 & 3 Storm Water Sample Collection and Handling Instructions

LUP Type 2 & 3 dischargers shall refer to Table 5 below for test Methods, detection Limits, and reporting Units. During storm water sample collection and handling, the LUP Type 2 & 3 discharger shall:

i Identify the parameters required for testing and the number of storm water discharge points that will be sampled. Request the laboratory to provide the appropriate number of sample containers, types of containers, sample container labels, blank chain of custody forms, and sample preservation instructions.

ii Determine how to ship the samples to the laboratory. The testing laboratory should receive samples within 48 hours of the physical sampling (unless otherwise required by the laboratory). The options are to either deliver the samples to the laboratory, arrange to have the laboratory pick them up, or ship them overnight to the laboratory.

iii Use only the sample containers provided by the laboratory to collect and store samples. Use of any other type of containers could contaminate your samples.

iv Prevent sample contamination, by not touching, or putting anything into the sample containers before collecting storm water samples.

v Not overfilling sample containers. Overfilling can change the analytical results.

vi Tightly screw the cap of each sample container without stripping the threads of the cap.

vii Complete and attach a label to each sample container. The label shall identify the date and time of sample collection, the person taking the sample, and the sample collection location or discharge point. The label should also identify any sample containers that have been preserved.

viii Carefully pack sample containers into an ice chest or refrigerator to prevent breakage and maintain temperature during shipment. Remember to place frozen ice packs into the shipping container. Samples should be kept as close to 4° C (39° F) as possible until arriving at the laboratory. Do not freeze samples.

ix Complete a Chain of Custody form for each set of samples. The Chain of Custody form shall include the discharger's name, address, and phone number, identification of each sample container and sample collection point, person collecting the samples, the date and time each sample container was filled, and the analysis that is required for each sample container.

x Upon shipping/delivering the sample containers, obtain both the signatures of the persons relinquishing and receiving the sample containers.

xi Designate and train personnel to collect, maintain, and ship samples in accordance with the above sample protocols and good laboratory practices.

xii Refer to the Surface Water Ambient Monitoring Program's (SWAMP) Quality Assurance Management Plan (QAMP) for more information on sampling collection and analysis. See http://www.waterboards.ca.gov/water_issues/programs/swamp/[15]

QAMP Link:
http://www.waterboards.ca.gov/water_issues/programs/swamp/qamp.shtml

[15] Additional information regarding QAMP can be found at http://mpsl.mlml.calstate.edu/swqacompare.htm.

Table 5. Test Methods, Detection Limits, Reporting Units and Applicable NALs/NELs

Parameter	Test Method	Discharge Type	Min. Detection Limit	Reporting Units	Numeric Action Levels	Numeric Effluent Limitation (LUP Type 3)
pH	Field test with calibrated portable instrument	Type 2 & 3	0.2	pH units	Lower = 6.5 upper = 8.5	Lower = 6.0 upper = 9.0
Turbidity	EPA 0180.1 and/or field test with calibrated portable instrument	Type 2 & 3	1	NTU	250 NTU	500 NTU
SSC	ASTM Method D 3977-97[16]	Type 3 if NEL is exceeded	5	Mg/L	N/A	N/A
Bioassessment	(STE) Level I of (SAFIT),[17] fixed-count of 600 org/sample	Type 3 LUPs > 30 acres	N/A	N/A	N/A	N/A

i. <u>LUP Type 2 & 3 Monitoring Methods</u>

i The LUP Type 2 or 3 discharger's project M&RP shall include a description of the following items:

(1) Visual observation locations, visual observation procedures, and visual observation follow-up and tracking procedures.

(2) Sampling locations, and sample collection and handling procedures. This shall include detailed procedures for sample collection, storage, preservation, and shipping to the testing lab to assure that consistent quality control and quality assurance is maintained. Dischargers shall attach to the monitoring program a copy of the Chain of Custody form used when handling and shipping samples.

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[16] ASTM, 1999, Standard Test Method for Determining Sediment Concentration in Water Samples: American Society of Testing and Materials, D 3977-97, Vol. 11.02, pp. 389-394

[17] The current SAFIT STEs (28 November 2006) list requirements for both the Level I and Level II taxonomic effort, and are located at: http://www.swrcb.ca.gov/swamp/docs/safit/ste_list.pdf. When new editions are published by SAFIT, they will supersede all previous editions. All editions will be posted at the State Water Board's SWAMP website.

(3) Identification of the analytical methods and related method detection limits (if applicable) for each parameter required in Section M.4.f above.

ii LUP Type 2 & 3 dischargers shall ensure that all sampling and sample preservation be in accordance with the current edition of "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association). All monitoring instruments and equipment (including a discharger's own field instruments for measuring pH and turbidity) shall be calibrated and maintained in accordance with manufacturers' specifications to ensure accurate measurements. All laboratory analyses shall be conducted according to test procedures under 40 CFR Part 136, unless other test procedures have been specified in this General Permit or by the Regional Water Board. With the exception of field analysis conducted by the discharger for turbidity and pH, all analyses shall be sent to and conducted at a laboratory certified for such analyses by the State Department of Health Services (SSC exception). The LUP discharger shall conduct its own field analysis of pH and may conduct its own field analysis of turbidity if the discharger has sufficient capability (qualified and trained employees, properly calibrated and maintained field instruments, etc.) to adequately perform the field analysis.

j. LUP Type 2 & 3 Analytical Methods

LUP Type 2 & 3 dischargers shall refer to Table 5 above for test Methods, detection Limits, and reporting Units.

i **pH**: LUP Type 2 & 3 dischargers shall perform pH analysis on-site with a calibrated pH meter or pH test kit. The LUP discharger shall record pH monitoring results on paper and retain these records in accordance with Section M.4.o, below.

ii **Turbidity**: LUP Type 2 & 3 dischargers shall perform turbidity analysis using a calibrated turbidity meter (turbidimeter), either on-site or at an accredited lab. Acceptable test methods include Standard Method 2130 or USEPA Method 180.1. The results shall be recorded in the site log book in Nephelometric Turbidity Units (NTU).

iii **Suspended sediment concentration (SSC)**: LUP Type 3 dischargers exceeding their NEL, shall perform SSC analysis using ASTM Method D3977-97.

iv **Bioassessment**: LUP Type 3 dischargers shall perform bioassessment sampling and analysis according to Appendix 3 of this General Permit.

k. Watershed Monitoring Option

If an LUP Type 2 or 3 discharger is part of a qualified regional watershed-based monitoring program the LUP Type 2 or 3 discharger may be eligible for relief from the monitoring requirements in this Attachment. The Regional Water Board may approve proposals to substitute an acceptable watershed-based monitoring program if it determines that the watershed-based monitoring program will provide information to determine each discharger's compliance with the requirements of this General Permit.

l. Particle Size Analysis for Risk Justification

LUP Type 2 & 3 dischargers justifying an alternative project risk shall report a soil particle size analysis used to determine the RUSLE K-Factor. ASTM D-422 (Standard Test Method for Particle-Size Analysis of Soils), as revised, shall be used to determine the percentages of sand, very fine sand, silt, and clay on the site.

m. NAL Exceedance Report

i In the event that any effluent sample exceeds an applicable NAL, the Regional Water Boards may require LUP Type 2 & 3 dischargers to submit NAL Exceedance Reports.

ii LUP Type 2 & 3 dischargers shall certify each NAL Exceedance Report in accordance with the Special Provisions for Construction Activity.

iii LUP Type 2 & 3 dischargers shall retain an electronic or paper copy of each NAL Exceedance Report for a minimum of three years after the date the exceedance report is filed.

iv LUP Type 2 & 3 dischargers shall include in the NAL Exceedance Report:

(1) the analytical method(s), method reporting unit(s), and method detection limit(s) of each analytical parameter (analytical results that are less than the method detection limit shall be reported as "less than the method detection limit"); and
(2) the date, place, time of sampling, visual observation (inspections), and/or measurements, including precipitation.

(3) Description of the current BMPs associated with the effluent sample that exceeded the NAL and the proposed corrective actions taken.

n. NEL Violation Report

i All LUP Type 3 dischargers shall electronically submit all storm event sampling results to the State Water Board no later than 5 days after the conclusion of the storm event.

ii In the event that a LUP Type 3 discharger has violated an applicable NEL, the discharger shall submit an NEL Violation Report to the State Water Board no later than 24 hours after the NEL exceedance has been identified.

iii The LUP Type 3 discharger shall certify each NEL Violation Report in accordance with the Special Provisions for Construction Activity.

iv The LUP Type 3 discharger shall retain an electronic or paper copy of each NEL Violation Report for a minimum of three years after the date the violation report is filed.

v The LUP Type 3 discharger shall include in the NEL Violation Report:

(1) the analytical method(s), method reporting unit(s), and method detection limit(s) of each analytical parameter (analytical results that are less than the method detection limit shall be reported as “less than the method detection limit”); and
(2) the date, place, time of sampling, visual observation (inspections), and/or measurements, including precipitation.
(3) Description of the current on-site BMPs, and the proposed corrective actions taken to manage the NEL exceedance.

vi Compliance Storm Exemption:
In the event that an applicable NEL has been exceeded during a storm event equal to or larger than the Compliance Storm Event (see Section F.2.c of this Attachment), the LUP Type 3 discharger shall report the on-site rain gauge and nearby governmental rain gauge readings for verification.

o. Monitoring Records

LUP Type 2 & 3 dischargers shall ensure that records of all storm water monitoring information and copies of all reports (including Annual Reports) required by this General Permit be retained for a period of at least three years. LUP Type 2 & 3 dischargers may retain records off-site and make them available upon request. These records shall include:

i The date, place, time of facility inspections, sampling, visual observation (inspections), and/or measurements, including precipitation (rain gauge);

ii The individual(s) who performed the facility inspections, sampling, visual observation (inspections), and or measurements;

iii The date and approximate time of analyses;

iv The individual(s) who performed the analyses;

v A summary of all analytical results from the last three years, the method detection limits and reporting units, the analytical techniques or methods used, and all chain of custody forms;

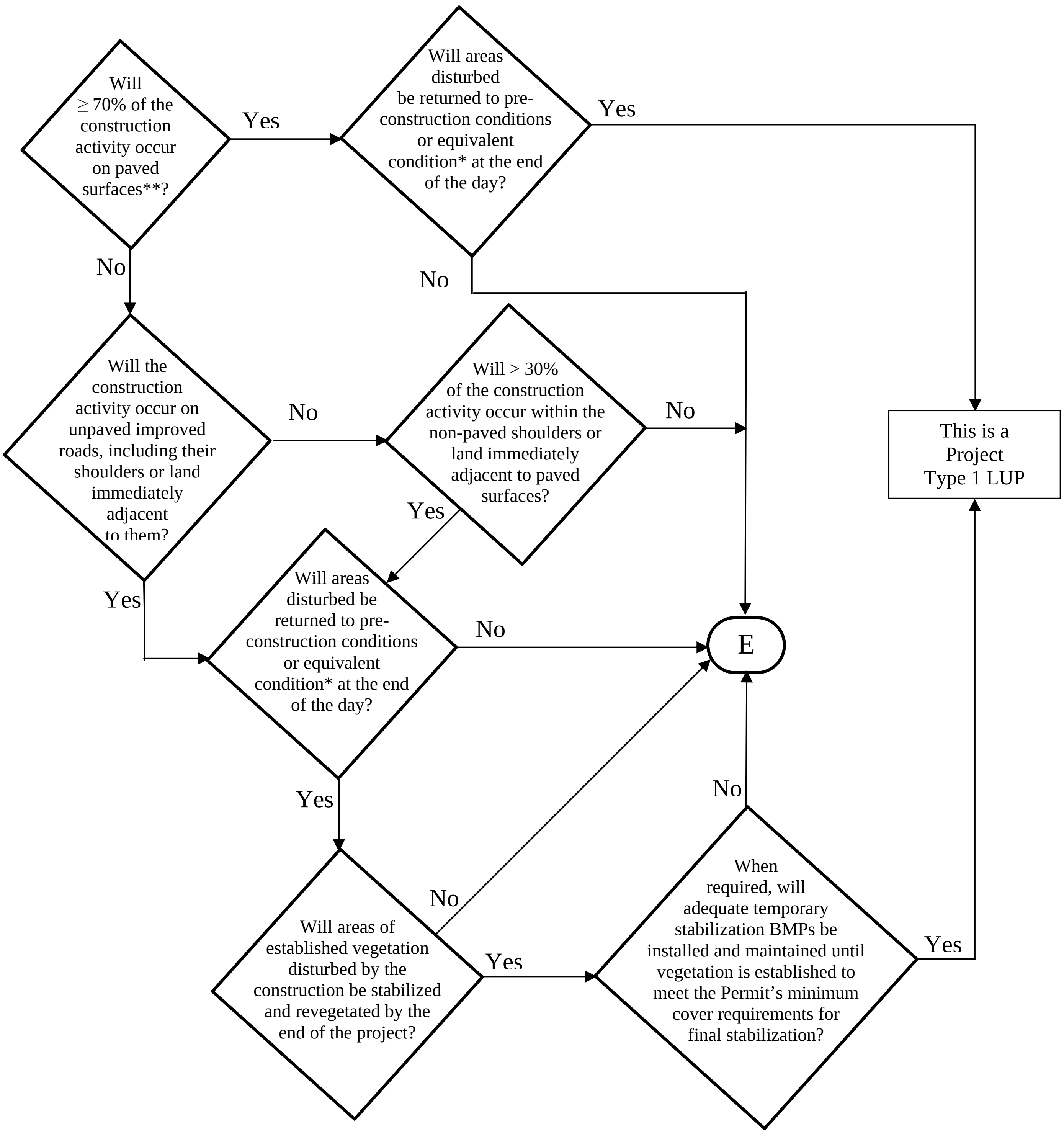
vi Quality assurance/quality control records and results;

vii Non-storm water discharge inspections and visual observation (inspections) and storm water discharge visual observation records (see Section M.4.a above);

viii Visual observation and sample collection exception records (see Section M.4.g above); and

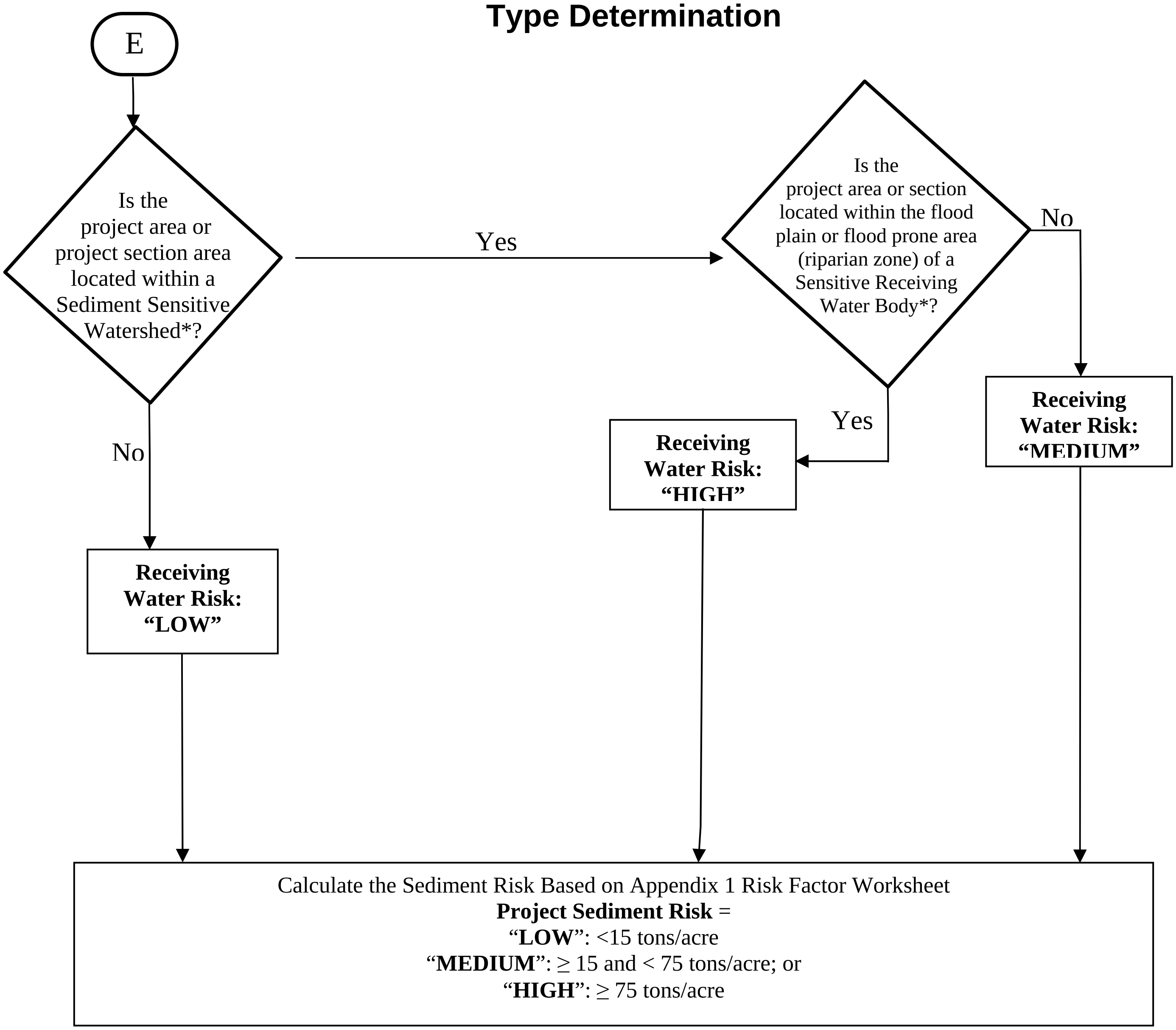
ix The records of any corrective actions and follow-up activities that resulted from analytical results, visual observation (inspections), or inspections.

ATTACHMENT A.1
LUP Project Area or Project Section Area Type Determination



*See Definition of Terms
** Or: "Will < 30% of the soil disturbance occur on unpaved surfaces?

ATTACHMENT A.1
LUP Project Area or Project Section Area Type Determination



* See Definition of Terms

PROJECT SEDIMENT RISK

RECEIVING WATER RISK	LOW	MEDIUM	HIGH
LOW	Type 1	Type 1	Type 2
MEDIUM	Type 1	Type 2	Type 3
HIGH	Type 2	Type 3	Type 3

ATTACHMENT A.1
Definition of Terms

1. **Equivalent Condition** – Means disturbed soils such as those from trench excavation are required to be hauled away, backfilled into the trench, and/or covered (e.g., metal plates, pavement, plastic covers over spoil piles) at the end of the construction day.
2. **Linear Construction Activity** – Linear construction activity consists of underground/ overhead facilities that typically include, but are not limited to, any conveyance, pipe or pipeline for the transportation of any gaseous, liquid (including water, wastewater for domestic municipal services), liquescent, or slurry substance; any cable line or wire for the transmission of electrical energy; any cable line or wire for communications (e.g., telephone, telegraph, radio or television messages); and associated ancillary facilities. Construction activities associated with LUPs include, but are not limited to those activities necessary for the installation of underground and overhead linear facilities (e.g., conduits, substructures, pipelines, towers, poles, cables, wires, connectors, switching, regulating and transforming equipment and associated ancillary facilities) and include, but are not limited to, underground utility mark-out, potholing, concrete and asphalt cutting and removal, trenching, excavation, boring and drilling, access road and pole/ tower pad and cable/ wire pull station, substation construction, substructure installation, construction of tower footings and/or foundations, pole and tower installations, pipeline installations, welding, concrete and/or pavement repair or replacement, and stockpile/ borrow locations.
3. **Sediment Sensitive Receiving Water Body –** Defined as a water body segment that is listed on EPA's approved CWA 303(d) list for sedimentation/siltation, turbidity, or is designated with beneficial uses of SPAWN, MIGRATORY, and COLD.
4. **Sediment Sensitive Watershed –** Defined as a watershed draining into a receiving water body listed on EPA's approved CWA 303(d) list for sedimentation/siltation, turbidity, or a water body designated with beneficial uses of SPAWN, MIGRATORY, and COLD.

ATTACHMENT A.2
PERMIT REGISTRATION DOCUMENTS (PRDs)
GENERAL INSTRUCTIONS FOR LINEAR UNDERGROUND/OVERHEAD PROJECTS TO COMPLY WITH THE CONSTRUCTION GENERAL PERMIT

GENERAL INSTRUCTIONS

Who Must Submit

This permit is effective on July 1, 2010.

The Legally Responsible Person (LRP) for construction activities associated with linear underground/overhead project (LUP) must electronically apply for coverage under this General Permit on or after July 1, 2010. If it is determined that the LUP construction activities require an NPDES permit, the Legally Responsible Person[1] (LRP) shall submit PRDs for this General Permit in accordance with the following:

LUPs associated with Private or Municipal Development Projects

1. For LUPs associated with pre-development and pre-redevelopment construction activities:

   The LRP must obtain coverage[2] under this General Permit for its pre-development and pre-redevelopment construction activities where the total disturbed land area of these construction activities is greater than 1 acre.

2. For LUPs associated with new development and redevelopment construction projects:

   The LRP must obtain coverage under this General Permit for LUP construction activities associated with new development and redevelopment projects where the total disturbed land area of the LUP is greater than 1 acre. Coverage under this permit is not required where the same LUP construction activities are covered by another NPDES permit.

LUPs not associated with private or municipal new development or redevelopment projects:

The LRP must obtain coverage under this General Permit on or after July 1, 2010 for its LUP construction activities where the total disturbed land area is greater than 1 acre.

PRD Submittal Requirements

Prior to the start of construction activities a LRP must submit PRDs and fees to the State Water Board for each LUP.

New and Ongoing LUPs

Dischargers of new LUPs that commence construction activities after the adoption date of this General Permit shall file PRDs prior to the commencement of construction and implement the SWPPP upon the start of construction.

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[1] person possessing the title of the land on which the construction activities will occur for the regulated site

[2] obtain coverage means filing PRDs for the project.

PERMIT REGISTRATION DOCUMENTS (PRDs)
GENERAL INSTRUCTIONS (CONTINUED)

Dischargers of ongoing LUPs that are currently covered under State Water Board Order No. 2003-0007 (Small LUP General Permit) shall electronically file Permit Registration Documents no later than July 1, 2010. After July 1, 2010, all NOIs subject to State Water Board Order No. 2003-0007-DWQ will be terminated. All existing dischargers shall be exempt from the risk determination requirements in Attachment A. All existing dischargers are therefore subject to LUP Type 1 requirements regardless of their project's sediment and receiving water risks. However, a Regional Board retains the authority to require an existing discharger to comply with the risk determination requirements in Attachment A.

Where to Apply

The Permit Registration Documents (PRDs) can be found at www.waterboards.ca.gov/water_issues/programs/stormwater/

Fees

The annual fee for storm water permits are established through the State of California Code of Regulations.

When Permit Coverage Commences

To obtain coverage under the General Permit, the LRP must include the complete PRDs and the annual fee. All PRDs deemed incomplete will be rejected with an explanation as to what is required to complete submittal. Upon receipt of complete PRDs and associated fee, each discharger will be sent a waste discharger's identification (WDID) number.

Projects and Activities Not Defined As Construction Activity

1. LUP construction activity does not include routine maintenance projects to maintain original line and grade, hydraulic capacity, or original purpose of the facility. Routine maintenance projects are projects associated with operations and maintenance activities that are conducted on existing lines and facilities and within existing right-of-way, easements, franchise agreements or other legally binding agreements of the discharger. Routine maintenance projects include, but are not limited to projects that are conducted to:

    - Maintain the original purpose of the facility, or hydraulic capacity.
    - Update existing lines[3] and facilities to comply with applicable codes, standards and regulations regardless if such projects result in increased capacity.
    - Repairing leaks.

    Routine maintenance does not include construction of new[4] lines or facilities resulting from compliance with applicable codes, standards and regulations.

[3] Update existing lines includes replacing existing lines with new materials or pipes.
[4] New lines are those that are not associated with existing facilities and are not part of a project to update or replace existing lines.

Routine maintenance projects do not include those areas of maintenance projects that are outside of an existing right-of-way, franchise, easements, or agreements. When a project must acquire new areas, those areas may be subject to this General Permit based on the area of disturbed land outside the original right-of-way, easement, or agreement.

2. LUP construction activity does not include field activities associated with the planning and design of a project (e.g., activities associated with route selection).

3. Tie-ins conducted immediately adjacent to “energized” or “pressurized” facilities by the discharger are not considered small construction activities where all other LUP construction activities associated with the tie-in are covered by a NOI and SWPPP of a third party or municipal agency.

Calculating Land Disturbance Areas of LUPs

The total land area disturbed for LUPs is the sum of the:

- Surface areas of trenches, laterals and ancillary facilities, plus
- Area of the base of stockpiles on unpaved surfaces, plus
- Surface area of the borrow area, plus
- Areas of paved surfaces constructed for the project, plus
- Areas of new roads constructed or areas of major reconstruction to existing roads (e.g. improvements to two-track surfaces or road widening) for the sole purpose of accessing construction activities or as part of the final project, plus
- Equipment and material storage, staging, and preparation areas (laydown areas) not on paved surfaces, plus
- Soil areas outside the surface area of trenches, laterals and ancillary facilities that will be graded, and/or disturbed by the use of construction equipment, vehicles and machinery during construction activities.

Stockpiling Areas

Stockpiling areas, borrow areas and the removal of soils from a construction site may or may not be included when calculating the area of disturbed soil for a site depending on the following conditions:

- For stockpiling of soils onsite or immediately adjacent to a LUP site and the stockpile is not on a paved surface, the area of the base of the stockpile is to be included in the disturbed area calculation.

- The surface area of borrow areas that are onsite or immediately adjacent to a project site are to be included in the disturbed area calculation.

- For soil that is hauled offsite to a location owned or operated by the discharger that is not a paved surface, the area of the base of the stockpile is to be included in the disturbed area calculation except when the offsite location is already subject to a separate storm water permit.

PERMIT REGISTRATION DOCUMENTS (PRDs)
GENERAL INSTRUCTIONS (CONTINUED)

- For soil that is brought to the project from an off-site location owned or operated by the discharger the surface area of the borrow pit is to be included in the disturbed area calculation except when the offsite location is already subject to a separate storm water permit.

- Trench spoils on a paved surface that are either returned to the trench or excavation or hauled away from the project daily for disposal or reuse will not be included in the disturbed area calculation.

If you have any questions concerning submittal of PRDs, please call the State Water Board at (866) 563-3107.

ATTACHMENT B
PERMIT REGISTRATION DOCUMENTS (PRDs) TO COMPLY WITH THE TERMS OF THE GENERAL PERMIT TO DISCHARGE STORM WATER ASSOCIATED WITH CONSTRUCTION ACTIVITY

GENERAL INSTRUCTIONS

A. All Linear Construction Projects shall comply with the PRD requirements in Attachment A.2 of this Order.

B. Who Must Submit

Discharges of storm water associated with construction that results in the disturbance of one acre or more of land must apply for coverage under the General Construction Storm Water Permit (General Permit). Any construction activity that is a part of a larger common plan of development or sale must also be permitted, regardless of size. (For example, if 0.5 acre of a 20-acre subdivision is disturbed by the construction activities of discharger A and the remaining 19.5 acres is to be developed by discharger B, discharger A must obtain a General Storm Water Permit for the 0.5 acre project).

Other discharges from construction activities that are covered under this General Permit can be found in the General Permit Section II.B.

It is the LRP's responsibility to obtain coverage under this General Permit by electronically submitting complete PRDs (Permit Registration Documents).

In all cases, the proper procedures for submitting the PRDs must be completed before construction can commence.

C. Construction Activity Not Covered By This General Permit

Discharges from construction that are not covered under this General Permit can be found in the General Permit Sections II.A &B..

D. Annual Fees and Fee Calculation

Annual fees are calculated based upon the total area of land to be disturbed not the total size of the acreage owned. However, the calculation includes all acres to be disturbed during the duration of the project. For example, if 10 acres are scheduled to be disturbed the first year and 10 in each subsequent year for 5 years, the annual fees would be based upon 50 acres of disturbance. The State Water Board will evaluate adding acreage to an existing Permit Waste Discharge Identification (WDID) number on a case-by-case basis. In general, any acreage to be considered must be contiguous to the permitted land area and the existing

SWPPP must be appropriate for the construction activity and topography of the acreage under consideration. As acreage is built out and stabilized or sold, the Change of Information (COI) form enables the applicant to remove those acres from inclusion in the annual fee calculation. Checks should be made payable to: State Water Board.

The Annual fees are established through regulations adopted by the State Water Board. The total annual fee is the current base fee plus applicable surcharges for all construction sites submitting an NOI, based on the total acreage to be disturbed during the life of the project. Annual fees are subject to change by regulation.

Dischargers that apply for and satisfy the Small Construction Erosivity Wavier requirements shall pay a fee of $200.00 plus an applicable surcharge, see the General Permit Section II.B.7.

E. When to Apply

LRP's proposing to conduct construction activities subject to this General Permit must submit their PRDs prior to the commencement of construction activity.

F. Requirements for Completing Permit Registration Documents (PRDs)

All dischargers required to comply with this General Permit shall electronically submit the required PRDs for their type of construction as defined below.

G. Standard PRD Requirements (All Dischargers)

1. Notice of Intent
2. Risk Assessment (Standard or Site-Specific)
3. Site Map
4. SWPPP
5. Annual Fee
6. Certification

H. Additional PRD Requirements Related to Construction Type

1. Discharger in unincorporated areas of the State (not covered under an adopted Phase I or II SUSMP requirements) and that are not a linear project shall also submit a completed:
   a. Post-Construction Water Balance Calculator (Appendix 2).

2. Dischargers who are proposing to implement ATS shall submit:
   a. Complete ATS Plan in accordance with Attachment F at least 14 days prior to the planned operation of the ATS and a paper copy shall be available onsite during ATS operation.

   b. Certification proof that design done by a professional in accordance with Attachment F.

3. Dischargers who are proposing an alternate Risk Justification:
   a. Particle Size Analysis.

I. Exceptions to Standard PRD Requirements

Construction sites with an R value less than 5 as determined in the Risk Assessment are not required to submit a SWPPP.

J. Description of PRDs

1. Notice of Intent (NOI)

2. Site Map(s) Includes:
   a. The project's surrounding area (vicinity)
   b. Site layout
   c. Construction site boundaries
   d. Drainage areas
   e. Discharge locations
   f. Sampling locations
   g. Areas of soil disturbance (temporary or permanent)
   h. Active areas of soil disturbance (cut or fill)
   i. Locations of all runoff BMPs
   j. Locations of all erosion control BMPs
   k. Locations of all sediment control BMPs
   l. ATS location (if applicable)
   m. Locations of sensitive habitats, watercourses, or other features which are not to be disturbed
   n. Locations of all post-construction BMPs
   o. Locations of storage areas for waste, vehicles, service, loading/unloading of materials, access (entrance/exits) points to construction site, fueling, and water storage, water transfer for dust control and compaction practices

3. **SWPPPs**
   A site-specific SWPPP shall be developed by each discharger and shall be submitted with the PRDs.

4. **Risk Assessment**
   All dischargers shall use the Risk Assessment procedure as describe in the General Permit Appendix 1.

   a. The Standard Risk Assessment includes utilization of the following:
      i. Receiving water Risk Assessment interactive map

   ii. EPA Rainfall Erosivity Factor Calculator Website
   iii. Sediment Risk interactive map
   iv. Sediment sensitive water bodies list

b. The Site-Specific Risk Assessment includes the completion of the hand calculated R value Risk Calculator

5. **Post-Construction Water Balance Calculator**
   All dischargers subject to this requirement shall complete the Water Balance Calculator (in Appendix 2) in accordance with the instructions.

6. **ATS Design Document and Certification**
   All dischargers using ATS must submit electronically their system design (as well as any supporting documentation) and proof that the system was designed by a qualified ATS design professional (See Attachment F).

To obtain coverage under the General Permit PRDs must be included and completed. If any of the required items are missing, the PRD submittal is considered incomplete and will be rejected. Upon receipt of a complete PRD submittal, the State Water Board will process the application package in the order received and assign a (WDID) number.

Questions?

If you have any questions on completing the PRDs please email stormwater@waterboards.ca.gov or call (866) 563-3107.

ATTACHMENT C
RISK LEVEL 1 REQUIREMENTS

A. Effluent Standards

[These requirements are the same as those in the General Permit order.]

1. Narrative – Risk Level 1 dischargers shall comply with the narrative effluent standards listed below:

   a. Storm water discharges and authorized non-storm water discharges regulated by this General Permit shall not contain a hazardous substance equal to or in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

   b. Dischargers shall minimize or prevent pollutants in storm water discharges and authorized non-storm water discharges through the use of controls, structures, and management practices that achieve BAT for toxic and non-conventional pollutants and BCT for conventional pollutants.

2. Numeric – Risk Level 1 dischargers are not subject to a numeric effluent standard.

B. Good Site Management "Housekeeping"

1. Risk Level 1 dischargers shall implement good site management (i.e., "housekeeping") measures for construction materials that could potentially be a threat to water quality if discharged. At a minimum, Risk Level 1 dischargers shall implement the following good housekeeping measures:

   a. Conduct an inventory of the products used and/or expected to be used and the end products that are produced and/or expected to be produced. This does not include materials and equipment that are designed to be outdoors and exposed to environmental conditions (i.e. poles, equipment pads, cabinets, conductors, insulators, bricks, etc.).

   b. Cover and berm loose stockpiled construction materials that are not actively being used (i.e. soil, spoils, aggregate, fly-ash, stucco, hydrated lime, etc.).

c. Store chemicals in watertight containers (with appropriate secondary containment to prevent any spillage or leakage) or in a storage shed (completely enclosed).

d. Minimize exposure of construction materials to precipitation. This does not include materials and equipment that are designed to be outdoors and exposed to environmental conditions (i.e. poles, equipment pads, cabinets, conductors, insulators, bricks, etc.).

e. Implement BMPs to prevent the off-site tracking of loose construction and landscape materials.

2. Risk Level 1 dischargers shall implement good housekeeping measures for waste management, which, at a minimum, shall consist of the following:

   a. Prevent disposal of any rinse or wash waters or materials on impervious or pervious site surfaces or into the storm drain system.

   b. Ensure the containment of sanitation facilities (e.g., portable toilets) to prevent discharges of pollutants to the storm water drainage system or receiving water.

   c. Clean or replace sanitation facilities and inspecting them regularly for leaks and spills.

   d. Cover waste disposal containers at the end of every business day and during a rain event.

   e. Prevent discharges from waste disposal containers to the storm water drainage system or receiving water.

   f. Contain and securely protect stockpiled waste material from wind and rain at all times unless actively being used.

   g. Implement procedures that effectively address hazardous and non-hazardous spills.

   h. Develop a spill response and implementation element of the SWPPP prior to commencement of construction activities. The SWPPP shall require that:

      i. Equipment and materials for cleanup of spills shall be available on site and that spills and leaks shall be cleaned up immediately and disposed of properly; and

ii. Appropriate spill response personnel are assigned and trained.

i. Ensure the containment of concrete washout areas and other washout areas that may contain additional pollutants so there is no discharge into the underlying soil and onto the surrounding areas.

3. Risk Level 1 dischargers shall implement good housekeeping for vehicle storage and maintenance, which, at a minimum, shall consist of the following:

   a. Prevent oil, grease, or fuel to leak in to the ground, storm drains or surface waters.

   b. Place all equipment or vehicles, which are to be fueled, maintained and stored in a designated area fitted with appropriate BMPs.

   c. Clean leaks immediately and disposing of leaked materials properly.

4. Risk Level 1 dischargers shall implement good housekeeping for landscape materials, which, at a minimum, shall consist of the following:

   a. Contain stockpiled materials such as mulches and topsoil when they are not actively being used.

   b. Contain fertilizers and other landscape materials when they are not actively being used.

   c. Discontinue the application of any erodible landscape material within 2 days before a forecasted rain event or during periods of precipitation.

   d. Apply erodible landscape material at quantities and application rates according to manufacture recommendations or based on written specifications by knowledgeable and experienced field personnel.

   e. Stack erodible landscape material on pallets and covering or storing such materials when not being used or applied.

5. Risk Level 1 dischargers shall conduct an assessment and create a list of potential pollutant sources and identify any areas of the site where additional BMPs are necessary to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges. This potential pollutant list shall be kept with the SWPPP and shall identify

all non-visible pollutants which are known, or should be known, to occur on the construction site. At a minimum, when developing BMPs, Risk Level 1 dischargers shall do the following:

a. Consider the quantity, physical characteristics (e.g., liquid, powder, solid), and locations of each potential pollutant source handled, produced, stored, recycled, or disposed of at the site.

b. Consider the degree to which pollutants associated with those materials may be exposed to and mobilized by contact with storm water.

c. Consider the direct and indirect pathways that pollutants may be exposed to storm water or authorized non-storm water discharges. This shall include an assessment of past spills or leaks, non-storm water discharges, and discharges from adjoining areas.

d. Ensure retention of sampling, visual observation, and inspection records.

e. Ensure effectiveness of existing BMPs to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges.

6. Risk Level 1 dischargers shall implement good housekeeping measures on the construction site to control the air deposition of site materials and from site operations. Such particulates can include, but are not limited to, sediment, nutrients, trash, metals, bacteria, oil and grease and organics.

C. Non-Storm Water Management

1. Risk Level 1 dischargers shall implement measures to control all non-storm water discharges during construction.

2. Risk Level 1 dischargers shall wash vehicles in such a manner as to prevent non-storm water discharges to surface waters or MS4 drainage systems.

3. Risk Level 1 dischargers shall clean streets in such a manner as to prevent unauthorized non-storm water discharges from reaching surface water or MS4 drainage systems.

D. Erosion Control

1. Risk Level 1 dischargers shall implement effective wind erosion control.

2. Risk Level 1 dischargers shall provide effective soil cover for inactive[1] areas and all finished slopes, open space, utility backfill, and completed lots.

3. Risk Level 1 dischargers shall limit the use of plastic materials when more sustainable, environmentally friendly alternatives exist. Where plastic materials are deemed necessary, the discharger shall consider the use of plastic materials resistant to solar degradation.

E. Sediment Controls

1. Risk Level 1 dischargers shall establish and maintain effective perimeter controls and stabilize all construction entrances and exits to sufficiently control erosion and sediment discharges from the site.

2. On sites where sediment basins are to be used, Risk Level 1 dischargers shall, at minimum, design sediment basins according to the method provided in CASQA's Construction BMP Guidance Handbook.

F. Run-on and Runoff Controls

Risk Level 1 dischargers shall effectively manage all run-on, all runoff within the site and all runoff that discharges off the site. Run-on from off site shall be directed away from all disturbed areas or shall collectively be in compliance with the effluent limitations in this General Permit.

G. Inspection, Maintenance and Repair

1. Risk Level 1 dischargers shall ensure that all inspection, maintenance repair and sampling activities at the project location shall be performed or supervised by a Qualified SWPPP Practitioner (QSP) representing the discharger. The QSP may delegate any or all of these activities to an employee trained to do the task(s) appropriately, but shall ensure adequate deployment.

2. Risk Level 1 dischargers shall perform weekly inspections and observations, and at least once each 24-hour period during extended

[1] Inactive areas of construction are areas of construction activity that have been disturbed and are not scheduled to be re-disturbed for at least 14 days.

storm events, to identify and record BMPs that need maintenance to operate effectively, that have failed, or that could fail to operate as intended. Inspectors shall be the QSP or be trained by the QSP.

3. Upon identifying failures or other shortcomings, as directed by the QSP, Risk Level 1 dischargers shall begin implementing repairs or design changes to BMPs within 72 hours of identification and complete the changes as soon as possible.

4. For each inspection required, Risk Level 1 dischargers shall complete an inspection checklist, using a form provided by the State Water Board or Regional Water Board or in an alternative format.

5. Risk Level 1 dischargers shall ensure that checklists shall remain onsite with the SWPPP and at a minimum, shall include:

    a. Inspection date and date the inspection report was written.

    b. Weather information, including presence or absence of precipitation, estimate of beginning of qualifying storm event, duration of event, time elapsed since last storm, and approximate amount of rainfall in inches.

    c. Site information, including stage of construction, activities completed, and approximate area of the site exposed.

    d. A description of any BMPs evaluated and any deficiencies noted.

    e. If the construction site is safely accessible during inclement weather, list the observations of all BMPs: erosion controls, sediment controls, chemical and waste controls, and non-storm water controls. Otherwise, list the results of visual inspections at all relevant outfalls, discharge points, downstream locations and any projected maintenance activities.

    f. Report the presence of noticeable odors or of any visible sheen on the surface of any discharges.

    g. Any corrective actions required, including any necessary changes to the SWPPP and the associated implementation dates.

    h. Photographs taken during the inspection, if any.

    i. Inspector's name, title, and signature.

H. Rain Event Action Plan
Not required for Risk Level 1 dischargers.

I. Risk Level 1 Monitoring and Reporting Requirements

Table 1- Summary of Monitoring Requirements

Risk Level	Visual Inspections					Sample Collection	
	Quarterly Non-storm Water Discharge	Pre-storm Event		Daily Storm BMP	Post Storm	Storm Water Discharge	Receiving Water
		Baseline	REAP				
1	X	X		X	X		

1. **Construction Site Monitoring Program Requirements**

   a. Pursuant to Water Code Sections 13383 and 13267, all dischargers subject to this General Permit shall develop and implement a written site-specific Construction Site Monitoring Program (CSMP) in accordance with the requirements of this Section. The CSMP shall include all monitoring procedures and instructions, location maps, forms, and checklists as required in this section. The CSMP shall be developed prior to the commencement of construction activities, and revised as necessary to reflect project revisions. The CSMP shall be a part of the Storm Water Pollution Prevention Plan (SWPPP), included as an appendix or separate SWPPP chapter.

   b. Existing dischargers registered under the State Water Board Order No. 99-08-DWQ shall make and implement necessary revisions to their Monitoring Programs to reflect the changes in this General Permit in a timely manner, but no later than July 1, 2010. Existing dischargers shall continue to implement their existing Monitoring Programs in compliance with State Water Board Order No. 99-08-DWQ until the necessary revisions are completed according to the schedule above.

   c. When a change of ownership occurs for all or any portion of the construction site prior to completion or final stabilization, the new discharger shall comply with these requirements as of the date the ownership change occurs.

2. **Objectives**

   The CSMP shall be developed and implemented to address the following objectives:

   a. To demonstrate that the site is in compliance with the Discharge Prohibitions;

b. To determine whether non-visible pollutants are present at the construction site and are causing or contributing to exceedances of water quality objectives;

c. To determine whether immediate corrective actions, additional Best Management Practice (BMP) implementation, or SWPPP revisions are necessary to reduce pollutants in storm water discharges and authorized non-storm water discharges; and

d. To determine whether BMPs included in the SWPPP are effective in preventing or reducing pollutants in storm water discharges and authorized non-storm water discharges.

3. **Risk Level 1 - Visual Monitoring (Inspection) Requirements for Qualifying Rain Events**

    a. Risk Level 1 dischargers shall visually observe (inspect) storm water discharges at all discharge locations within two business days (48 hours) after each qualifying rain event.

    b. Risk Level 1 dischargers shall visually observe (inspect) the discharge of stored or contained storm water that is derived from and discharged subsequent to a qualifying rain event producing precipitation of ½ inch or more at the time of discharge. Stored or contained storm water that will likely discharge after operating hours due to anticipated precipitation shall be observed prior to the discharge during operating hours.

    c. Risk Level 1 dischargers shall conduct visual observations (inspections) during business hours only.

    d. Risk Level 1 dischargers shall record the time, date and rain gauge reading of all qualifying rain events.

    e. Within 2 business days (48 hours) prior to each qualifying rain event, Risk Level 1 dischargers shall visually observe (inspect):

        i. All storm water drainage areas to identify any spills, leaks, or uncontrolled pollutant sources. If needed, the discharger shall implement appropriate corrective actions.

        ii. All BMPs to identify whether they have been properly implemented in accordance with the SWPPP. If needed, the discharger shall implement appropriate corrective actions.

iii. Any storm water storage and containment areas to detect leaks and ensure maintenance of adequate freeboard.

f. For the visual observations (inspections) described in e.i and e.iii above, Risk Level 1 dischargers shall observe the presence or absence of floating and suspended materials, a sheen on the surface, discolorations, turbidity, odors, and source(s) of any observed pollutants.

g. Within two business days (48 hours) after each qualifying rain event, Risk Level 1 dischargers shall conduct post rain event visual observations (inspections) to (1) identify whether BMPs were adequately designed, implemented, and effective, and (2) identify additional BMPs and revise the SWPPP accordingly.

h. Risk Level 1 dischargers shall maintain on-site records of all visual observations (inspections), personnel performing the observations, observation dates, weather conditions, locations observed, and corrective actions taken in response to the observations.

4. **Risk Level 1 – Visual Observation Exemptions**

a. Risk Level 1 dischargers shall be prepared to conduct visual observation (inspections) until the minimum requirements of Section I.3 above are completed. Risk Level 1 dischargers are not required to conduct visual observation (inspections) under the following conditions:

i. During dangerous weather conditions such as flooding and electrical storms.

ii. Outside of scheduled site business hours.

b. If no required visual observations (inspections) are collected due to these exceptions, Risk Level 1 dischargers shall include an explanation in their SWPPP and in the Annual Report documenting why the visual observations (inspections) were not conducted.

5. **Risk Level 1 – Monitoring Methods**

Risk Level 1 dischargers shall include a description of the visual observation locations, visual observation procedures, and visual observation follow-up and tracking procedures in the CSMP.

6. **Risk Level 1 – Non-Storm Water Discharge Monitoring Requirements**

a. Visual Monitoring Requirements:

   i. Risk Level 1 dischargers shall visually observe (inspect) each drainage area for the presence of (or indications of prior) unauthorized and authorized non-storm water discharges and their sources.

   ii. Risk Level 1 dischargers shall conduct one visual observation (inspection) quarterly in each of the following periods: January-March, April-June, July-September, and October-December. Visual observation (inspections) are only required during daylight hours (sunrise to sunset).

   iii. Risk Level 1 dischargers shall ensure that visual observations (inspections) document the presence or evidence of any non-storm water discharge (authorized or unauthorized), pollutant characteristics (floating and suspended material, sheen, discoloration, turbidity, odor, etc.), and source. Risk Level 1 dischargers shall maintain on-site records indicating the personnel performing the visual observation (inspections), the dates and approximate time each drainage area and non-storm water discharge was observed, and the response taken to eliminate unauthorized non-storm water discharges and to reduce or prevent pollutants from contacting non-storm water discharges.

7. **Risk Level 1 – Non-Visible Pollutant Monitoring Requirements**

   a. Risk Level 1 dischargers shall collect one or more samples during any breach, malfunction, leakage, or spill observed during a visual inspection which could result in the discharge of pollutants to surface waters that would not be visually detectable in storm water.

   b. Risk Level 1 dischargers shall ensure that water samples are large enough to characterize the site conditions.

   c. Risk Level 1 dischargers shall collect samples at all discharge locations that can be safely accessed.

   d. Risk Level 1 dischargers shall collect samples during the first two hours of discharge from rain events that occur during business hours and which generate runoff.

   e. Risk Level 1 dischargers shall analyze samples for all non-visible pollutant parameters (if applicable) - parameters indicating the presence of pollutants identified in the pollutant source assessment required (Risk Level 1 dischargers shall modify their CSMPs to address these additional parameters in accordance with any updated SWPPP pollutant source assessment).

f. Risk Level 1 dischargers shall collect a sample of storm water that has not come in contact with the disturbed soil or the materials stored or used on-site (uncontaminated sample) for comparison with the discharge sample.

g. Risk Level 1 dischargers shall compare the uncontaminated sample to the samples of discharge using field analysis or through laboratory analysis.[2]

h. Risk Level 1 dischargers shall keep all field /or analytical data in the SWPPP document.

8. **Risk Level 1 – Particle Size Analysis for Project Risk Justification**

Risk Level 1 dischargers justifying an alternative project risk shall report a soil particle size analysis used to determine the RUSLE K-Factor. ASTM D-422 (Standard Test Method for Particle-Size Analysis of Soils), as revised, shall be used to determine the percentages of sand, very fine sand, silt, and clay on the site.

9. **Risk Level 1 – Records**

Risk Level 1 dischargers shall retain records of all storm water monitoring information and copies of all reports (including Annual Reports) for a period of at least three years. Risk Level 1 dischargers shall retain all records on-site while construction is ongoing. These records include:

a. The date, place, time of facility inspections, sampling, visual observation (inspections), and/or measurements, including precipitation.

b. The individual(s) who performed the facility inspections, sampling, visual observation (inspections), and or measurements.

c. The date and approximate time of analyses.

d. The individual(s) who performed the analyses.

[2] For laboratory analysis, all sampling, sample preservation, and analyses must be conducted according to test procedures under 40 CFR Part 136. Field discharge samples shall be collected and analyzed according to the specifications of the manufacturer of the sampling devices employed.

e. A summary of all analytical results from the last three years, the method detection limits and reporting units, and the analytical techniques or methods used.

f. Rain gauge readings from site inspections.

g. Quality assurance/quality control records and results.

h. Non-storm water discharge inspections and visual observation (inspections) and storm water discharge visual observation records (see Sections I.3 and I.6 above).

i. Visual observation and sample collection exception records (see Section I.4 above).

j. The records of any corrective actions and follow-up activities that resulted from analytical results, visual observation (inspections), or inspections.

ATTACHMENT D
RISK LEVEL 2 REQUIREMENTS

A. Effluent Standards

[These requirements are the same as those in the General Permit order.]

1. Narrative – Risk Level 2 dischargers shall comply with the narrative effluent standards listed below:

    a. Storm water discharges and authorized non-storm water discharges regulated by this General Permit shall not contain a hazardous substance equal to or in excess of reportable quantities established in 40 C.F.R. §§ 117.3 and 302.4, unless a separate NPDES Permit has been issued to regulate those discharges.

    b. Dischargers shall minimize or prevent pollutants in storm water discharges and authorized non-storm water discharges through the use of controls, structures, and management practices that achieve BAT for toxic and non-conventional pollutants and BCT for conventional pollutants.

2. Numeric – Risk level 2 dischargers are subject to a pH NAL of 6.5-8.5, and a turbidity NAL of 250 NTU.

B. Good Site Management "Housekeeping"

1. Risk Level 2 dischargers shall implement good site management (i.e., "housekeeping") measures for construction materials that could potentially be a threat to water quality if discharged. At a minimum, Risk Level 2 dischargers shall implement the following good housekeeping measures:

    a. Conduct an inventory of the products used and/or expected to be used and the end products that are produced and/or expected to be produced. This does not include materials and equipment that are designed to be outdoors and exposed to environmental conditions (i.e. poles, equipment pads, cabinets, conductors, insulators, bricks, etc.).

    b. Cover and berm loose stockpiled construction materials that are not actively being used (i.e. soil, spoils, aggregate, fly-ash, stucco, hydrated lime, etc.).

c. Store chemicals in watertight containers (with appropriate secondary containment to prevent any spillage or leakage) or in a storage shed (completely enclosed).

d. Minimize exposure of construction materials to precipitation. This does not include materials and equipment that are designed to be outdoors and exposed to environmental conditions (i.e. poles, equipment pads, cabinets, conductors, insulators, bricks, etc.).

e. Implement BMPs to prevent the off-site tracking of loose construction and landscape materials.

2. Risk Level 2 dischargers shall implement good housekeeping measures for waste management, which, at a minimum, shall consist of the following:

   a. Prevent disposal of any rinse or wash waters or materials on impervious or pervious site surfaces or into the storm drain system.

   b. Ensure the containment of sanitation facilities (e.g., portable toilets) to prevent discharges of pollutants to the storm water drainage system or receiving water.

   c. Clean or replace sanitation facilities and inspecting them regularly for leaks and spills.

   d. Cover waste disposal containers at the end of every business day and during a rain event.

   e. Prevent discharges from waste disposal containers to the storm water drainage system or receiving water.

   f. Contain and securely protect stockpiled waste material from wind and rain at all times unless actively being used.

   g. Implement procedures that effectively address hazardous and non-hazardous spills.

   h. Develop a spill response and implementation element of the SWPPP prior to commencement of construction activities. The SWPPP shall require:

      i. Equipment and materials for cleanup of spills shall be available on site and that spills and leaks shall be cleaned up immediately and disposed of properly.

ii. Appropriate spill response personnel are assigned and trained.

i. Ensure the containment of concrete washout areas and other washout areas that may contain additional pollutants so there is no discharge into the underlying soil and onto the surrounding areas.

3. Risk Level 2 dischargers shall implement good housekeeping for vehicle storage and maintenance, which, at a minimum, shall consist of the following:

   a. Prevent oil, grease, or fuel to leak in to the ground, storm drains or surface waters.

   b. Place all equipment or vehicles, which are to be fueled, maintained and stored in a designated area fitted with appropriate BMPs.

   c. Clean leaks immediately and disposing of leaked materials properly.

4. Risk Level 2 dischargers shall implement good housekeeping for landscape materials, which, at a minimum, shall consist of the following:

   a. Contain stockpiled materials such as mulches and topsoil when they are not actively being used.

   b. Contain all fertilizers and other landscape materials when they are not actively being used.

   c. Discontinue the application of any erodible landscape material within 2 days before a forecasted rain event or during periods of precipitation.

   d. Apply erodible landscape material at quantities and application rates according to manufacture recommendations or based on written specifications by knowledgeable and experienced field personnel.

   e. Stack erodible landscape material on pallets and covering or storing such materials when not being used or applied.

5. Risk Level 2 dischargers shall conduct an assessment and create a list of potential pollutant sources and identify any areas of the site where additional BMPs are necessary to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges. This potential pollutant list shall be kept with the SWPPP and shall identify

all non-visible pollutants which are known, or should be known, to occur on the construction site. At a minimum, when developing BMPs, Risk Level 2 dischargers shall do the following:

a. Consider the quantity, physical characteristics (e.g., liquid, powder, solid), and locations of each potential pollutant source handled, produced, stored, recycled, or disposed of at the site.

b. Consider the degree to which pollutants associated with those materials may be exposed to and mobilized by contact with storm water.

c. Consider the direct and indirect pathways that pollutants may be exposed to storm water or authorized non-storm water discharges. This shall include an assessment of past spills or leaks, non-storm water discharges, and discharges from adjoining areas.

d. Ensure retention of sampling, visual observation, and inspection records.

e. Ensure effectiveness of existing BMPs to reduce or prevent pollutants in storm water discharges and authorized non-storm water discharges.

6. Risk Level 2 dischargers shall implement good housekeeping measures on the construction site to control the air deposition of site materials and from site operations. Such particulates can include, but are not limited to, sediment, nutrients, trash, metals, bacteria, oil and grease and organics.

7. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall document all housekeeping BMPs in the SWPPP and REAP(s) in accordance with the nature and phase of the construction project. Construction phases at traditional land development projects include Grading and Land Development Phase, Streets and Utilities, or Vertical Construction for traditional land development projects.

C. Non-Storm Water Management

1. Risk Level 2 dischargers shall implement measures to control all non-storm water discharges during construction.

2. Risk Level 2 dischargers shall wash vehicles in such a manner as to prevent non-storm water discharges to surface waters or MS4 drainage systems.

3. Risk Level 2 dischargers shall clean streets in such a manner as to prevent unauthorized non-storm water discharges from reaching surface water or MS4 drainage systems.

D. Erosion Control

1. Risk Level 2 dischargers shall implement effective wind erosion control.

2. Risk Level 2 dischargers shall provide effective soil cover for inactive[1] areas and all finished slopes, open space, utility backfill, and completed lots.

3. Risk Level 2 dischargers shall limit the use of plastic materials when more sustainable, environmentally friendly alternatives exist. Where plastic materials are deemed necessary, the discharger shall consider the use of plastic materials resistant to solar degradation.

E. Sediment Controls

1. Risk Level 2 dischargers shall establish and maintain effective perimeter controls and stabilize all construction entrances and exits to sufficiently control erosion and sediment discharges from the site.

2. On sites where sediment basins are to be used, Risk Level 2 dischargers shall, at minimum, design sediment basins according to the method provided in CASQA's Construction BMP Guidance Handbook.

3. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall implement appropriate erosion control BMPs (runoff control and soil stabilization) in conjunction with sediment control BMPs for areas under active[2] construction.

4. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall apply linear sediment controls along the toe of the slope, face of the slope, and at the grade breaks of exposed slopes to comply with sheet flow lengths[3] in accordance with Table 1.

[1] Inactive areas of construction are areas of construction activity that have been disturbed and are not scheduled to be re-disturbed for at least 14 days.
[2] Active areas of construction are areas undergoing land surface disturbance. This includes construction activity during the preliminary stage, mass grading stage, streets and utilities stage and the vertical construction stage.
[3] Sheet flow length is the length that shallow, low velocity flow travels across a site.

Table 1 - Critical Slope/Sheet Flow Length Combinations

Slope Percentage	Sheet flow length not to exceed
0-25%	20 feet
25-50%	15 feet
Over 50%	10 feet

5. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall ensure that construction activity traffic to and from the project is limited to entrances and exits that employ effective controls to prevent offsite tracking of sediment.

6. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall ensure that all storm drain inlets and perimeter controls, runoff control BMPs, and pollutant controls at entrances and exits (e.g. tire washoff locations) are maintained and protected from activities that reduce their effectiveness.

7. **Additional Risk Level 2 Requirement:** Risk Level 2 dischargers shall inspect on a daily basis all immediate access roads daily. At a minimum daily (when necessary) and prior to any rain event, the discharger shall remove any sediment or other construction activity-related materials that are deposited on the roads (by vacuuming or sweeping).

F. Run-on and Run-off Controls

Risk Level 2 dischargers shall effectively manage all run-on, all runoff within the site and all runoff that discharges off the site. Run-on from off site shall be directed away from all disturbed areas or shall collectively be in compliance with the effluent limitations in this General Permit.

G. Inspection, Maintenance and Repair

1. Risk Level 2 dischargers shall ensure that all inspection, maintenance repair and sampling activities at the project location shall be performed or supervised by a Qualified SWPPP Practitioner (QSP) representing the discharger. The QSP may delegate any or all of these activities to an employee appropriately trained to do the task(s).

2. Risk Level 2 dischargers shall perform weekly inspections and observations, and at least once each 24-hour period during extended storm events, to identify and record BMPs that need maintenance to operate effectively, that have failed, or that could fail to operate as intended. Inspectors shall be the QSP or be trained by the QSP.

3. Upon identifying failures or other shortcomings, as directed by the QSP, Risk Level 2 dischargers shall begin implementing repairs or design changes to BMPs within 72 hours of identification and complete the changes as soon as possible.

4. For each inspection required, Risk Level 2 dischargers shall complete an inspection checklist, using a form provided by the State Water Board or Regional Water Board or in an alternative format.

5. Risk Level 2 dischargers shall ensure that checklists shall remain onsite with the SWPPP and at a minimum, shall include:

   a. Inspection date and date the inspection report was written.

   b. Weather information, including presence or absence of precipitation, estimate of beginning of qualifying storm event, duration of event, time elapsed since last storm, and approximate amount of rainfall in inches.

   c. Site information, including stage of construction, activities completed, and approximate area of the site exposed.

   d. A description of any BMPs evaluated and any deficiencies noted.

   e. If the construction site is safely accessible during inclement weather, list the observations of all BMPs: erosion controls, sediment controls, chemical and waste controls, and non-storm water controls. Otherwise, list the results of visual inspections at all relevant outfalls, discharge points, downstream locations and any projected maintenance activities.

   f. Report the presence of noticeable odors or of any visible sheen on the surface of any discharges.

   g. Any corrective actions required, including any necessary changes to the SWPPP and the associated implementation dates.

   h. Photographs taken during the inspection, if any.

   i. Inspector's name, title, and signature.

H. Rain Event Action Plan

1. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP develop a Rain Event Action Plan (REAP) 48 hours prior to any

likely precipitation event. A likely precipitation event is any weather pattern that is forecast to have a 50% or greater probability of producing precipitation in the project area. The discharger shall ensure a QSP obtain a printed copy of precipitation forecast information from the National Weather Service Forecast Office (e.g., by entering the zip code of the project's location at http://www.srh.noaa.gov/forecast).

2. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP develop the REAPs for all phases of construction (i.e., Grading and Land Development, Streets and Utilities, Vertical Construction, Final Landscaping and Site Stabilization).

3. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP ensure that the REAP include, at a minimum, the following site information:

   a. Site Address
   b. Calculated Risk Level (2 or 3)
   c. Site Storm Water Manager Information including the name, company, and 24-hour emergency telephone number
   d. Erosion and Sediment Control Provider information including the name, company, and 24-hour emergency telephone number
   e. Storm Water Sampling Agent information including the name, company, and 24-hour emergency telephone number

4. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP include in the REAP, at a minimum, the following project phase information:

   a. Activities associated with each construction phase
   b. Trades active on the construction site during each construction phase
   c. Trade contractor information
   d. Suggested actions for each project phase

5. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP develop additional REAPs for project sites where construction activities are indefinitely halted or postponed (Inactive Construction). At a minimum, Inactive Construction REAPs must include:

   a. Site Address
   b. Calculated Risk Level (2 or 3)
   c. Site Storm Water Manager Information including the name, company, and 24-hour emergency telephone number

d. Erosion and Sediment Control Provider information including the name, company, and 24-hour emergency telephone number
e. Storm Water Sampling Agent information including the name, company, and 24-hour emergency telephone number
f. Trades active on site during Inactive Construction
g. Trade contractor information
h. Suggested actions for inactive construction sites

6. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP begin implementation and make the REAP available onsite no later than 24 hours prior to the likely precipitation event.

7. **Additional Risk Level 2 Requirement:** The discharger shall ensure a QSP maintain onsite a paper copy of each REAP onsite in compliance with the record retention requirements of the Special Provisions in this General Permit.

I. Risk Level 2 Monitoring and Reporting Requirements

Table 2- Summary of Monitoring Requirements

Risk Level	Visual Inspections					Sample Collection	
	Quarterly Non-storm Water Discharge	Pre-storm Event		Daily Storm BMP	Post Storm	Storm Water Discharge	Receiving Water
		Baseline	REAP				
2	X	X	X	X	X	X	

1. Construction Site Monitoring Program Requirements

   a. Pursuant to Water Code Sections 13383 and 13267, all dischargers subject to this General Permit shall develop and implement a written site-specific Construction Site Monitoring Program (CSMP) in accordance with the requirements of this Section. The CSMP shall include all monitoring procedures and instructions, location maps, forms, and checklists as required in this section. The CSMP shall be developed prior to the commencement of construction activities, and revised as necessary to reflect project revisions. The CSMP shall be a part of the Storm Water Pollution Prevention Plan (SWPPP), included as an appendix or separate SWPPP chapter.

   b. Existing dischargers registered under the State Water Board Order No. 99-08-DWQ shall make and implement necessary revisions to their Monitoring Program to reflect the changes in this General Permit in a timely manner, but no later than July 1, 2010. Existing dischargers shall continue to implement their existing Monitoring Programs in compliance with State Water Board Order No. 99-08-DWQ until the necessary revisions are completed according to the schedule above.

   c. When a change of ownership occurs for all or any portion of the construction site prior to completion or final stabilization, the new discharger shall comply with these requirements as of the date the ownership change occurs.

2. **Objectives**

   The CSMP shall be developed and implemented to address the following objectives:

a. To demonstrate that the site is in compliance with the Discharge Prohibitions and applicable Numeric Action Levels (NALs)/Numeric Effluent Limitations (NELs) of this General Permit.

b. To determine whether non-visible pollutants are present at the construction site and are causing or contributing to exceedances of water quality objectives.

c. To determine whether immediate corrective actions, additional Best Management Practice (BMP) implementation, or SWPPP revisions are necessary to reduce pollutants in storm water discharges and authorized non-storm water discharges.

d. To determine whether BMPs included in the SWPPP/Rain Event Action Plan (REAP) are effective in preventing or reducing pollutants in storm water discharges and authorized non-storm water discharges.

3. **Risk Level 2 – Visual Monitoring (Inspection) Requirements for Qualifying Rain Events**

a. Risk Level 2 dischargers shall visually observe (inspect) storm water discharges at all discharge locations within two business days (48 hours) after each qualifying rain event.

b. Risk Level 2 dischargers shall visually observe (inspect) the discharge of stored or contained storm water that is derived from and discharged subsequent to a qualifying rain event producing precipitation of ½ inch or more at the time of discharge. Stored or contained storm water that will likely discharge after operating hours due to anticipated precipitation shall be observed prior to the discharge during operating hours.

c. Risk Level 2 dischargers shall conduct visual observations (inspections) during business hours only.

d. Risk Level 2 dischargers shall record the time, date and rain gauge reading of all qualifying rain events.

e. Within 2 business days (48 hours) prior to each qualifying rain event, Risk Level 2 dischargers shall visually observe (inspect):

i. all storm water drainage areas to identify any spills, leaks, or uncontrolled pollutant sources. If needed, the discharger shall implement appropriate corrective actions.

ii. all BMPs to identify whether they have been properly implemented in accordance with the SWPPP/REAP. If needed, the discharger shall implement appropriate corrective actions.

iii. any storm water storage and containment areas to detect leaks and ensure maintenance of adequate freeboard.

f. For the visual observations (inspections) described in c.i and c.iii above, Risk Level 2 dischargers shall observe the presence or absence of floating and suspended materials, a sheen on the surface, discolorations, turbidity, odors, and source(s) of any observed pollutants.

g. Within two business days (48 hours) after each qualifying rain event, Risk Level 2 dischargers shall conduct post rain event visual observations (inspections) to (1) identify whether BMPs were adequately designed, implemented, and effective, and (2) identify additional BMPs and revise the SWPPP accordingly.

h. Risk Level 2 dischargers shall maintain on-site records of all visual observations (inspections), personnel performing the observations, observation dates, weather conditions, locations observed, and corrective actions taken in response to the observations.

4. **Risk Level 2 – Water Quality Sampling and Analysis**

a. Risk Level 2 dischargers shall collect storm water grab samples from sampling locations, as defined in Section I.5. The storm water grab sample(s) obtained shall be representative of the flow and characteristics of the discharge.

b. At minimum, Risk Level 2 dischargers shall collect 3 samples per day of the qualifying event.

c. Risk Level 2 dischargers shall ensure that the grab samples collected of stored or contained storm water are from discharges subsequent to a qualifying rain event (producing precipitation of ½ inch or more at the time of discharge).

<u>Storm Water Effluent Monitoring Requirements</u>

d. Risk Level 2 dischargers shall analyze their effluent samples for:

i. pH and turbidity.

ii. Any additional parameters for which monitoring is required by the Regional Water Board.

5. **Risk Level 2 – Storm Water Discharge Water Quality Sampling Locations**

<u>Effluent Sampling Locations</u>

a. Risk Level 2 dischargers shall perform sampling and analysis of storm water discharges to characterize discharges associated with construction activity from the entire project disturbed area.

b. Risk Level 2 dischargers shall collect effluent samples at all discharge points where storm water is discharged off-site.

c. Risk Level 2 dischargers shall ensure that storm water discharge collected and observed represent[4] the effluent in each drainage area based on visual observation of the water and upstream conditions.

d. Risk Level 2 dischargers shall monitor and report site run-on from surrounding areas if there is reason to believe run-on may contribute to an exceedance of NALs or NELs.

e. Risk Level 2 dischargers who deploy an ATS on their site, or a portion on their site, shall collect ATS effluent samples and measurements from the discharge pipe or another location representative of the nature of the discharge.

f. Risk Level 2 dischargers shall select analytical test methods from the list provided in Table 3 below.

g. All storm water sample collection preservation and handling shall be conducted in accordance with Section I.7 “Storm Water Sample Collection and Handling Instructions” below.

6. **Risk Level 2 – Visual Observation and Sample Collection Exemptions**

a. Risk Level 2 dischargers shall be prepared to collect samples and conduct visual observation (inspections) until the minimum requirements of Sections I.3 and I.4 above are completed. Risk

[4] For example, if there has been concrete work recently in an area, or drywall scrap is exposed to the rain, a pH sample shall be taken of drainage from the relevant work area. Similarly, if sediment laden water is flowing through some parts of a silt fence, samples shall be taken of the sediment-laden water even if most water flowing through the fence is clear.

Level 2 dischargers are not required to physically collect samples or conduct visual observation (inspections) under the following conditions:

i. During dangerous weather conditions such as flooding and electrical storms.

ii. Outside of scheduled site business hours.

b. If no required samples or visual observation (inspections) are collected due to these exceptions, Risk Level 2 dischargers shall include an explanation in their SWPPP and in the Annual Report documenting why the sampling or visual observation (inspections) were not conducted.

7. **Risk Level 2 – Storm Water Sample Collection and Handling Instructions**

a. Risk Level 2 dischargers shall refer to Table 3 below for test methods, detection limits, and reporting units.

b. Risk Level 2 dischargers shall ensure that testing laboratories will receive samples within 48 hours of the physical sampling (unless otherwise required by the laboratory), and shall use only the sample containers provided by the laboratory to collect and store samples.

c. Risk Level 2 dischargers shall designate and train personnel to collect, maintain, and ship samples in accordance with the Surface Water Ambient Monitoring Program's (SWAMP) 2008 Quality Assurance Program Plan (QAPrP).[5]

8. **Risk Level 2 – Monitoring Methods**

a. Risk Level 2 dischargers shall include a description of the following items in the CSMP:

i. Visual observation locations, visual observation procedures, and visual observation follow-up and tracking procedures.

ii. Sampling locations, and sample collection and handling procedures. This shall include detailed procedures for sample

[5] Additional information regarding SWAMP's QAPrP and QAMP can be found at http://www.waterboards.ca.gov/water_issues/programs/swamp/.
QAPrP:http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/qapp/swamp_qapp_master090108a.pdf.
QAMP: http://www.waterboards.ca.gov/water_issues/programs/swamp/qamp.shtml.

collection, storage, preservation, and shipping to the testing lab to assure that consistent quality control and quality assurance is maintained. Dischargers shall attach to the monitoring program an example Chain of Custody form used when handling and shipping samples.

iii. Identification of the analytical methods and related method detection limits (if applicable) for each parameter required in Section I.4 above.

b. Risk Level 2 dischargers shall ensure that all sampling and sample preservation are in accordance with the current edition of "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association). All monitoring instruments and equipment (including a discharger's own field instruments for measuring pH and turbidity) should be calibrated and maintained in accordance with manufacturers' specifications to ensure accurate measurements. Risk Level 2 dischargers shall ensure that all laboratory analyses are conducted according to test procedures under 40 CFR Part 136, unless other test procedures have been specified in this General Permit or by the Regional Water Board. With the exception of field analysis conducted by the discharger for turbidity and pH, all analyses should be sent to and conducted at a laboratory certified for such analyses by the State Department of Health Services. Risk Level 2 dischargers shall conduct their own field analysis of pH and may conduct their own field analysis of turbidity if the discharger has sufficient capability (qualified and trained employees, properly calibrated and maintained field instruments, etc.) to adequately perform the field analysis.

9. **Risk Level 2 – Analytical Methods**

a. Risk Level 2 dischargers shall refer to Table 3 below for test methods, detection limits, and reporting units.

b. **pH**: Risk Level 2 dischargers shall perform pH analysis on-site with a calibrated pH meter or a pH test kit. Risk Level 2 dischargers shall record pH monitoring results on paper and retain these records in accordance with Section I.14, below.

c. **Turbidity**: Risk Level 2 dischargers shall perform turbidity analysis using a calibrated turbidity meter (turbidimeter), either on-site or at an accredited lab. Acceptable test methods include Standard Method 2130 or USEPA Method 180.1. The results will be recorded in the site log book in Nephelometric Turbidity Units (NTU).

10. **Risk Level 2 - Non-Storm Water Discharge Monitoring Requirements**

a. Visual Monitoring Requirements:

i. Risk Level 2 dischargers shall visually observe (inspect) each drainage area for the presence of (or indications of prior) unauthorized and authorized non-storm water discharges and their sources.

ii. Risk Level 2 dischargers shall conduct one visual observation (inspection) quarterly in each of the following periods: January-March, April-June, July-September, and October-December. Visual observation (inspections) are only required during daylight hours (sunrise to sunset).

iii. Risk Level 2 dischargers shall ensure that visual observations (inspections) document the presence or evidence of any non-storm water discharge (authorized or unauthorized), pollutant characteristics (floating and suspended material, sheen, discoloration, turbidity, odor, etc.), and source. Risk Level 2 dischargers shall maintain on-site records indicating the personnel performing the visual observation (inspections), the dates and approximate time each drainage area and non-storm water discharge was observed, and the response taken to eliminate unauthorized non-storm water discharges and to reduce or prevent pollutants from contacting non-storm water discharges.

b. Effluent Sampling Locations:

i. Risk Level 2 dischargers shall sample effluent at all discharge points where non-storm water and/or authorized non-storm water is discharged off-site.

ii. Risk Level 2 dischargers shall send all non-storm water sample analyses to a laboratory certified for such analyses by the State Department of Health Services.

iii. Risk Level 2 dischargers shall monitor and report run-on from surrounding areas if there is reason to believe run-on may contribute to an exceedance of NALs.

11. **Risk Level 2 – Non-Visible Pollutant Monitoring Requirements**

a. Risk Level 2 dischargers shall collect one or more samples during any breach, malfunction, leakage, or spill observed during a visual inspection which could result in the discharge of pollutants to surface waters that would not be visually detectable in storm water.

b. Risk Level 2 dischargers shall ensure that water samples are large enough to characterize the site conditions.

c. Risk Level 2 dischargers shall collect samples at all discharge locations that can be safely accessed.

d. Risk Level 2 dischargers shall collect samples during the first two hours of discharge from rain events that occur during business hours and which generate runoff.

e. Risk Level 2 dischargers shall analyze samples for all non-visible pollutant parameters (if applicable) - parameters indicating the presence of pollutants identified in the pollutant source assessment required (Risk Level 2 dischargers shall modify their CSMPs to address these additional parameters in accordance with any updated SWPPP pollutant source assessment).

f. Risk Level 2 dischargers shall collect a sample of storm water that has not come in contact with the disturbed soil or the materials stored or used on-site (uncontaminated sample) for comparison with the discharge sample.

g. Risk Level 2 dischargers shall compare the uncontaminated sample to the samples of discharge using field analysis or through laboratory analysis.[6]

h. Risk Level 2 dischargers shall keep all field /or analytical data in the SWPPP document.

12. **Risk Level 2 – Watershed Monitoring Option**

Risk Level 2 dischargers who are part of a qualified regional watershed-based monitoring program may be eligible for relief from the requirements in Sections I.5. The Regional Water Board may approve proposals to substitute an acceptable watershed-based monitoring program by determining if the watershed-based monitoring program

[6] For laboratory analysis, all sampling, sample preservation, and analyses must be conducted according to test procedures under 40 CFR Part 136. Field discharge samples shall be collected and analyzed according to the specifications of the manufacturer of the sampling devices employed.

will provide substantially similar monitoring information in evaluating discharger compliance with the requirements of this General Permit.

13. **Risk Level 2 – Particle Size Analysis for Project Risk Justification**

Risk Level 2 dischargers justifying an alternative project risk shall report a soil particle size analysis used to determine the RUSLE K-Factor. ASTM D-422 (Standard Test Method for Particle-Size Analysis of Soils), as revised, shall be used to determine the percentages of sand, very fine sand, silt, and clay on the site.

14. **Risk Level 2 – Records**

Risk Level 2 dischargers shall retain records of all storm water monitoring information and copies of all reports (including Annual Reports) for a period of at least three years. Risk Level 2 dischargers shall retain all records on-site while construction is ongoing. These records include:

a. The date, place, time of facility inspections, sampling, visual observation (inspections), and/or measurements, including precipitation.

b. The individual(s) who performed the facility inspections, sampling, visual observation (inspections), and or measurements.

c. The date and approximate time of analyses.

d. The individual(s) who performed the analyses.

e. A summary of all analytical results from the last three years, the method detection limits and reporting units, the analytical techniques or methods used, and the chain of custody forms.

f. Rain gauge readings from site inspections;

g. Quality assurance/quality control records and results.

h. Non-storm water discharge inspections and visual observation (inspections) and storm water discharge visual observation records (see Sections I.3 and I.10 above).

i. Visual observation and sample collection exception records (see Section I.6 above).

j. The records of any corrective actions and follow-up activities that resulted from analytical results, visual observation (inspections), or inspections.

15. **Risk Level 2 – NAL Exceedance Report**

a. In the event that any effluent sample exceeds an applicable NAL, Risk Level 2 dischargers shall electronically submit all storm event sampling results to the State Water Board no later than 10 days after the conclusion of the storm event. The Regional Boards have the authority to require the submittal of an NAL Exceedance Report.

b. Risk Level 2 dischargers shall certify each NAL Exceedance Report in accordance with the Special Provisions for Construction Activity.

c. Risk Level 2 dischargers shall retain an electronic or paper copy of each NAL Exceedance Report for a minimum of three years after the date the annual report is filed.

d. Risk Level 2 dischargers shall include in the NAL Exceedance Report:

i. The analytical method(s), method reporting unit(s), and method detection limit(s) of each analytical parameter (analytical results that are less than the method detection limit shall be reported as "less than the method detection limit").

ii. The date, place, time of sampling, visual observation (inspections), and/or measurements, including precipitation.

iii. A description of the current BMPs associated with the effluent sample that exceeded the NAL and the proposed corrective actions taken.

Table 3 – Risk Level 2 Test Methods, Detection Limits, Reporting Units and Applicable NALs/NELs

Parameter	Test Method / Protocol	Discharge Type	Min. Detection Limit	Reporting Units	Numeric Action Level
pH	Field test with calibrated portable instrument	Risk Level 2 Discharges	0.2	pH units	lower NAL = 6.5 upper NAL = 8.5
Turbidity	EPA 0180.1 and/or field test with calibrated portable instrument	Risk Level 2 Discharges other than ATS	1	NTU	250 NTU
		For ATS discharges	1	NTU	N/A

ATTACHMENT F:
Active Treatment System (ATS) Requirements

Table 1 – Numeric Effluent Limitations, Numeric Action Levels, Test Methods, Detection Limits, and Reporting Units

Parameter	Test Method	Discharge Type	Min. Detection Limit	Units	Numeric Action Level	Numeric Effluent Limitation
Turbidity	EPA 0180.1 and/or field test with a calibrated portable instrument	For ATS discharges	1	NTU	N/A	10 NTU for Daily Flow-Weighted Average & 20 NTU for Any Single Sample

A. Dischargers choosing to implement an Active Treatment System (ATS) on their site shall comply with all of the requirements in this Attachment.

B. The discharger shall maintain a paper copy of each ATS specification onsite in compliance with the record retention requirements in the Special Provisions of this General Permit.

C. ATS Design, Operation and Submittals

1. The ATS shall be designed and approved by a Certified Professional in Erosion and Sediment Control (CPESC), a Certified Professional in Storm Water Quality (CPSWQ); a California registered civil engineer; or any other California registered engineer.

2. The discharger shall ensure that the ATS is designed in a manner to preclude the accidental discharge of settled floc[1] during floc pumping or related operations.

3. The discharger shall design outlets to dissipate energy from concentrated flows.

4. The discharger shall install and operate an ATS by assigning a lead person (or project manager) who has either a minimum of five years construction storm

[1] Floc is defined as a clump of solids formed by the chemical action in ATS systems.

water experience or who is a licensed contractors specifically holding a California Class A Contractors license.[2]

5. The discharger shall prepare an ATS Plan that combines the site-specific data and treatment system information required to safely and efficiently operate an ATS. The ATS Plan shall be electronically submitted to the State Water Board at least 14 days prior to the planned operation of the ATS and a paper copy shall be available onsite during ATS operation. At a minimum, the ATS Plan shall include:

   a. ATS Operation and Maintenance Manual for All Equipment.

   b. ATS Monitoring, Sampling & Reporting Plan, including Quality Assurance/Quality Control (QA/QC).

   c. ATS Health and Safety Plan.

   d. ATS Spill Prevention Plan.

6. The ATS shall be designed to capture and treat (within a 72-hour period) a volume equivalent to the runoff from a 10-year, 24-hour storm event using a watershed runoff coefficient of 1.0.

D. Treatment – Chemical Coagulation/Flocculation

1. Jar tests shall be conducted using water samples selected to represent typical site conditions and in accordance with ASTM D2035-08 (2003).

2. The discharger shall conduct, at minimum, six site-specific jar tests (per polymer with one test serving as a control) for each project to determine the proper polymer and dosage levels for their ATS.

3. Single field jar tests may also be conducted during a project if conditions warrant, for example if construction activities disturb changing types of soils, which consequently cause change in storm water and runoff characteristics.

E. Residual Chemical and Toxicity Requirements

1. The discharger shall utilize a residual chemical test method that has a method detection limit (MDL) of 10% or less than the maximum allowable threshold

[2] Business and Professions Code Division 3, Chapter 9, Article 4, Class A Contractor: A general engineering contractor is a contractor whose principal contracting business is in connection with fixed works requiring specialized engineering knowledge and skill. [http://www.cslb.ca.gov/General-Information/library/licensing-classifications.asp].

concentration[3] (MATC) for the specific coagulant in use and for the most sensitive species of the chemical used.

2. The discharger shall utilize a residual chemical test method that produces a result within one hour of sampling.

3. The discharger shall have a California State certified laboratory validate the selected residual chemical test. Specifically the lab will review the test protocol, test parameters, and the detection limit of the coagulant. The discharger shall electronically submit this documentation as part of the ATS Plan.

4. If the discharger cannot utilize a residual chemical test method that meets the requirements above, the discharger shall operate the ATS in Batch Treatment[4] mode.

5. A discharger planning to operate in Batch Treatment mode shall perform toxicity testing in accordance with the following:

   a. The discharger shall initiate acute toxicity testing on effluent samples representing effluent from each batch prior to discharge[5]. All bioassays shall be sent to a laboratory certified by the Department of Health Services (DHS) Environmental Laboratory Accreditation Program (ELAP). The required field of testing number for Whole Effluent Toxicity (WET) testing is E113.[6]

   b. Acute toxicity tests shall be conducted with the following species and protocols. The methods to be used in the acute toxicity testing shall be those outlined for a 96-hour acute test in "Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organisms, USEPA-841-R-02-012" for Fathead minnow, *Pimephales promelas* (fathead minnow). Acute toxicity for *Oncorhynchus mykiss* (Rainbow Trout) may be used as a substitute for testing fathead minnows.

   c. All toxicity tests shall meet quality assurance criteria and test acceptability criteria in the most recent versions of the EPA test method for WET testing.

   d. The discharger shall electronically report all acute toxicity testing.

[3] The Maximum Allowable Threshold Concentration (MATC) is the allowable concentration of residual, or dissolved, coagulant/flocculant in effluent. The MATC shall be coagulant/flocculant-specific, and based on toxicity testing conducted by an independent, third-party laboratory. A typical MATC would be:
The MATC is equal to the geometric mean of the NOEC (No Observed Effect Concentration) and LOEC (Lowest Observed Effect Concentration) Acute and Chronic toxicity results for most sensitive species determined for the specific coagulant. The most sensitive species test shall be used to determine the MATC.
[4] Batch Treatment mode is defined as holding or recirculating the treated water in a holding basin or tank(s) until treatment is complete or the basin or storage tank(s) is full.
[5] This requirement only requires that the test be initiated prior to discharge.
[6] http://www.dhs.ca.gov/ps/ls/elap/pdf/FOT_Desc.pdf.

F. Filtration

1. The ATS shall include a filtration step between the coagulant treatment train and the effluent discharge. This is commonly provided by sand, bag, or cartridge filters, which are sized to capture suspended material that might pass through the clarifier tanks.

2. Differential pressure measurements shall be taken to monitor filter loading and confirm that the final filter stage is functioning properly.

G. Residuals Management

1. Sediment shall be removed from the storage or treatment cells as necessary to ensure that the cells maintain their required water storage (i.e., volume) capability.

2. Handling and disposal of all solids generated during ATS operations shall be done in accordance with all local, state, and federal laws and regulations.

H. ATS Instrumentation

1. The ATS shall be equipped with instrumentation that automatically measures and records effluent water quality data and flow rate.

2. The minimum data recorded shall be consistent with the Monitoring and Reporting requirements below, and shall include:

   a. Influent Turbidity

   b. Effluent Turbidity

   c. Influent pH

   d. Effluent pH

   e. Residual Chemical

   f. Effluent Flow rate

   g. Effluent Flow volume

3. Systems shall be equipped with a data recording system, such as data loggers or webserver-based systems, which records each measurement on a frequency no longer than once every 15 minutes.

4. Cumulative flow volume shall be recorded daily. The data recording system shall have the capacity to record a minimum of seven days continuous data.

5. Instrumentation systems shall be interfaced with system control to provide auto shutoff or recirculation in the event that effluent measurements exceed turbidity or pH.

6. The system shall also assure that upon system upset, power failure, or other catastrophic event, the ATS will default to a recirculation mode or safe shut down.

7. Instrumentation (flow meters, probes, valves, streaming current detectors, controlling computers, etc.) shall be installed and maintained per manufacturer's recommendations, which shall be included in the QA/QC plan.

8. The QA/QC plan shall also specify calibration procedures and frequencies, instrument method detection limit or sensitivity verification, laboratory duplicate procedures, and other pertinent procedures.

9. The instrumentation system shall include a method for controlling coagulant dose, to prevent potential overdosing. Available technologies include flow/turbidity proportional metering, periodic jar testing and metering pump adjustment, and ionic charge measurement controlling the metering pump.

I. ATS Effluent Discharge

1. ATS effluent shall comply with all provisions and prohibitions in this General Permit, specifically the NELs.

2. NELs for discharges from an ATS:

   a. Turbidity of all ATS discharges shall be less than 10 NTU for daily flow-weighted average of all samples and 20 NTU for any single sample.

   b. Residual Chemical shall be < 10% of MATC[7] for the most sensitive species of the chemical used.

3. If an analytical effluent sampling result is outside the range of pH NELs (i.e., is below the lower NEL for pH or exceeds the upper NEL for pH) or exceeds the turbidity NEL (as listed in Table 1), the discharger is in violation of this General

[7] The Maximum Allowable Threshold Concentration (MATC) is the allowable concentration of residual, or dissolved, coagulant/flocculant in effluent. The MATC shall be coagulant/flocculant-specific, and based on toxicity testing conducted by an independent, third-party laboratory. The MATC is equal to the geometric mean of the NOEC (No Observed Effect Concentration) and LOEC (Lowest Observed Effect Concentration) Acute and Chronic toxicity results for most sensitive species determined for the specific coagulant. The most sensitive species test shall be used to determine the MATC.

Permit and shall electronically file the results in violation within 24-hours of obtaining the results.

4. If ATS effluent is authorized to discharge into a sanitary sewer system, the discharger shall comply with any pre-treatment requirements applicable for that system. The discharger shall include any specific criteria required by the municipality in the ATS Plan.

5. Compliance Storm Event:

   Discharges of storm water from ATS shall comply with applicable NELs (above) unless the storm event causing the discharges is determined after the fact to be equal to or larger than the Compliance Storm Event (expressed in inches of rainfall). The Compliance Storm Event for ATS discharges is the 10 year, 24 hour storm, as determined using these maps:

   http://www.wrcc.dri.edu/pcpnfreq/nca10y24.gif
   http://www.wrcc.dri.edu/pcpnfreq/sca10y24.gif

   This exemption is dependent on the submission of rain gauge data verifying the storm event is equal to or larger than the Compliance Storm.

J. Operation and Maintenance Plan

1. Each Project shall have a site-specific Operation and Maintenance (O&M) Manual covering the procedures required to install, operate and maintain the ATS.[8]

2. The O&M Manual shall only be used in conjunction with appropriate project-specific design specifications that describe the system configuration and operating parameters.

3. The O&M Manual shall have operating manuals for specific pumps, generators, control systems,and other equipment.

K. Sampling and Reporting Quality Assurance/ Quality Check (QA/QC) Plan

4. A project-specific QA/QC Plan shall be developed for each project. The QA/QC Plan shall include at a minimum:

   a. Calibration – Calibration methods and frequencies for all system and field instruments shall be specified.

[8] The manual is typically in a modular format covering generalized procedures for each component that is utilized in a particular system.

b. Method Detection Limits (MDLs) – The methods for determining MDLs shall be specified for each residual coagulant measurement method. Acceptable minimum MDLs for each method, specific to individual coagulants, shall be specified.

c. Laboratory Duplicates – Requirements for monthly laboratory duplicates for residual coagulant analysis shall be specified.

L. Personnel Training

1. Operators shall have training specific to using an ATS and liquid coagulants for storm water discharges in California.

2. The training shall be in the form of a formal class with a certificate and requirements for testing and certificate renewal.

3. Training shall include a minimum of eight hours classroom and 32 hours field training. The course shall cover the following topics:

   a. Coagulation Basics –Chemistry and physical processes

   b. ATS System Design and Operating Principles

   c. ATS Control Systems

   d. Coagulant Selection – Jar testing, dose determination, etc.

   e. Aquatic Safety/Toxicity of Coagulants, proper handling and safety

   f. Monitoring, Sampling, and Analysis

   g. Reporting and Recordkeeping

   h. Emergency Response

M. Active Treatment System (ATS) Monitoring Requirements

Any discharger who deploys an ATS on their site shall conduct the following:

1. Visual Monitoring

   a. A designated responsible person shall be on site daily at all times during treatment operations.

b. Daily on-site visual monitoring of the system for proper performance shall be conducted and recorded in the project data log.

   i. The log shall include the name and phone number of the person responsible for system operation and monitoring.

   ii. The log shall include documentation of the responsible person's training.

2. Operational and Compliance Monitoring

   a. Flow shall be continuously monitored and recorded at not greater than 15-minute intervals for total volume treated and discharged.

   b. Influent and effluent pH must be continuously monitored and recorded at not greater than 15-minute intervals.

   c. Influent and effluent turbidity (expressed in NTU) must be continuously monitored and recorded at not greater than 15-minute intervals.

   d. The type and amount of chemical used for pH adjustment, if any, shall be monitored and recorded.

   e. Dose rate of chemical used in the ATS system (expressed in mg/L) shall be monitored and reported 15-minutes after startup and every 8 hours of operation.

   f. Laboratory duplicates – monthly laboratory duplicates for residual coagulant analysis must be performed and records shall be maintained onsite.

   g. Effluent shall be monitored and recorded for residual chemical/additive levels.

   h. If a residual chemical/additive test does not exist and the ATS is operating in a batch treatment mode of operation refer to the toxicity monitoring requirements below.

3. Toxicity Monitoring

   A discharger operating in batch treatment mode shall perform toxicity testing in accordance with the following:

   a. The discharger shall initiate acute toxicity testing on effluent samples representing effluent from each batch prior to discharge.[9] All bioassays shall be sent to a laboratory certified by the Department of Health Services (DHS)

[9] This requirement only requires that the test be initiated prior to discharge.

Environmental Laboratory Accreditation Program (ELAP). The required field of testing number for Whole Effluent Toxicity (WET) testing is E113.[10]

b. Acute toxicity tests shall be conducted with the following species and protocols. The methods to be used in the acute toxicity testing shall be those outlined for a 96-hour acute test in "Methods for Measuring the Acute Toxicity of Effluents and Receiving Water to Freshwater and Marine Organisms, USEPA-841-R-02-012" for Fathead minnow, *Pimephales promelas or* Rainbow trout *Oncorhynchus mykiss* may be used as a substitute for fathead minnow.

c. All toxicity tests shall meet quality assurance criteria and test acceptability criteria in the most recent versions of the EPA test method for WET testing.[11]

4. Reporting and Recordkeeping

At a minimum, every 30 days a LRP representing the discharger shall access the State Water Boards Storm Water Mulit-Application and Report Tracking system (SMARTS) and electronically upload field data from the ATS. Records must be kept for three years after the project is completed .

5. Non-compliance Reporting

a. Any indications of toxicity or other violations of water quality objectives shall be reported to the appropriate regulatory agency as required by this General Permit.

b. Upon any measurements that exceed water quality standards, the system operator shall immediately notify his supervisor or other responsible parties, who shall notify the Regional Water Board.

c. If any monitoring data exceeds any applicable NEL in this General Permit, the discharger shall electronically submit a NEL Violation Report to the State Water Board within 24 hours after the NEL exceedance has been identified.

i. ATS dischargers shall certify each NEL Violation Report in accordance with the Special Provisions for Construction Activity in this General Permit.

ii. ATS dischargers shall retain an electronic or paper copy of each NEL Violation Report for a minimum of three years after the date the annual report is filed.

iii. ATS dischargers shall include in the NEL Violation Report:

[10] http://www.dhs.ca.gov/ps/ls/elap/pdf/FOT_Desc.pdf.
[11] http://www.epa.gov/waterscience/methods/wet/.

(1) The analytical method(s), method reporting unit(s), and method detection limit(s) of each analytical parameter (analytical results that are less than the method detection limit shall be reported as "less than the method detection limit");

(2) The date, place, time of sampling, visual observation (inspections), and/or measurements, including precipitation; and

(3) A description of the current onsite BMPs, and the proposed corrective actions taken to manage the NEL exceedance.

iv. Compliance Storm Exemption - In the event that an applicable NEL has been exceeded during a storm event equal to or larger than the Compliance Storm Event, ATS dischargers shall report the on-site rain gauge reading and nearby governmental rain gauge readings for verification.

RB-AR35536

COUNTY OF LOS ANGELES

DEPARTMENT OF PUBLIC WORKS

"To Enrich Lives Through Effective and Caring Service"

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ADDRESS ALL CORRESPONDENCE TO:
P.O. BOX 1460
ALHAMBRA, CALIFORNIA 91802-1460

January 31, 2005

IN REPLY PLEASE
REFER TO FILE: WM-9

Mr. Jonathon Bishop
Executive Officer
Los Angeles Regional Water Quality Control Board
320 West 4th Street, Suite 200
Los Angeles, CA 90013-2343

Attention Dr. Xavier Swamikannu

Dear Mr. Bishop:

INTERIM PEAK FLOW RUNOFF CRITERIA FOR NEW DEVELOPMENT

For the past year, in accordance with the Development Planning Program and the Special Monitoring Studies of the Los Angeles National Pollutant Discharge Elimination System Municipal Storm Water Permit, Public Works and the Southern California Storm Water Monitoring Coalition have been conducting a study of the possible impacts on natural streams due to upstream development. A report from the consultant on the work done to date will be forwarded to you under separate cover by the Southern California Coastal Waters Research Project. The Municipal Storm Water Permit requires that each permittee develop and implement numerical criteria for peak flow control in accordance with the findings of the study by February 1, 2005.

However, due to the unexpected hospitalization of a key consultant team member, the study will not be completed in a manner sufficient to develop comprehensive numerical standards. As the result of the latest meeting of the Executive Committee of the Storm Water Monitoring Coalition, the Executive Committee has decided to discuss follow-up options for the research at the next meeting on March 1, 2005.

Therefore, as discussed with Dr. Swamikannu, we are adopting the enclosed Interim Peak Flow Standard to be effective until such time as a final standard can be adopted based on a complete scientific report. Enclosure A is the Interim Standard and Enclosure B, as requested by Dr. Swamikannu, is a comparative table of similar standards in place around the Country. This Interim Standard is derived from the Interim Peak Flow Standard already approved by your Board for the County of Ventura and the Standard Urban Storm Water Mitigation Plan provisions of the Los Angeles

Municipal Storm Water Permit. Because there is only scarce research to support numerical peak flow limits at this time, our intent is to provide protection for natural streams to the extent supported by the study using practical construction practices.

You will note that this Interim Standard will apply to discretionary development projects only. We believe that it will be more effective in the short term for Public Works to impose interim peak flow standards through its discretionary authority for new development. We believe that the discretionary process will capture the majority of all development in unincorporated areas of the County tributary to natural drainage systems. Enclosure C is a list of some major discretionary projects already approved by Public Works, and therefore projects that will not have the Interim Peak Flow Standards imposed upon them.

Finally, as discussed with Dr. Swamikannu, we will participate in the continuation of the peak flow impact study with the other members of the Storm Water Monitoring Coalition. There is approximately $40,000 of unspent funds remaining from the consultant's incomplete study. Public Works is committed to participating with the Southern California Storm Water Monitoring Coalition in the research necessary to quantify numerical limits associated with peak flow impacts, as will be discussed in the March 1 meeting.

If you have any questions, please call Mr. Dan Lafferty of Watershed Management Division at (626) 458-4325.

Very truly yours,

Donald L Wolfe

DONALD L. WOLFE
Acting Director of Public Works

BD:sw
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Enc.

cc: All Permittees
Department of Regional Planning (Lee Stark, Julie Lowry)

ENCLOSURE A

PEAK FLOW STANDARD
INTERIM

Objective

The objective of the Peak Flow Standard is to control postdevelopment peak storm water runoff in order to prevent accelerated stream erosion and to protect stream habitat.

Design Storms

The Peak Flow Standard shall require that all postdevelopment runoff from a 2-year, 24-hour storm shall not exceed the predevelopment peak flow rate, burned, from a 2-year, 24-hour storm when the predevelopment peak flow equals or exceeds five cubic feet per second. Discharge flow rates shall be calculated using the County of Los Angeles Modified Rational Method. The Peak Flow Standard shall also require that postdevelopment runoff from the 50-year capital storm shall not exceed the predevelopment peak flow rate, burned and bulked, from the 50-year capital storm.

Natural Drainage Systems

The Peak Flow Standard shall apply only to areas tributary to Natural Drainage Systems in the Malibu Creek, Topanga Canyon Creek, Upper Los Angeles River, Upper San Gabriel River, Santa Clara River, and Los Angeles County coastal stream watersheds.

Floodway Protection

The Peak Flow Standard shall prohibit construction within County-adopted floodways in compliance with Federal Emergency Management Agency Regulations Title 44 CFR, Section 60.3, and County Code Title 11, Chapter 11.60.

Discretionary Priority Projects

The Peak Flow standard shall apply to Discretionary Priority Projects whose applications have not been approved or deemed complete according to County Department of Regional Planning's Development Monitoring System in the following categories only:

- Housing developments (includes single-family homes, multifamily homes, condominiums, and apartments) of 20 units or more;

- A two-acre or more hydraulically connected impervious surface area industrial/commercial development;
- Automotive service facilities (SIC 5013, 5014, 5541, 7532-7534 and 7536-7539) [10,000 square feet or more of surface area];
- Retail gasoline outlets [10,000 square feet or more of surface area and with projected Average Daily Traffic (ADT) of 200 or more vehicles]. Subsurface Peak Flow controls that may endanger public safety (i.e., create an explosive environment) are considered not appropriate;
- Restaurants (SIC 5812) [10,000 square feet or more of surface area];
- Parking lots 10,000 square feet or more of surface area or with 50 or more parking spaces;
- Projects located in, adjacent to or discharging directly to an Environmentally Sensitive Area that create 5,000 square feet or more of hydraulically connected impervious surface area and that discharge stormwater and urban runoff that is likely to impact a sensitive biological species or habitat;
- Redevelopment projects in the above categories that meet redevelopment thresholds.

GLOSSARY OF TERMS FOR PEAK FLOW STANDARDS

2-year, 24-hour Storm: a design rainfall event lasting at least 24 hours with a 2-year return period (50 percent probability).

50-year Capital Storm: the 4-day, 50-year return period (2 percent probability) design storm defined in the latest DPW Hydrology and Sedimentation Manual and addenda.

Bulked: the inclusion of inorganic debris in the peak flow rate calculation as the result of a burned watershed, in accordance with the latest DPW Hydrology and Sedimentation Manual and addenda.

Burned: the assumption of a brush fire on a tributary area in the calculation of peak flow rates, in accordance with the latest DPW Hydrology and Sedimentation Manual and addenda.

Discretionary Project: a development project that requires the exercise of judgment or deliberation when the public agency or body decides to approve or disapprove a particular activity, as distinguished from situations where the public agency or body merely has to determine whether there has been conformity with applicable statutes, ordinances, or regulations (Johnson v. State of California, 1968).

Hydraulically connected impervious surface area: within the project boundaries, pavement, roofs, driveways, sidewalks, hardscape, exposed bedrock, anthropogenically compacted and natural hardpan soil, etc., that is impervious to infiltration of storm water and whose flow lines are directly linked to each other during the 2-year, 24-hour storm.

Natural Drainage System: an unlined or unimproved (not engineered) creek, stream, river or similar waterway.

Redevelopment threshold: land-disturbing activity that results in the creation, addition, or replacement of 10,000 square feet or more of hydraulically connected impervious surface area on an already developed site. Redevelopment includes, but is not limited to: the expansion of a building footprint; addition or replacement of a structure; replacement of hydraulically connected impervious surface area that is not part of a routine maintenance activity; and land-disturbing activities related to structural or impervious surfaces. It does not include routine maintenance to maintain original line and grade, hydraulic capacity, or original purpose of facility, nor does it include emergency construction activities required to immediately protect public health and safety.

INTERNATIONAL STORMWATER BMP DATABASE
www.bmpdatabase.org

International Stormwater BMP Database Summary of BMP Categories by State as of November 2011

Category	BMP Category	AL	CA	CO	CT	DE	FL	GA	IL	MA	MD	MI	MN	NC	NH	NJ	NY	OH	OR	PA	TX	VA	WA	WI	Non-U.S.	Total
BR	Bioretention					1				1				11	3				1	1		1	1	4		24
CO	Composite (Treatment Train)		1	5			3						2								8	1	1			21
CX	Control			6			2							1	1					2	2			1	2	17
DB	Detention Basin	2	5	1			3	1		1	1	1	1	1	1		4		2		7	6	2			39
GR	Green Roof			1															7	3						11
GS	Biofilter (Swales & Filter Strips)		40				13							6	1				5		4	11	1		1	82
IB	Infiltration Basin		1																							1
LD	LID (Site Scale)																							1		1
MD	Manufactured Device (Multiple Types)	4	12		1	7	11				1				7	5	1		1	1	9	6	6	5	1	78
MF	Media Filter	1	11	2		1	5								1		1		1		10	1	1			35
MP	Maintenance Practice		2						4					2									12	8		28
OT	Other						1																		1	2
PP	Porous Pavement			6			2						1	4	1			1		3	7				1	26
PT	Percolation Trench/Well						9						1								1					11
RP	Retention Pond	2	4	5			27	1	1			3	5	3	1						8		3	1	1	65
WB	Wetland Basin	2	1				6				3	1			1				1		8	6				29
WC	Wetland Channel	4	3	2			2						4								2					17
Total		**15**	**80**	**28**	**1**	**9**	**84**	**2**	**5**	**2**	**5**	**5**	**14**	**28**	**17**	**5**	**6**	**1**	**18**	**10**	**66**	**32**	**27**	**20**	**7**	**487**

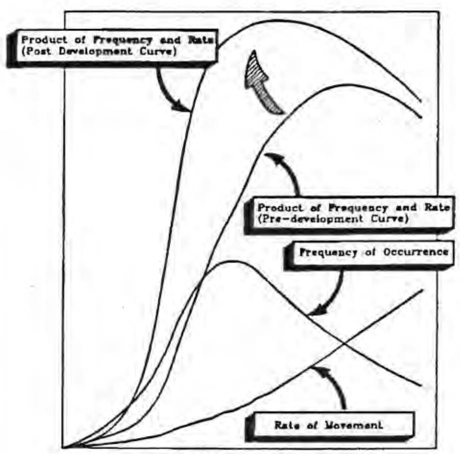
Source: International Stormwater BMP Database, November 17, 2011.

An Alternate Design Approach for the Control of Instream Erosion Potential in Urbanizing Watersheds

Craig R. MacRae, Ph.D.
Gore & Storrie Ltd.,
857 Norwest Rd., Kingston, Ontario, K7P 2N2

I. INTRODUCTION

Case studies have demonstrated the potentially adverse effects of uncontrolled urban storm water runoff on stream channel form. The concepts of detention and retention were employed in the form of Best Management Practices (BMPs) to mitigate these impacts through the reduction of flow rates by storage routing effects. Studies have shown that stormwater control facilities designed using current techniques may be ineffective or may aggravate erosion hazard in some instances (McCuen, 1979; Lorant, 1983, 1988). These and other studies suggest that the criteria upon which current design techniques are based may not adequately meet the intent of Stormwater Management (SWM) practice. The challenge then, is to develop criteria and ultimately a design procedure which more adequately deals with the instream erosion issue.



PROBABLE ALTERATION OF LEOPOLD ET AL.'S (1964) EFFECTIVE WORK CURVE

Figure 1

Current design practice is based on criteria developed from studies of non-urban stream channel systems. In an influential study, Leopold et al. (1964) demonstrated that "effective work" achieved an absolute maximum at bankfull stage that was in accord with a flood recurrence interval (RI), of 1:1.5 to 1:2 years (Figure 1). However, numerous studies have shown that the hydrologic and sediment regimes in urban systems are altered from their pre-development state. MacRae and Rowney (1992) demonstrated that under urban conditions the absolute maximum on the effective work curve increased in magnitude and shifted to flows of 1:0.5 to 1:1.5 year return period (Figure 1). These events occur more frequently than previously considered and they are not specifically addressed in current design practice.

Heterogeneities in boundary material composition and bank structure may also have implications on design practice. The apparent significance of the "least resistant bank toe stratigraphic unit" (MacRae and Rowney, 1991), suggests that the use of a one-dimensional representation of the stream channel, as used in current design practice, may not adequately characterize the resistance of the channel to scour and subsequently, its response to a change in erosion potential.

II. INDEX OF INSTREAM EROSION POTENTIAL

A two-dimensional index of scour potential is proposed to account for heterogeneities in boundary material composition and bank structure (MacRae, 1991). The index is applied on a multi-event basis to address the affect of the non-uniform increase in flow frequency following urbanization. Based on shear stress concepts and a comparative pre- versus post-development approach, the index has the general form,

$$\Delta(E_S)_P = [(E_S)_{POST} - (E_S)_{PRE}]_P \tag{1}$$

where (ΔE_S) is the change in instream erosion potential at point P about the channel perimeter and the subscripts PRE and POST refer to the pre- and post-development condition respectively. Assuming the pre-development channel represents a stable state, then a non-zero value of the index would represent a change in the potential for channel deformation at point P about the channel perimeter.

The functional form of Eqn. (1) may be written as,

$$(\Delta E_S)_P = \left(\int_0^T [(q_S)_O - (q_S)_I]\, dt\right)_{POST} - \left(\int_0^T [(q_S)_O - (q_S)_I]\, dt\right)_{PRE} \tag{2}$$

in which q_s is the sediment transport potential and the subscripts I and O refer to the influx and outflux of sediment through a channel reach respectively. The explicit form of the index will depend upon the exact form of the sediment transport relation. When $\Delta(E_S)_P > 0$, erosion of the channel boundary will occur either along the bed (degradation), the bank (basal scour) or both. If $\Delta(E_S)_P < 0$, aggradation of the bed will occur with erosion of the bank ensuing. Finally, $\Delta(E_S)_P = 0$, defines a stable (no scour) scenario. The ability of the index to represent scour potential was demonstrated through a one-to-one correspondence between the rank of the index values with a ranking of depths of degradation. Depths of scour were predicted using a one-dimensional mobile bed model in a trapezoidal channel formed in homogeneous, non-cohesive, sand sized material.

Determination of the index at points about the channel perimeter defines a two-dimensional measure of the potential for channel deformation. An aggregate measure of the change in scour potential would yield,

$$(\Delta E_S)_{AGG} = \int_0^{L_x} |\,(\Delta E_S)_P\,|\, dz \tag{3}$$

where $\Delta(E_S)_{AGG}$ is the aggregate change in scour potential about a channel cross-section, L_x is the length of wetted perimeter, and z is the transverse cross-sectional axis. The absolute value of $\Delta(E_S)_{AGG}$ is used to encompass the special case of aggradation of the bed combined with erosion of the banks.

III. EVALUATION OF CURRENT DESIGN PRACTICE

The scour index was incorporated into QUALHYMO, a continuous hydrologic simulation model (Rowney and MacRae, 1991). The model was then used to evaluate two of the most commonly applied current design procedures: the "zero runoff increase" (ZRI) concept; the "over control" approach. The ZRI

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method is a hydrologic approach where the post-development 1:2 year peak flow rate is reduced using detention storage to the pre-development flow rate. It is a one-dimensional, discrete event approach with no consideration of boundary material characteristics. The OC method, initially proposed by Whipple et al., (1981), provides detention storage in addition to that required by the ZRI technique to reduce aggregate erosion to pre-development levels. This method also uses a one-dimensional, discrete event approach although it does account for sediment characteristics averaged over the cross-section.

McCuen and Moglen (1988) demonstrated the OC approach by reducing the peak outflow rate from a control pond until the post-development sediment transport rate, as measured by unit width bed transport potential, approached the pre-development level. For their specific case study, this represented an 85 percent reduction of the 1:2 year pre-development peak flow rate. Storage in addition to that required for ZRI control is necessary to obtain the additional reduction in peak flow rates hence the term "over control" (OC). The OC approach was evaluated using the proposed index for 50 to 90% reductions in the 1:2 year pre-development peak flow rate.

Both techniques were tested using a trapezoidal channel formed in uniform, non-cohesive materials and a channel formed in stratified, cohesive materials. Figures 2 and 3 present the transverse distribution of the index for these control philosophies for channels formed in very soft and firm cohesive boundary materials respectively. Table 1 presents a summary of the value of $(E_S)_P$ for the mid bed and bank toe regions as a ratio (R) of post- to pre-development conditions for materials formed in very soft to stiff cohesive boundary materials.

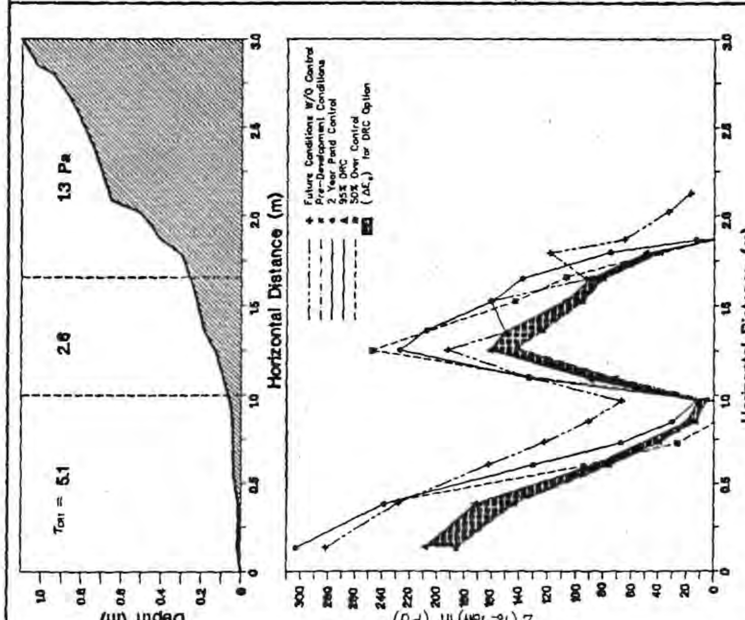
TABLE 1: Pre- Versus Post-Development Ratio (R) of $((E_S)_P)_{BED}$ and $((E_S)_P)_{TOE}$

METHOD	VERY SOFT	SOFT	FIRM	STIFF
ZRI	1.64	1.51	1.74	2.06
	1.55	1.45	1.64	3.12
OC (50%)	1.64	1.29	1.12	0.06
	1.69	1.50	1.57	2.12
DRC	1.14	1.02	1.19	1.22
	1.10	1.05	1.17	2.12

The ZRI method failed to prevent a significant increase in the potential for downcutting $((R_{BED}) > 1)$, and undercutting $(R_{TOE} > 1)$. Erosion hazard increased with respect to the no-control scenario in channels formed in very soft to soft, cohesive boundary materials, and there was no significant improvement over post-development flows without SWM controls for a channel formed in firm boundary materials.

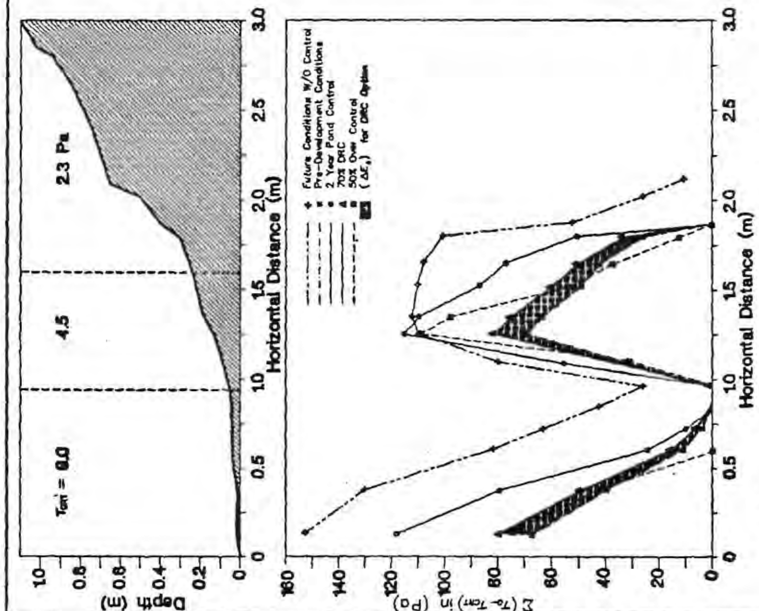
These results are consistent with observations of channel enlargement in seven streams in Surrey B.C. under 1:5 year SWM control (Lee and Ham, 1988). McCuen (1979), noted that while post-development outflow rates were controlled to pre-development levels the duration of high flows increased several fold. This increase in the duration of high flows translated into a higher sediment transport capacity which would likely increase scour potential and hence channel instability.

The OC method also failed to prevent an increase in the potential for downcutting or undercutting in very soft to soft, cohesive boundary materials, (the lowest values of $(\Delta E_S)_{AGG}$ were obtained with a 50% reduction in the 1:2 year pre-development peak flow rate). It significantly reduced the potential for downcutting and undercutting for channels formed in firm, cohesive boundary materials although the potential undercutting was still elevated above the pre-development condition. This reflects the poor reproduction of the transverse distribution of the index due to the alteration in flow geometry in the receiver downstream of the OC storage facility for those flows that exceed the erosion threshold. For channels formed in stiff, cohesive boundary materials the OC method produced aggrading conditions. At 90% reduction the OC approach resulted in aggrading conditions for all channel types except those formed



TRANSVERSE DISTRIBUTION OF EXTAU ABOUT AN ELLIPTICAL CHANNEL SEMI-PERIMETER FOR SELECTED SWM STORAGE ALTERNATIVES IN VERY SOFT CLAY

Figure 2



TRANSVERSE DISTRIBUTION OF EXTAU ABOUT AN ELLIPTICAL CHANNEL SEMI-PERIMETER FOR SELECTED SWM STORAGE ALTERNATIVES IN FIRM CLAY

Figure 3

RB-AR35543

in very soft, cohesive boundary materials.

Flow conditions which result in either degradation or aggradation represent unstable channel states. Degradation results in bed downcutting and bank undercutting. Aggradation results in sedimentation patterns which may be equally disruptive of the physical channel environment and the associated ecosystem. The preferred design approach should attain a balance between "under control" resulting in degradation and "over control" causing aggradation.

IV: DISTRIBUTED RUNOFF CONTROL

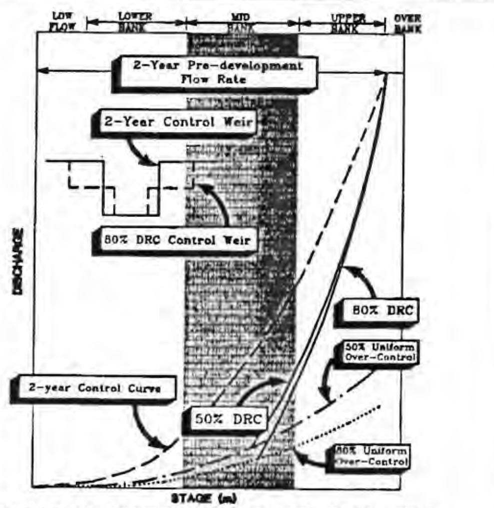
A philosophy for the control of instream erosion potential is proposed predicated on the assumption that change in instream erosion potential will be minimized if the magnitude and transverse distribution of ΔE_s is held constant with pre-development conditions ($(\Delta E_s)_{AGG} \approx 0$). This technique recognizes the contribution of the range of moderate to bankfull flow events for the determination of channel form and distributes the degree of storage control by stage in proportion to the non-uniform increase (post- minus pre-development) in scour potential. The proposed technique is referred to as "Distributed Runoff Control" (DRC) because of the non-uniform distribution of storage by stage.

Three critical zones on the DRC curve (Figure 4), may be defined as follows:

i) low to mid bank flows: the degree of control is independent of erosion objectives because shear forces are less than the threshold for scour of the least resistant stratigraphic unit;

ii) mid bank flows: the degree of control follows the OC curve to the stage of maximum effective work; and,

iii) upper bank flows: the degree of control decreases to the ZRI control level at bankfull stage.



STAGE-DISCHARGE CURVES FOR SELECTED SWM DETENTION CONTROL METHODS Figure 4

Spillage of flows onto the floodplain serves as a natural limit to the magnitude of shear forces acting on the bed which means that the control of flows in excess of bankfull stage is not required.

Although pre-development flows are not reproduced in all aspects, the DRC approach does reproduce the 1:2 year pre-development hydrograph for flows above the erosion threshold defined for the least resistant stratigraphic unit. Figures 2 and 3 show that in comparison to current methods the DRC approach provided the closest reproduction of the magnitude and transverse distribution of the scour index. The comparison is summarized in Table 1 which shows that the DRC technique consistently provides the highest degree of control of instream erosion potential over the range of channel boundary materials examined in this

study.

V. CONCLUSIONS

New criteria for the design of SWM facilities for the control of instream erosion protection has been proposed. These criteria state that the change in erosion potential associated with an alteration in the hydrologic regime will be minimized if the magnitude and transverse distribution of an erosion index is maintained at pre-development levels. This assumes that the pre-development case represents a stable channel system. An index of scour potential is also proposed based on a pre- versus post-development comparison of sediment mass balance at a point about a channel perimeter. Temporal characteristics of the flow field were incorporated into the index through integration with respect to time. Transverse variations in boundary material resistance to scour was addressed by integrating the index across the wetted perimeter.

Evaluation of current design practice indicate that these control techniques may not satisfy the intent of Stormwater Management. An alternate design procedure was proposed based on maintaining the pre-development value of the index at a point about the channel perimeter. It follows that the change in scour potential following urbanization is minimized if the transverse distribution of the index is maintained constant with pre-development conditions. Comparison with current design practice shows that the proposed approach most closely satisfied the proposed design criteria under the range of channel forms and material types considered in this research.

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RB-AR35544

RB-AR35545

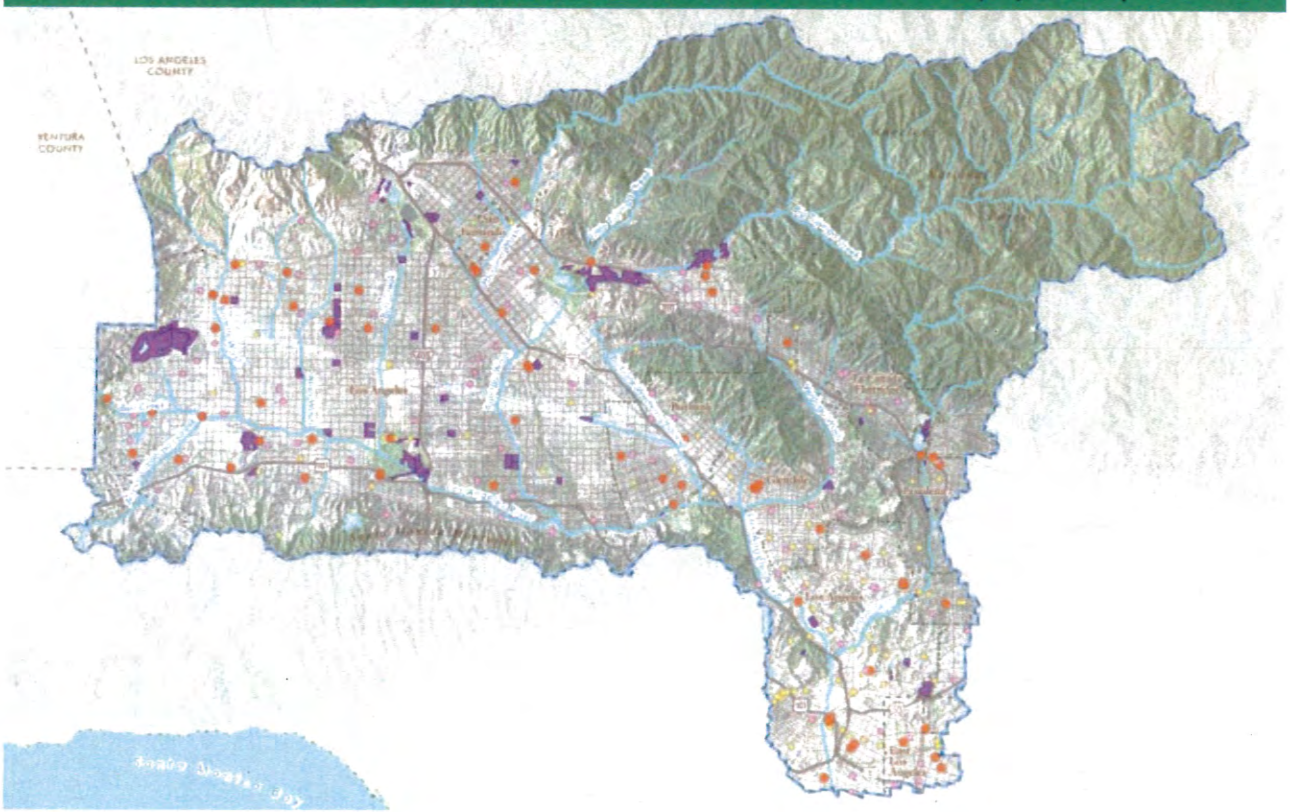
COMMUNITY CONSERVATION SOLUTIONS

THE GREEN SOLUTION PROJECT

UPPER L.A. RIVER WATERSHED, Phase II

Strategic Approach to Naturally Cleaning Polluted Runoff

Quantifying water quality, community and conservation needs to evaluate projects on public lands



Funded By

Santa Monica Mountains Conservancy

ABOUT Community Conservation Solutions

COMMUNITY CONSERVATION SOLUTION'S MISSION is to tackle the most complex and challenging problems created when people and nature intersect. Community Conservation Solutions (CCS) does this by developing creative, practical and lasting solutions that unite diverse communities and interests and leverage investments of public funds. CCS has successfully crafted innovative solutions to serious environmental problems affecting California's natural and human communities by integrating the protection and restoration of natural lands and waters with compatible community uses, economic benefits and permanent public benefits.

Community Conservation Solutions works on diverse projects in urban and rural areas that help both natural habitats and people. Our projects range from parks and beaches to wilderness and watersheds, and from recreational sites to mixed-use developments. CCS is a 501(c)(3) non-profit, tax-exempt organization.

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ABOUT The Green Solution Project

COMMUNITY CONSERVATION SOLUTIONS' GREEN SOLUTION PROJECT is a major paradigm shift in how we clean up polluted runoff on a regional watershed scale. The Green Solution Project is a quantified, prioritized and practical approach to identifying public lands that can be converted to naturally capture and clean polluted runoff while creating new parks, wildlife habitat and recreation lands. The Green Solution Project uses cutting-edge digital technology to integrate hydrology with water quality, community and conservation needs. This provides cities and counties throughout California with a strategic road map to meet their runoff clean-up needs through conversion of lands already in public ownership to "smart," designed green open space that can clean, store and reuse runoff. CCS' Green Solution Project challenges conventional assumptions about the role that "green approaches" can play in naturally cleaning up polluted runoff throughout California and beyond. CCS' Green Solution Project is being considered as a solution to growing water pollution problems affecting California's rivers, lakes, wetlands, bays, beaches and ocean waters.

ABOUT The Project Team

CCS' GREEN SOLUTION PROJECT TEAM includes **PSOMAS** and **GreenInfo Netwok**. Psomas is a leading consulting engineering firm serving clients in the water/wastewater, transportation, public, institutional and private land development markets, and is committed to the advancement and implementation of sustainable stormwater solutions. GreenInfo Network is a non profit organization providing Geographic Information System (GIS) and related technology, data analysis and support to a wide range of water, land conservation and many other types of projects throughout California and the United States.

For an electronic copy of this report, go to
www.conservationsolutions.org/greensolution.html

For more information, contact us at:
2554 Lincoln Boulevard, Suite 223 Los Angeles, CA 90291 (310) 398-8584

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COMMUNITY CONSERVATION SOLUTIONS

THE GREEN SOLUTION PROJECT

UPPER L.A. RIVER WATERSHED, Phase II

Strategic Approach to Naturally Cleaning Polluted Runoff

Quantifying water quality, community and conservation needs to evaluate projects on public lands

Technical Report, Analysis and Mapping By

PSOMAS

GreenInfo Network

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MARCH 2011

RB-AR35548

EXECUTIVE SUMMARY

RB-AR35549

EXECUTIVE SUMMARY

Green Solution Projects improve water quality by using soil and plants to capture, filter and clean polluted urban and stormwater runoff, while creating new parks, natural habitat, recreation and other open space lands.

This Executive Summary summarizes the results of Community Conservation Solutions' (CCS) Green Solution Project Phase II analysis for the Upper Los Angeles River Watershed and presents our findings and conclusions. This study expanded our innovative Phase I findings on the use of existing public lands to naturally treat polluted runoff while creating a network of new, green open space lands. We are pleased to present this quantified evaluation of public parcels for potential project implementation for use in efforts to improve water quality in San Pedro Bay and in rivers and creeks throughout the Upper Los Angeles River Watershed. Due to state budget cuts, integration of multiple benefit factors, prioritization and ranking of parcels were eliminated from this Phase II analysis.

The project team included Community Conservation Solutions, Psomas, who provided engineering support and prepared the Technical Report, and GreenInfo Network, who provided Geographic Information System (GIS) data analysis and mapping.

The Phase I Green Solution Project analysis presented an innovative and ground-breaking approach to cleaning up polluted runoff by identifying existing public lands suitable for conversion and retrofit of impervious lands to "smart" green spaces that can act as natural filters and treatment areas, while also providing badly-needed new parks, natural habitat and open space. This Phase II analysis focused on evaluating public lands in selected land uses for their hydrology, water quality, pollutant loading, community needs and conservation needs attributes. A full Phase II analysis would include integration of these factors and prioritization and ranking of the targeted opportunity public parcels for future project implementation.

Polluted stormwater and urban (dry weather) runoff contaminates all 51 miles of the Los Angeles River, over 45 miles of the L.A. River's tributaries in the Upper L.A. River Watershed, and San Pedro Bay, beaches north and south of the L.A. River's mouth, and ocean waters. All of the Upper L.A. River and most of its' contributing waters are in violation of the U.S. Clean Water Act, with pollutant loads above state and federal standards developed to protect human health and marine and aquatic life. Local governments are under increasing pressure to improve water quality in these water bodies.

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Pollutants in the Upper Los Angeles River Watershed in violation of the U.S. Clean Water Act include: fecal coliform, nutrients, toxic substances, trash and metals (including copper, lead and selenium) and are regulated by Total Maximum Daily Loads (TMDLs), which have already been developed for trash, nutrients and metals and are in the process of development for bacteria, organics and oils.

Polluted stormwater and urban runoff contaminates all 51 miles of the L.A. River, most of its tributaries, San Pedro Bay, beaches and ocean waters.

By focusing on existing public lands, Community Conservation Solutions' Green Solution Project analysis provides a practical, quantified strategy to ...clean up polluted runoff on a regional watershed scale.

By focusing on existing public lands, Community Conservation Solutions' Green Solution Project analysis provides a practical, quantified strategy to help public agencies solve these serious water quality problems, clean up polluted runoff on a regional watershed scale, meet L.A. Regional Water Quality Control Board requirements, and create multiple benefits through creation of new park, habitat and green open space lands in communities with tremendous need for these amenities.

The results of our analysis are exciting, and show that there are over 300 high-priority sites comprising over 5,000 acres that are suitable for Green Solution projects in the selected land uses (schools, colleges and vacant lands). This strategic Green Solution approach to cleaning up polluted runoff could significantly improve water quality in the Upper Los Angeles River Watershed and create networks of green open space. Implementing Green Solution projects on these sites could treat polluted runoff from up to 15,000 acres – equal to over four times the area of downtown Los Angeles - while providing badly-needed new parks, habitat and open space, particularly in densely-populated, park-poor communities. Our public health analysis demonstrates how Green Solution projects can be implemented to safeguard public health and safety, using strict guidelines for site design, operations and maintenance.

Opportunity Public Parcels
Upper Los Angeles River Watershed

Implementing Green Solution Projects on public parcels in the Upper Los Angeles River Watershed could treat polluted runoff from up to 15,000 acres.

Green Solutions include:

- Prioritizing projects by integrating water quality, conservation and community needs[1]
- Converting impervious areas to "smart" green spaces
- Using soils and plants to naturally capture and filter pollutants from runoff
- Creating new parks, habitat and open space lands
- Improving water quality in polluted creeks, rivers, beaches, bays and ocean waters

What is a Green Solution?

Green Solution projects are evaluated to provide a strategic "road map" so that the best projects are implemented. The CCS Team's quantified approach integrates cutting-edge technology, engineering and strategic site selection to create "smart" green spaces that naturally capture, filter and clean polluted runoff. The CCS team developed a unique methodology to quantify hydrology, pollutant loading, conservation and community needs in order to evaluate existing public lands for future project implementation.[2]

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Green Solutions effectively utilize natural treatment processes which take advantage of the natural functions of soils and plants to filter, treat and reduce the volume of runoff. These natural processes include:

- **Biofiltration**
  The filtration of pollutants through vegetation and soil
- **Bio-uptake**
  Biological processes such as the assimilation of pollutants such as nitrogen and phosphorous, which soil and plants can convert for their beneficial use
- **Infiltration**
  The process by which water on the ground moves into the soil
- **Evapotranspiration**
  The process of transferring moisture from the earth to the atmosphere by evaporation and transpiration from plants
- **Other**
  Biological , physical, and biochemical processes

Natural treatment processes can also be more cost effective than other types of structural Best Management Practices because they are passive systems and require little energy, operations or maintenance.

Integrating Multiple Benefit Factors: Unique Methodology of the CCS Team

CCS' Green Solution Project provides a rational, quantified approach to identifying and prioritizing opportunity parcels for water quality improvement projects that provide multiple benefits. This technical methodology can be applied in any region with polluted runoff problems. The CCS Team evaluated the following multiple benefit factors to identify over 300 opportunity public parcels in the Upper Los Angeles River Watershed:[3]

A state-of-the-art Green Solution Project. *The Tujunga Wash Greenway Project in the San Fernando Valley improves water quality in the Tujunga Wash – a tributary of the L.A. River – by naturally treating polluted runoff from surrounding urban areas with a naturalized stream, alders, willows and other native plants. The project recharges groundwater supplies – and visitors enjoy a shaded stream, creek-side trail, natural habitat and picnic areas.*

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A Quantified Green Solution Project Approach is Essential to Cleaning Up Polluted Runoff

The CCS Team's Green Solution methodology is essential to help public agencies meet water quality improvement goals and strict clean-up timelines for creeks and rivers in the Upper Los Angeles River Watershed.

The CCS Team's Green Solution quantified approach is essential to help public agencies meet water quality improvement goals and strict clean-up timelines for the Upper Los Angeles River Watersheds. It identifies specific projects for potential implementation based on evaluating multiple benefits, including watershed hydrology, pollutant loading, community needs and conservation priorities, and ensures that public funds are invested wisely in sites that provide the highest overall benefit. This analysis-based Green Solution Project strategy is critical to achieving water quality improvement goals because it:

- Helps implement projects that can provide the highest overall benefit
- Ensures cost effective investment of public funds
- Allows treatment of offsite runoff
- Focuses on existing public lands to make best use of existing resources
- Maximizes natural treatment of polluted runoff while providing greatest multiple benefits
- Focuses on high pollutant loading areas
- Helps meet conservation priorities
- Provides new green open space in communities with the greatest needs

This analytical Green Solutions approach provides the basis for a strategic "road map" for conversion of lands already in public ownership to new, "smart" green spaces that naturally clean up polluted runoff, can help recycle and reuse stormwater and recharge groundwater supplies. The Green Solution Project focus on existing public lands offers a cost-effective and readily available solution not only to the increasingly serious water quality problems in Los Angeles County, but also to the demand to make communities healthier and more livable by creating a green network of park, habitat, recreation and open space lands. Green Solution Projects also help address drought and global warming by conserving and recycling our increasingly precious water resources.

The Urgency: Polluted Runoff Problems in the Upper Los Angeles River Watershed

There is an urgent need to clean up polluted runoff to improve water quality in the L.A. River, San Pedro Bay, rivers and creeks throughout the Upper L.A. River Watershed and at world-renowned beaches along the coast. Polluted urban and stormwater runoff is a serious problem here, where extensive urbanization has resulted in vast areas of paved surfaces and high daily volumes of contaminated runoff. Nearly all of the natural habitat in the developed areas of the Upper Los Angeles River Watershed has been destroyed by over 100 years of urban growth, and these densely-developed urban areas have some of the greatest park and open space deficits in California.

Solving water pollution problems in the Upper L.A. River is also essential to successfully revitalizing the L.A. River and its major

Polluted Waters of the Upper L.A. River Watershed

Nearly all of the Los Angeles River and most of its tributaries are in violation of the U.S. Clean Water Act, with pollutant loads above the state and federal standards developed to protect human health and marine and aquatic life.

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Dry weather runoff from sprinklers, yards, car washing and hosing down driveways generates 46.2 million gallons of water every day – enough to fill the Rose Bowl in less than 2 days.

tributaries – including the Tujunga Wash, Pacoima Wash and Arroyo Seco – and to creating vibrant, healthy river greenways throughout the San Fernando Valley and in surrounding cities. Revitalization of the L.A. River has been supported by state agencies, Los Angeles County, City of Los Angeles, and numerous communities, organizations and civic leaders.

Nearly all properties in the watershed produce runoff that flows - untreated in any way - through county and city storm drains every day, even in dry weather. Dry weather runoff generates a total of 46.2 million gallons of water every day[4] – **enough to fill the Rose Bowl in less than two days**. When it rains, the problem is far worse, as the high volumes of stormwater carry huge amounts of trash and pollutants through the county's drainage system very quickly.

Pollutants in waters of the Upper L. A. River Watershed are in violation of the U.S. Clean Water Act.

Many pollutants in waters of the Upper Los Angeles River Watershed are significantly above federal and state public health standards and in violation of the U.S. Clean Water Act, which sets water quality standards intended to protect human health and marine and aquatic life. These pollutants include infection-causing bacteria, toxic metals, pesticides, household and industrial chemicals, trash, oil, oxygen-choking fertilizers and other toxins. To enforce federal standards, the L.A. Regional Water Quality Control Board has established six different Total Maximum Daily Loads (TMDL) limits – with more anticipated - for runoff flowing into the L.A. River, and cities and the county are required to meet these TMDL limits.

Polluted runoff endangers the health of people, animals and the aquatic and marine life dependent on river and ocean waters for survival, and contaminates ocean waters around the world.[5] The L.A. River dumps millions of tons of trash on nearby beaches every year – and this does not count the additional millions of tons carried by ocean currents and accumulating in huge floating "rafts" of plastic trash in the Pacific Ocean between California and Japan.

Trash chokes one million seabirds worldwide every year; plastic is found in the stomachs of seabirds, turtles and marine mammals around the worlds, and toxic pollutants and bacteria from runoff can be fatal to marine mammals. Low oxygen "dead zones" are spreading due to increasing fertilizer use and growing coastal populations.[6] UCLA and Stanford University scientists found that up to 1.5 million people get sick each year from infections and gastrointestinal illnesses caused by bacteria at L.A. County beaches.[7]

The CCS team developed a unique methodology to quantify hydrology, pollutant loading, conservation and community needs... for evaluating existing public lands for future project implementation.

Pollution associated with stormwater and daily urban runoff can only be solved by addressing the generation of pollutants throughout the watershed. This includes taking full advantage of all opportunities for conversion of paved, impervious surfaces to pervious surfaces that allow soil and plants to naturally capture, infiltrate and clean runoff and installing "smart", engineered Green Solutions that can act as natural filters and treatment areas.

The CCS Team's Green Solution Project: Site Evaluation Findings

By using state-of-the-art technology and engineering, the CCS team developed a unique methodology to quantify hydrology, pollutant loading, conservation and community needs in order to create the framework for evaluating (and future possible prioritization)[8] of existing public lands for future project implementation. The result is a strategic road map to identifying potential project sites that ensures cost-effective use of public funds. A full Phase II analysis[9] would prioritize and rank these sites to ensure implementation of projects that can maximize both natural capture and clean-up of runoff and creation of new "smart" parks, habitat and green open space for public use.

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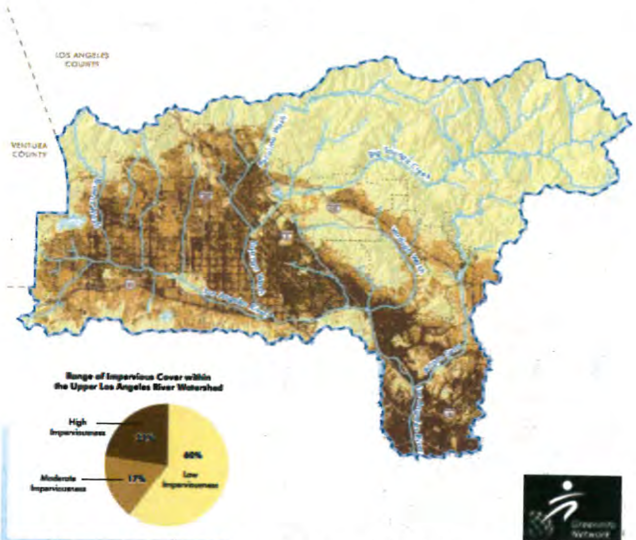
The amount of runoff produced in the watershed depends on the extent of imperviousness in each area. The map below illustrates the imperviousness of all areas of the Upper L.A. River Watershed.

Contribution of Runoff from Impervious Lands in Upper L.A. River Watershed

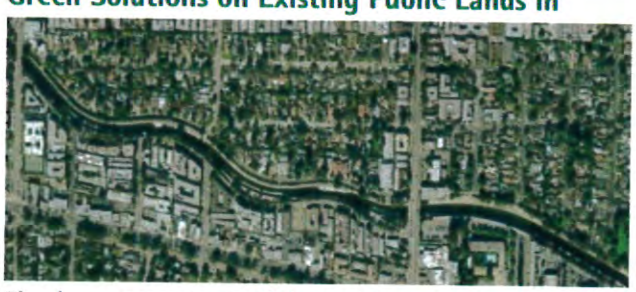


Densly populated, park-poor communities in urban areas have the highest percentage of impervious surfaces and benefit the most from Green Solution projects.

Pollutants of concern in the Upper L.A. River Watershed that can be addressed by Green Solutions are:

- Bacteria
- Nitrates and other fertilizer-based chemicals
- Heavy metals, including lead and copper
- Oil and grease
- Oxygen-demanding substances
- Sediment
- Trash and debris

Green Solutions on Existing Public Lands In



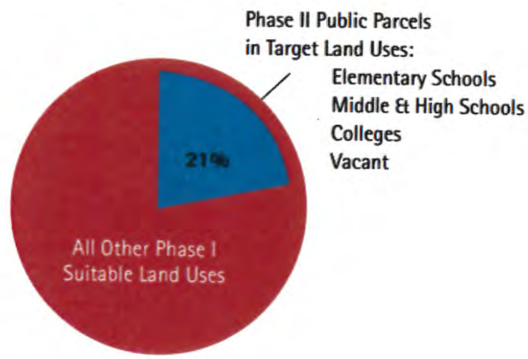
The large percentage of impervious surfaces in the San Fernando Valley contribute polluted runoff to the L.A. River.

Specific Land Uses: Schools, Colleges and Vacant Lands

This Phase II analysis focused on four of the fourteen land uses identified as suitable in Phase I: elementary, middle and high schools, colleges and vacant lands.

Overturning conventional assumptions about the limited role

Parcels in Target Land Uses



that green approaches might play in naturally cleaning up polluted runoff in developed areas, CCS' Phase I study identified nearly 14,000 acres of public lands suitable for Green Solution Projects in the Upper Los Angeles River Watershed. The four targeted land uses analyzed in Phase II represent approximately 20% of the Phase I suitable parcels in all public land uses.

The purpose of the Phase II analysis was to expand the Phase I study and evaluate these four particular land uses at a detailed level, so as to provide a strategic, quantified approach to identifying (and future potential prioritization of)[10] the parcels for project implementation. This rigorous analysis included screening for parcel size, slope, level of pollutant loading in surrounding area, and portion of parcels suitable for runoff capture and treatment. Parcels less than ½ acres were not included, and all parcels had to be within 500 feet of a storm drain at least 36" in diameter. All parcels were evaluated for each of these factors: hydrology, pollutant loading, community needs and conservation priorities.

The factors evaluated by the team included:

- **Hydrology of the watershed:** rainfall and runoff volume, storm drain locations and size, runoff flow
- **Community needs:** open space deficit, youth and senior density, income, access to car, percent renters
- **Conservation priorities:** proximity to existing parks, trails, rivers and habitat.

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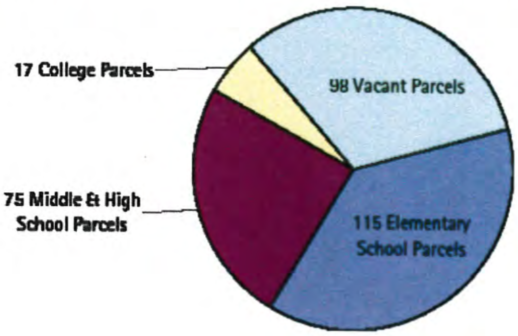
Over 300 Potential Project Sites Identified

The CCS Team identified over 300 opportunity public parcels in these specific four public land uses, comprising a total area of over 5,000 acres.

Green Solution Opportunity Public Parcels by Land Use



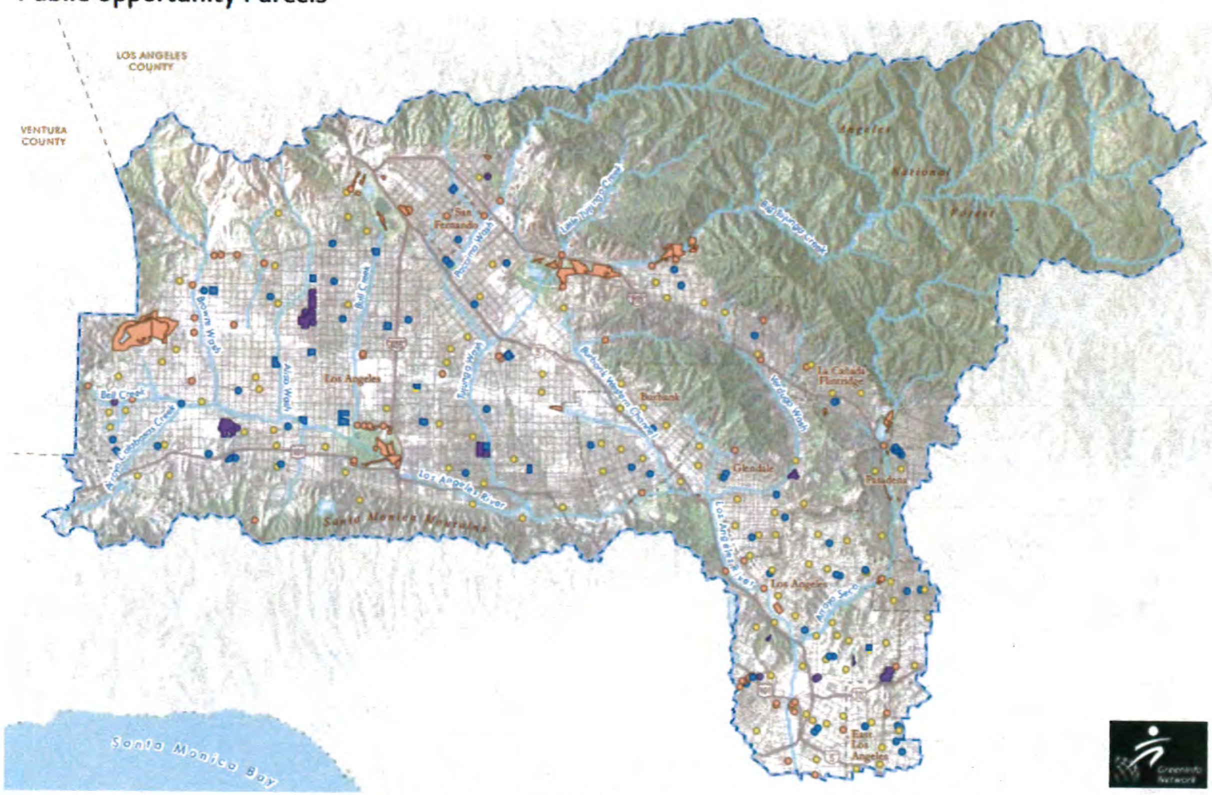
These parcels passed the rigorous screening and evaluation for suitability. Based on the analysis, which took into account actual area potentially available in each land use for conversion or retrofit for use as runoff treatment and park, habitat or other green open space, these parcels have a net of up to 2,650 acres of land that are suitable for Green Solution projects. Table 1 shows the number of opportunity public parcels and acres of public lands suitable for Green Solution projects within the Upper L.A. River Watershed.

Table 1. Potential Green Solution Projects (GSP): Parcels & Acres Suitable in Target Land Uses

		Acres Suitable for Green Solution Projects		
Watershed	Number of Opportunity Parcels	Low	Ave	High
Upper L.A. River	305	1,523	2,086	2,650

The map below shows the distribution of evaluated public opportunity parcels throughout the watershed. There are 305 priority sites.[11]

Public Opportunity Parcels



Over 300 priority public parcels provide 5,000 acres suitable for Green Solution Projects and could treat runoff from up to 15,000 acres of the Upper Los Angeles River Watershed.

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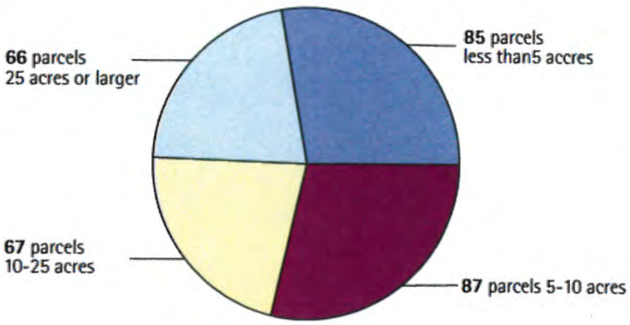
Green Solution Opportunity Public Parcels by Size



If implemented as Green Solution projects, these 305 priority opportunity public parcels could treat polluted runoff from up to 15,000 acres of the Upper Los Angeles River Watershed – an area equal to over four times the size of downtown Los Angeles. Table 2 shows the acres treatable if all of these priority opportunity public parcels were implemented as Green Solution projects.

Table 2. Acres of Watershed Treated by Public Opportunity Parcels

		Potential Acres Treatable		
Watershed	Total Land Acres	Low	Ave	High
Upper L.A. River	374,721	9,400	11,200	15,000

Safeguarding Public Health and Safety

Our analysis shows that Green Solution projects treating off-site runoff can be safely implemented on school, college and vacant lands. Public health and safety can be ensured through proper and thoughtful design specific to the land use, education, and regular and proper operations and maintenance. Designs using ponds, wetlands and other similar natural water treatment elements can be used on middle and high school, college and vacant sites, while elementary school sites should not include these elements.

The following design and maintenance "toolbox" includes examples of the types of public health and safety safeguard measures that should be used:

- Adhere to Health Department requirements; design stormwater facilities to drain within 72 hours
- Restrict access and prevent contact through fences, setbacks, signage and landscaping
- Minimize inlets and outlets to treatment facilities
- Perform regular maintenance to ensure proper function and prevent buildup of potential conditions of concern
- Monitor stormwater pollutants at upstream sampling points and remove sediment when necessary
- Monitor soil contaminant levels via regular soil sampling and remove sediment when necessary
- Use subdrains and impermeable liners preventing groundwater contamination and drawdown times

A state-of-the-art Green Solution Project. *The Sun Valley Watershed Project uses underground vaults, a surface park, habitat and recreation area to naturally capture and treat polluted runoff from surrounding urban areas. New open space benefits this park-poor community and the project recharges the San Fernando Groundwater Basin, while improving water quality in the L.A. River.*

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CONCLUSION

This Green Solution approach provides a quantified, strategic road map to improving water quality, ensures wise investment of public funds, maximizes cleanup of polluted runoff and addresses conservation and community needs.

The Green Solution: A Smart & Effective Tool for Treating Polluted Runoff

Green Solution Projects are proving to be one of the most effective and cost-efficient ways to make lasting water quality improvements consistent with the requirements of the State Water Resources Control Board and the L.A. Regional Water Quality Control Board. Green Solutions provide park and recreation opportunities in heavily urbanized and park-poor areas, provide important natural habitat, and can be effective "water recyclers", reducing the effects of drought caused by global warming by catching, storing and re-using stormwater for landscaping.

Many water quality experts and scientists believe that much of the toxins, bacteria and other contaminants carried by stormwater and daily dry weather runoff can be permanently addressed by directing these polluted waters to a network of well-designed Green Solutions: new and restored natural habitat, parks, and recreation lands that allow soil and plants to naturally filter and uptake water and pollutants, while providing a wide range of open space and other benefits.

These Green Solution projects provide one of the most viable and effective means of permanently cleaning up polluted runoff because they address wide-spread imperviousness due to decades of urban growth and development, and help restore the natural functions of soil and plants to capture, filter and clean contaminants from runoff before it reaches creeks, rivers, beaches and San Pedro Bay.

Community Conservation Solutions' Green Solution Project for the Upper Los Angeles River Watershed, Phase II (Partial) identifies and quantifies the many opportunities on existing public school, college and vacant lands for naturally capturing, filtering and cleaning polluted runoff from up to 15,000 acres of the watershed – while identifying parcels that could help create a network of new, state-of-the-art "smart" green parks, habitat and open space in urban areas.

If implemented as Green Solution projects, these 305 priority opportunity public parcels could treat polluted runoff from up to 15,000 acres of the Upper Los Angeles River Watershed while creating over 2,500 acres of new parks.

This analytical approach to improving water quality in rivers, bays and ocean waters breaks new ground by evaluating projects for implementation based on quantified demographic and stormwater factors, so that future potential projects can be identified in a rational manner. This quantified Green Solution approach is essential to help public agencies better meet water quality improvement goals and to select projects that can address other pressing community and conservation

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needs – including creating badly-needed networks of green open space in the heavily impervious Upper L.A. River Watershed.

The CCS Team identified over 300 priority potential water quality improvement project sites totaling 5,000 acres on existing public school, college and vacant lands. CCS found that implementing smart Green Solution projects on these sites could treat up to 15,000 acres of the Upper Los Angeles River Watershed - an area over four times the size of downtown Los Angeles - while creating over 2,500 acres of new parks, habitat and open space in park-poor areas. The CCS Team's analysis also showed how these Green Solution projects could be implemented to protect public health and safety by identifying guidelines for design, operations and maintenance.

CCS' analytical Green Solution approach breaks new ground by evaluating projects for implementation based on quantified demographic and stormwater factors... to help public agencies efficiently meet water quality improvement goals for the L.A. River.

This quantified, analytical Green Solution approach presents a practical and strategic way to move forward efficiently and in an informed way to improve water quality in the Upper Los Angeles River and its tributaries, as well as in San Pedro Bay, beaches and coastal waters - while identifying sites that can help create new habitat, parks and other green open space throughout the watershed in communities where these amenities are most needed.

Community Conservation Solution's unique methodology provides a rational quantified approach to selecting public lands for conversion to engineered green spaces that naturally capture and clean polluted runoff.

Community Conservation Solutions' quantified and strategic Green Solution approach can be implemented in any area which needs to address pressing water quality problems due to runoff, and which wishes to make best use of existing land resources and limited funding while creating the important public benefits that can be achieved by Green Solution Projects through restoring and creating "smart" habitat, park and other green open space.

The CCS Team's Green Solution approach quantifies hydrology, pollutant loading, conservation priorities and community needs to evaluate public opportunity parcels. Next steps would integrate these factors to prioritize and rank parcels for future water quality improvement projects.

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Recommendations and Next Steps

Next steps should include completing the Phase II analysis[12] by integrating watershed hydrology, storm drain information, pollutant loading, community needs and conservation needs to score and prioritize suitable project sites. This prioritization would provide a strategic road map to ensure that public funds are spent wisely and that selected projects can maximize cleanup of polluted runoff, meet conservation priorities, and are located where community needs are greatest.

Next steps should also include selecting specific high-priority sites identified through the above prioritization process for potential project implementation, and conducting the site-specific technical review and preliminary site design necessary to define runoff treatment capacity, site hydrology and hydraulics, and site-specific park, habitat and open space opportunities. Next steps should include developing inter-agency partnerships with site owners, estimating costs and identifying funding for site construction.

Funders

This project was funded by the Santa Monica Mountains Conservancy.

1. Due to state budget cuts, prioritization of parcels was eliminated from this Phase II analysis.
2. *Ibid.*
3. *Ibid.*
4. Los Angeles County Department of Public Works, adjusted for Upper Los Angeles River Watershed percent of total for L.A. County Flood Control District.
5. Kenneth R. Weiss and Usha Lee McFarling, *"Altered Oceans, A five-part series on the crisis in the seas,"* Los Angeles Times, July-August 2006.
6. *Ibid.*
7. Suzan Given et al, *"Regional Public Health Cost Estimates of Contaminated Coastal Waters: A Case Study of Gastroenteritis at Southern California Beaches,"* Environmental Science & Technology, Vol. 40. No. 16 (2006): 1.
8. *Ibid.* 1
9. *Ibid.*
10. Suzan Given et al, *"Regional Public Health Cost Estimates of Contaminated Coastal Waters: A Case Study of Gastroenteritis at Southern California Beaches,"* Environmental Science & Technology, Vol. 40. No. 16 (2006): 1.
11. A full Phase II analysis would rank and prioritize these parcels based on integrated stormwater and demographic factors and by intensity of pollutant loading in the watershed
12. *Ibid.* 1

ABOUT The Project Team

COMMUNITY CONSERVATION SOLUTIONS

Community Conservation Solution's mission is to tackle the most complex and challenging problems created when people and nature intersect. CCS does this by developing creative, practical and lasting solutions that unite diverse communities and interests and leverage investments of public funds. CCS has successfully crafted innovative solutions to serious environmental problems affecting California's natural and human communities, by integrating the protection and restoration of natural lands and waters with compatible community uses, economic benefits and permanent public benefits.

CCS' successful project solutions include: the two-square mile Baldwin Hills Park in the heart of urban Los Angeles; wetland restoration in Upper Newport Bay; acquisition of the Spring Street Center for the Los Angeles Conservation Corps; the Los Angeles River Natural Park to naturally treat urban runoff while creating a regional river public access gateway; and developing new, quantified approaches to improving water quality through the Green Solution Project.

Community Conservation Solution works on diverse projects in urban and rural areas that help both natural habitats and people. Our projects range from parks and beaches to wilderness and watersheds, and from recreational sites to mixed-use developments. CCS is a non-profit, 501(c)(3) organization.

PSOMAS

Psomas is a leading consulting engineering firm serving clients in the water/wastewater; transportation; and public, institutional and private land development markets. Ranked as one of Engineering News Record (ENR) magazine's Top 100 Pure Design Firms in the United States, Psomas offers civil engineering, land surveying, planning and entitlements, program/construction management, natural resources, GIS consulting, and Special District Financing services to the public and private sector. Founded over 60 years ago, Psomas provides services from offices throughout California, Arizona, and Utah.

Psomas specializes in delivery of sustainable storm water management consulting and design solutions to municipalities, public and quasi-public organizations, and private sector clients. Psomas' projects range from studies to constructed solutions; challenging infill development to city and county-wide initiatives; and from integrated low impact development measures to purpose-built treatment wetland systems.

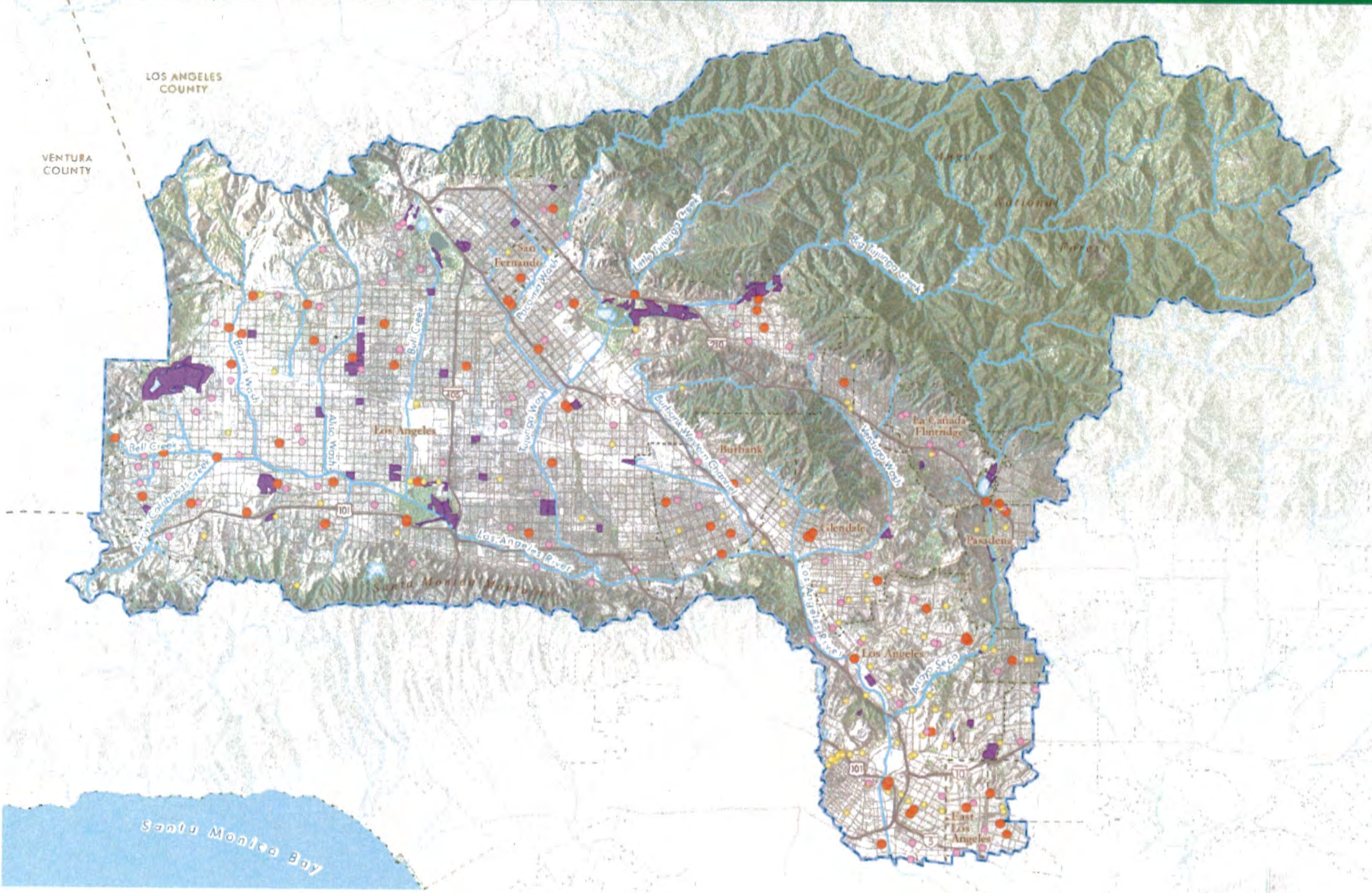
GREENINFO NETWORK

Over the past 15 years, GreenInfo Network (www.greeninfo.org) has provided Geographic Information System (GIS) and related technology support to a wide range of water, land conservation and many other types of projects throughout California and the U.S. A non-profit, GreenInfo Network assists other public interest groups and agencies working at local, regional and national scales, providing them with services including data creation and acquisition, geospatial analyses, geographic modeling, conservation and land use planning, watershed-based planning and modeling, database development, and high quality communications design and cartography. GreenInfo Network's staff is highly skilled in effective, efficient and creative use of information technology to help clients more effectively understand and communicate the relationships between issues, people and places.

COMMUNITY CONSERVATION SOLUTIONS

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*

Opportunity Public Parcels by Size, Not Prioritized



GREEN SOLUTION PROJECT, PHASE II OPPORTUNITY PUBLIC PARCELS BY SIZE

●	Less than 5 acres	85 parcels
●	5 to 10 acres	87 parcels
●	10 to 25 acres	67 parcels
■	25 acres or larger	66 parcels

Parcels shown are elementary, middle and high schools, colleges and vacant lands that met these criteria:

> ½ acre
slope < 10%
within 500' of 36" storm drain

WATER FEATURES

- Watershed Boundary
- River, Stream or Channel
- Lake or Reservoir

ADMINISTRATIVE FEATURES

- Highway
- City Boundary
- County Boundary

PSOMAS

Map created by GreenInfo Network
www.greeninfo.org, January 2011

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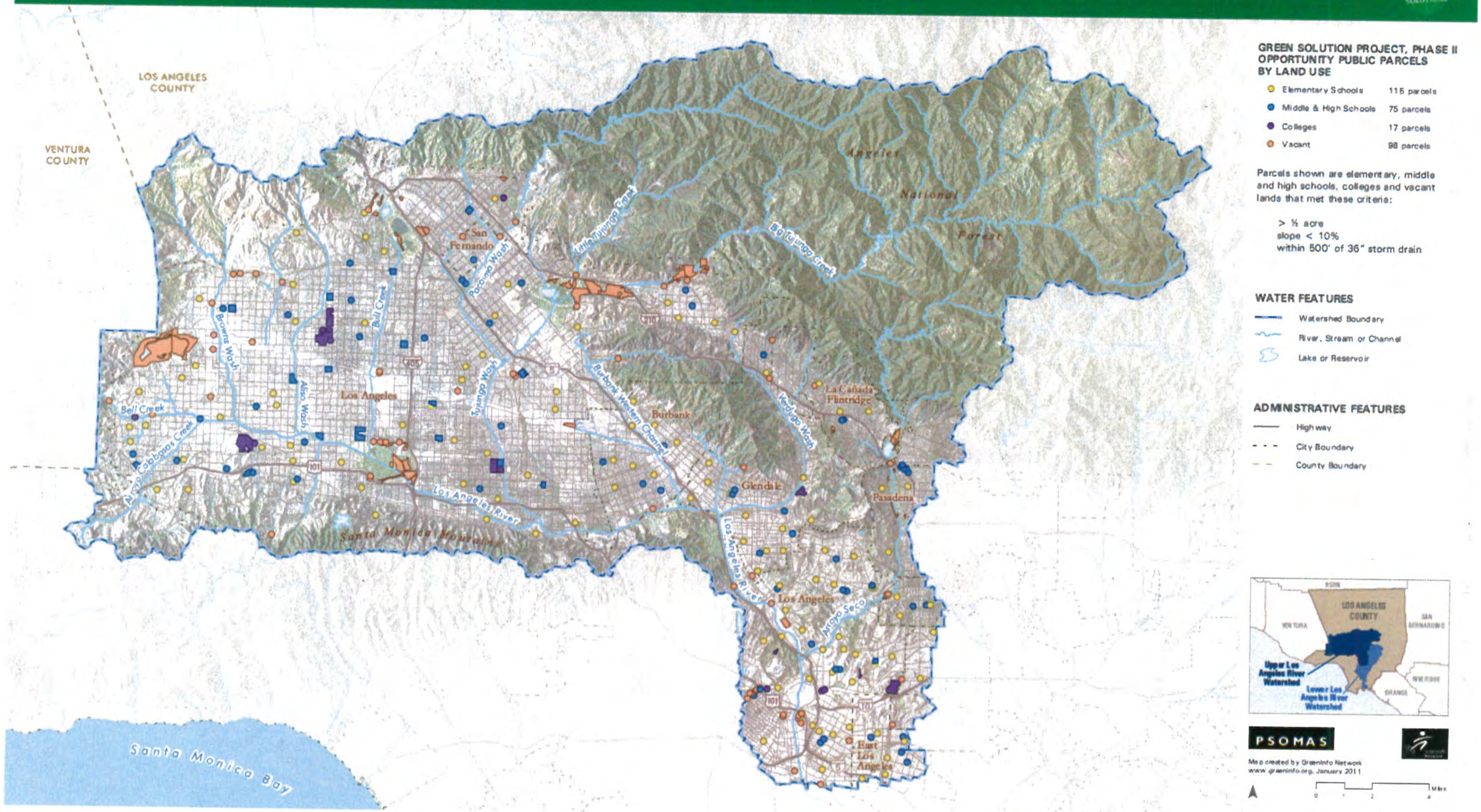
GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II (Partial)

Opportunity Public Parcels by Land Use, Not Prioritized



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TECHNICAL REPORT

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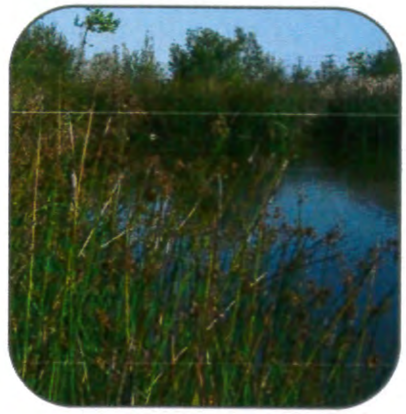
PSOMAS

Green Solution Project Upper Los Angeles River Watershed

Los Angeles, CA



Phase II Report

Presented to

Santa Monica Mountains Conservancy

Prepared in Conjunction with

GreenInfo Network

Community Conservation Solutions

March 2011

Psomas Project No.
1CCI010101

PSOMAS

Balancing the Natural and Built Environment

RB-AR35566

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CONSERVATION SOLUTIONS

PSOMAS

RB-AR35567

ABSTRACT

Nearly all water bodies in Los Angeles County are in violation of the U.S. Clean Water Act, which sets water quality standards to protect human health, aquatic life and marine habitat. Green Solutions Projects (GSPs) aim to improve urban and stormwater runoff quality through natural treatment processes while providing multi-purpose benefits to the community. GSPs convert or retrofit primarily public lands to implement BMPs that treat on-site and off-site urban and stormwater runoff. GSPs also provide parks, open space, trails, recreational facilities, and other community amenities. GSP Phase I study was completed in 2008 and focused on all of the public lands in Los Angeles County. This GSP Phase II (Partial) study focuses on only four public land uses within the Upper Los Angeles River Watershed: elementary schools, middle/senior schools, colleges, and vacant lands. Each subwatershed is analyzed to determine BMP treatment needs and each land use is analyzed to determine potential treatment. Various demographic and storm water factors are identified for each opportunity parcel. These various factors could be used to select a particular opportunity parcel that meets certain criteria including identifying underserved communities. Due to state budget constraints parcel prioritization scoring based on integration of multiple-benefit factors was removed from the scope of this report but could be incorporated in an addendum or a future phase. Through this analysis, 305 opportunity public parcels were identified within the Upper L.A. River Watershed. All of the public opportunity parcels identified as a part of this small subset of land uses could potentially treat up to 15,000 acres of the watershed. This GSP Phase II approach, when entirely completed, establishes an effective system for addressing water quality needs in a quantified manner while also providing multi-purpose benefits to the community.

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TABLE OF CONTENTS

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EXHIBITS

APPENDICES

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GLOSSARY

The terms listed below appear in this technical report.

AC	Acres
BMP	Best Management Practice
CASQA	California Stormwater Quality Association
CPI	Catchment Prioritization Index
CCS	Community Conservation Solutions
GSP Area	Green Solution Project Area
GSP Phase I	Green Solution Project Phase I
GSP Phase II	Green Solution Project Phase II
GSP Phase III	Green Solution Project Phase IIII
LF	Linear Feet
LARWQCB	Los Angeles Regional Water Quality Control Board
LID	Low Impact Development
NPDES	National Pollutant Discharge Elimination System
NCDC	National Climatic Data Center
SWRCB	State Water Resources Control Board
SUSMP	Standard Urban Stormwater Management Plan
TAR	Treatment Area Ratio
TF Area	Treatment Footprint Area
TPF	Treatment Potential Factor
TMDL	Total Maximum Daily Load
ULAR	Upper Los Angeles River

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DEFINITIONS

Conversion Area Impervious area that could be converted to pervious surfaces and/or installed with underground storage facilities.

Distributed BMPs Generally have smaller footprints and treat smaller areas compared to regional BMPs. Typically these would be located throughout a site and could treat on-site runoff as well as portions of off-site drainage.

Drainage/Stormwater Runoff/Urban Runoff All dry weather flow and the required first flush storm event as defined by the Los Angeles County MS4 Permit issued by the State Water Resources Control Board.

First-flush Critical runoff that occurs in the early phase of a precipitation event. Within the Los Angeles region the "first flush" is defined as the runoff volume generated from 0.75-inches of rainfall.

GSP Area Green Solution Project Area: all of the project elements including pre-treatment facilities, vegetated swales, basins, wet ponds, trails, interpretive signs, parking and staging areas, etc.

Green Solution BMPs Best Management Practices that include conversion of existing paved and impervious surfaces to permeable or pervious surfaces that allow water to infiltrate and be treated on-site using soils, plants and natural processes to remove pollutants, and retrofitting of existing pervious surfaces to provide more effective storage and treatment of runoff. Green Solution BMPs are BMPs which utilize natural treatment measures where possible and can also provide multiple community and public benefits such as active and passive recreation, water conservation, and wildlife habitat.

Regional BMPs Regional Best Management Practices that generally have larger footprints to provide treatment for larger areas. Regional BMPs could treat on-site runoff as well as larger portions of runoff from off-site, surrounding areas and/or storm drains.

Retrofit Area Pervious area that could be retrofitted with treatment facilities such as detention/retention basins, wet ponds, infiltration facilities, etc.

Treatment Footprint Area The area over which a depth is computed to generate a treatment volume (area x depth).

Treatment Area Ratio Ratio of the effective drainage area divided by the Green BMP footprint area and depends on both the type of BMP and the potential location within a watershed (from GSP Phase I).

RB-AR35573

1. INTRODUCTION

Nearly all water bodies in Los Angeles County are in violation of the U.S. Clean Water Act, which sets water quality standards intended to protect human health and marine and aquatic life.[1] To address these water quality issues, the Los Angeles Regional Water Quality Control Board encourages multiple-benefit projects, or Green Solution Best Management Practice projects ("Green Solution BMPs"). These Green Solution BMPs include conversion of existing paved and impervious surfaces to permeable or pervious surfaces that allow water to infiltrate and be treated on-site using soils, plants and natural processes to remove pollutants, and retrofitting of existing pervious surfaces to provide more effective storage and treatment of runoff. Green Solution BMPs are categorized as BMPs which utilize natural treatment measures where possible and can also provide multiple community and public benefits such as active and passive recreation, water conservation, and wildlife habitat.

Community Conservation Solutions' (CCS) Green Solution Project Phase I (GSP Phase I) (March 2008) determined that transforming public lands to naturally capture, filter and clean polluted runoff could address nearly 40%, on average with a maximum of up to 50% of Los Angeles County's polluted runoff problem, which has long-term damaging impacts on beaches, aquatic life, human health and on the health of oceans, birds and marine mammals. The results of GSP Phase I showed that there are up to 20,000 acres of public lands throughout watersheds in the County which are suitable for Green Solution projects that involve "unpaving" impervious areas, and retrofitting pervious areas on existing public lands to help improve water quality and increase green open space lands.

Within Los Angeles County, the major watersheds include the Santa Clara River, the Los Angeles River, Ballona Creek, Dominguez Channel, the San Gabriel River, and the Santa Monica Bay Coastal streams (including Malibu Creek). This report focuses on the Upper Los Angeles River (ULAR) Watershed, which is shown on Exhibit A. For the purposes of this report, the Upper L.A. River Watershed includes Reaches 3, 4, 5, & 6 of the Los Angeles River and its major tributaries.

1.1 Goals and Objectives

As identified in GSP Phase I, the objectives of Green Solution Projects include:

- Establishing a suite of readily implemented "green" BMPs that could be operated and maintained on publicly-owned properties in Los Angeles County and are appropriate for treating the primary pollutants of concern;
- Establishing, on a gross-scale, locations and estimated area of potentially suitable public land for Green Solution BMP implementation within each watershed; and
- Identifying and defining the water quality and quantity metrics for quantifying impacts and benefits; and utilizing an approach by listing all assumptions and using public domain tools as feasible and appropriate.

The overall goal of this Phase II (Partial) technical study is to further develop the principles and ideas presented in GSP Phase I for the Upper Los Angeles River (ULAR) Watershed by integrating water treatment, community and conservation needs. This study focuses on a specific subset of land uses, including elementary schools, middle/senior schools, colleges, and vacant lands. By introducing multiple factors, GSP Phase II (Partial) aims to identify potential projects that can help improve water quality and optimize water treatment while at the same time being able to include demographic and other information related to a project's locale.

The initial GSP Phase I study developed broad concepts and estimates for the following, by watershed: acres needing treatment, treatable drainage area, potential opportunity public parcels, and potential treatment needs met by GSPs. This study refined those estimates and narrowed the scope of the study that was undertaken in the initial GSP Phase I report.

1. Community Conservation Solutions, Green Solution Project. March 2008.

1. GSP Phase I – Identified potentially suitable opportunity public parcels from all land uses that could be used to naturally capture and treat polluted runoff, including:

- identified areas in each watershed with the highest clean-up needs
- quantified contributing area
- quantified acreage needed for the treatment footprint area
- analyzed the complete public parcel roll
- evaluated and identified potentially suitable opportunity public parcels
- utilized a Treatment Area Ratio (TAR) to quantify treatable area
- quantified acres potentially suitable for GSP, and % need potentially met
- identified watersheds with greatest pollutant loading at general scale

2. GSP Phase II (Partial) –Focuses on targeted land use parcels within the watershed and:

- identifies water quality, water quantity, community need, open space deficit and conservation factors which are quantified for the targeted opportunity public parcels
- refines potential parcel selection/identification
- introduces Treatment Potential Factor (TPF) to aid in summarizing the treatment potential of the targeted public parcels
- if fully funded, would also include integration of the multiple-benefit factors to rank and prioritize the public opportunity parcels

Green Solution BMPs are intended to assist with complying with Federal and State Storm Water Regulations, including the National Pollution Discharge Elimination System (NPDES) permit program, which is administered by the Los Angeles Regional Water Quality Control Board for the Los Angeles region. This NPDES Permit regulates municipal stormwater and urban runoff discharges with the ultimate goal of reducing the amount of pollutants in stormwater and urban runoff. The ULAR Watershed has waterways included in the 2008 Clean Water Act Section 303(d) List of Water Quality Limited Sections (***Regional Board Approved July 16, 2009***). Under the Clean Water Act, the Los Angeles County NPDES permit also contains Total Maximum Daily Load (TMDL) compliance regulations for receiving waters included on the 303(d) list.

This report's proposed Green Solution BMPs would assist in meeting NPDES permit requirements, as well as compliance with Total Maximum Daily Loads (TMDLs) established for the ULAR Watershed.

1.2 Scope & Scale

The County of Los Angeles covers more than 4,000 square miles of land with many different land uses. Although this report focuses solely on the ULAR Watershed, the applicability of this methodology extends throughout the State as the approach could be applied to other watersheds in other locations.

Table 1-2. Total Area by Watershed

Area	Square Miles	Percent of County
Total Area of Los Angeles County	4,084	
Upper L.A. River Watershed	587	14%

The scope of this GSP Phase II (Partial) report includes identifying and evaluating publicly owned lands within the ULAR Watershed for the following land uses: elementary schools, middle/senior schools, colleges, and vacant land.

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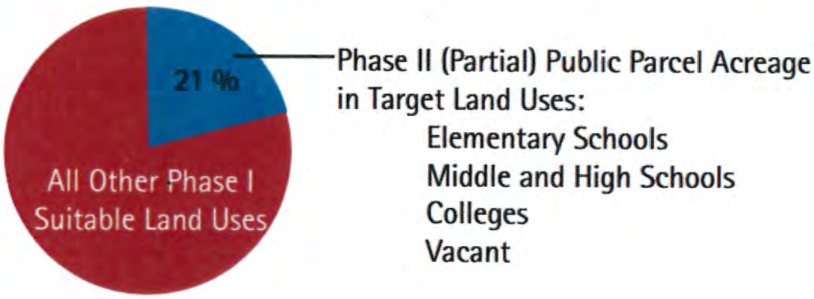
GSP Phase II (Partial) amplifies the research and analysis completed in GSP Phase I by focusing on specific types of public lands within a target watershed as well as identifying demographic, conservation and storm water factors associated with a potential project area. This includes developing site-specific example concept designs that combine park, habitat and recreation with water quality improvements aimed at naturally cleaning polluted runoff while at the same time identifying water quality, land conservation and community needs.

GSP Phase 1 Opportunity Public Parcels and corresponding Opportunity Public Parcels in four (4) targeted land uses included in this GSP Phase II (Partial):

Figure 1-1. Phase I versus Phase II (Partial) Opportunity public parcels and corresponding Opportunity Public Parcels for the Upper L.A. River Watershed



As illustrated in the figure above, the four targeted land uses comprise approximately 1/5 of the opportunity parcel acreage that was identified in GSP Phase 1

1.3 Document Organization

Following this introductory section, Section 2 describes the technical approach used to analyze the geographic data, estimate the area needed to improve water quality, and identify potentially suitable public land opportunities. Section 3 summarizes the results of the analysis by identifying the water quality needs and improvement opportunities and includes concept site designs. Section 4 provides conclusions from the analysis as well as a discussion of supplemental water quality improvement solutions, and recommendations for further study. The Appendices include more detailed technical information related to the demographic and storm water factors associated with each potential opportunity parcel.

1.4 Limitations

The analysis presented herein was developed to meet the preliminary project objectives. No other use or application of study results is intended. Presentation of results by any individuals should be made with a full understanding of the limitations presented herein. The analysis was conducted in a manner consistent with the standard of practice given limitations in scope, and no other warranty is expressed or implied.

The intent of this GSP Phase II (Partial) study was to further focus the principles established in the GSP Phase I study. This report focuses on "Green Solution" structural BMPs. It is acknowledged that many site design and source control BMPs as well as LID techniques can aid in reducing or treating polluted runoff; however, such techniques were not analyzed as a part of this report. It is important to note that data presented as ranges should be considered as such and that average values have been provided for convenience but may not necessarily represent values with the highest likelihood.

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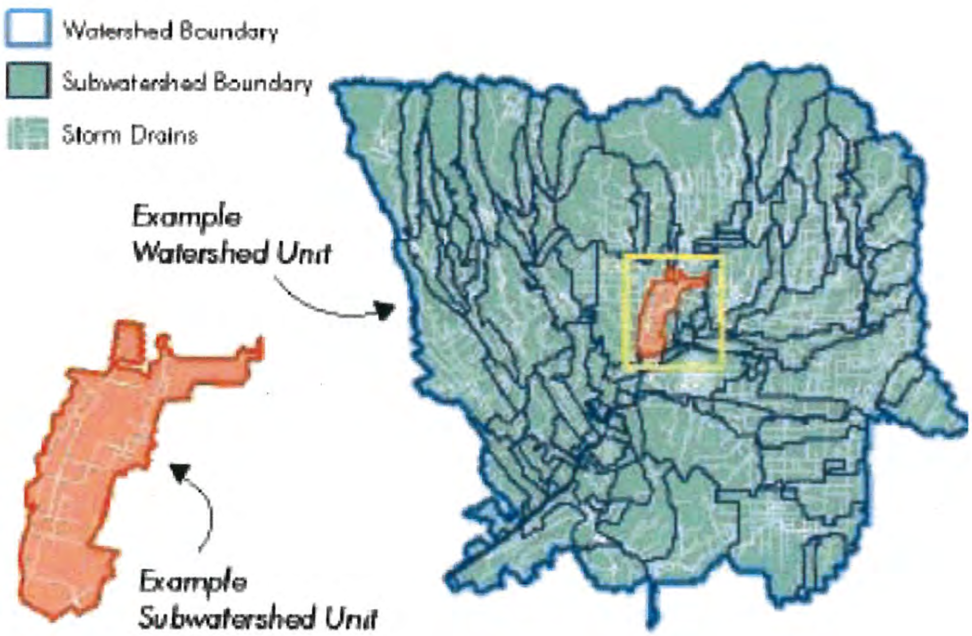
Additionally, due to unanticipated budget cuts during the project, the multiple benefit factors were not integrated, the targeted public opportunity parcels were not ranked or prioritized for potential implementation, and Catchment Prioritization Index (CPI) was not calculated.

2. TECHNICAL APPROACH

2.1 Upper Los Angeles River Watershed

The GSP Phase I report outlined 10 major watersheds within Los Angeles County. This GSP Phase II (Partial) report focuses on the Upper L.A. River Watershed. The watershed is approximately 587 square miles and includes the communities of Alhambra, Burbank, Calabasas, Commerce (very small portion), Glendale, Hidden Hills, La Canada Flintridge, Los Angeles, Monterey Park, Pasadena, San Fernando, Santa Clarita (very small portion), South Pasadena, Vernon (very small portion).

Subwatersheds are small (approximately 500 acre) drainage units based on Los Angeles County watershed "sub areas" delineated for use in National Pollutant Discharge Elimination System (NPDES) permitting.[2] Watersheds are larger drainage areas based on Los Angeles County Watershed Management Areas. The figure below provides an example of a subwatershed unit within a larger watershed.



There are 649 subwatersheds in the Upper L.A. River Watershed.

2. Source: Los Angeles County GIS Data and hydrologic units used are available online at: http://gis.dpw.lacounty.gov/oia/metadata.cfm?path=subwatershed.htm&zip=Watershed%20Sub%20Basins.zip and http://gis.dpw.lacounty.gov/oia/metadata.cfm?path=wma.htm&zip=Watershed%20Basins.zip

Exhibit A – Watersheds and Subwatersheds

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2.2 Tools and Strategies

Stormwater treatment at public sites throughout the Los Angeles region has proven effective in reducing flooding impacts, replenishing groundwater, reducing polluted runoff, reducing heat island effect, creating native habitat and expanding green recreation and open space and outdoor education areas, among other benefits. Post-construction water quality BMPs on public lands provide numerous benefits that assist in protecting public health and safety by reducing impairments in receiving waters.

The Los Angeles River is divided into six reaches by the Los Angeles Regional Water Quality Control Board (LARWCB):

- Reach 1 - Estuary to Carson Street
- Reach 2 - Carson to Figueroa Street
- Reach 3 - Figueroa Street to Riverside Drive
- Reach 4 - Riverside Drive to Sepulveda Dam
- Reach 5 - At Sepulveda Basin
- Reach 6 - Above Sepulveda Flood Control Basin

The Upper L.A. River Watershed as defined for this report includes reaches 3, 4, 5 and 6.

Under the Clean Water Act, the Los Angeles County NPDES permit also requires Total Maximum Daily Load (TMDL) compliance for 303(d) listed receiving waters. A Consent Decree issued on March 23, 1999 and signed by Heal the Bay, Santa Monica BayKeeper, and the United States Environmental Protection Agency (EPA) mandated a schedule for the development of TMDLs for the L.A. River for the following constituents:

- Trash
- Nutrients
- Metals
- Bacteria
- Organics
- Oils

TMDLs for trash, nutrients and metals have already been developed and a TMDL for bacteria is currently being developed. Based on the 2008 Clean Water Act Section 303(d) List of Water Quality Limited Sections (Regional Board Approved July 16, 2009), the following lists the limited segments for the Upper L.A. River Watershed:

- Reach 3 – Ammonia, Copper, Coliform Bacteria, Lead, Nutrients, Oil, Trash
- Reach 4 – Ammonia, Copper, Coliform, Lead, Nutrients, Trash
- Reach 5 – Ammonia, Copper, Lead, Nutrients, Oil, Trash
- Reach 6 – Coliform Bacteria, Selenium

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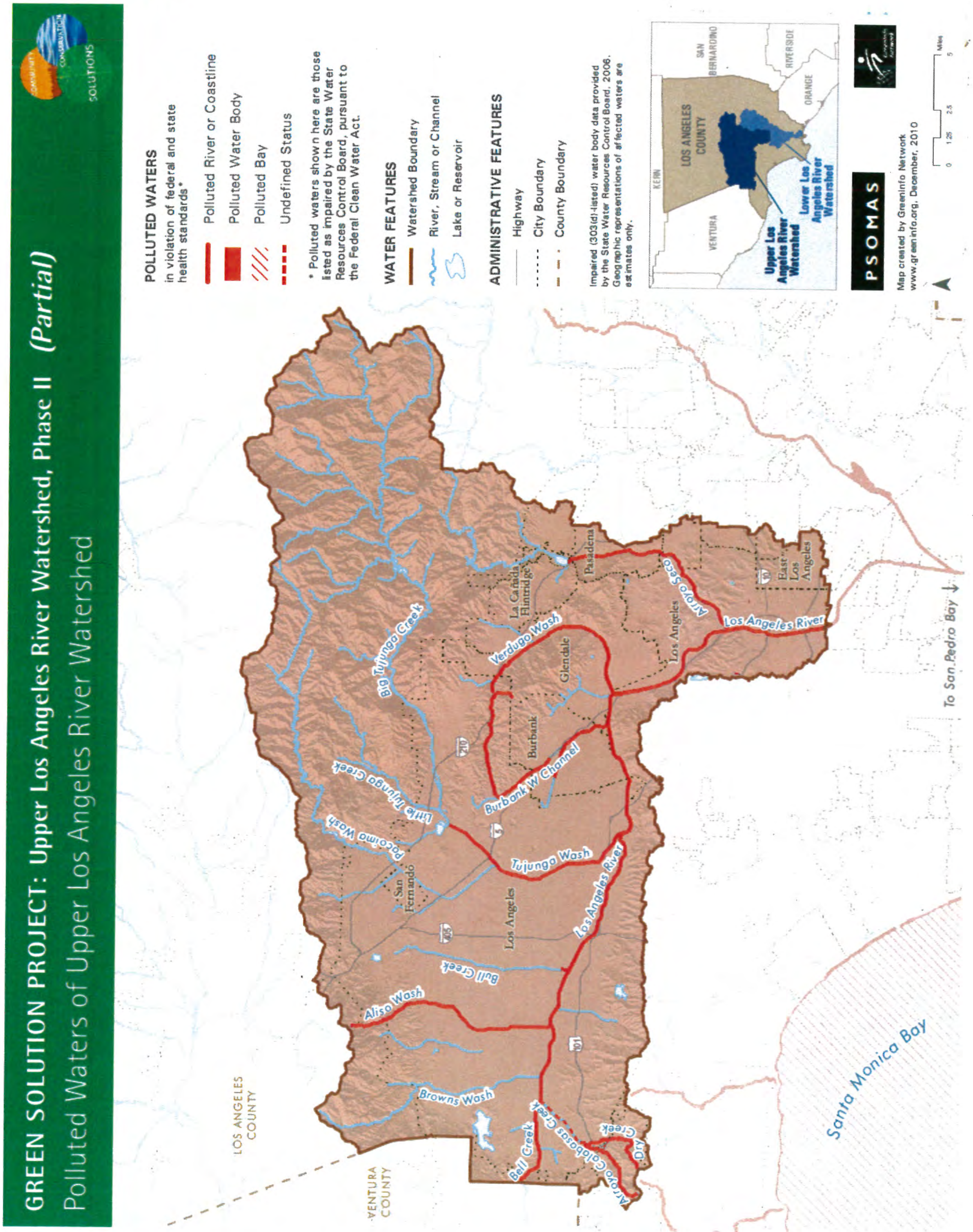

Exhibit B – Polluted Waters of Upper Los Angeles River Watershed

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Certain stormwater BMPs are more effective in treating for particular pollutants of concern. The most common types of BMPs are described in the following Sections.

2.2.1 Green Solution BMP Types

Water quality can be improved through many processes; however the most common are through settling and filtration. These processes can be achieved through mechanical devices or through natural methods. In addition to providing multi-use benefits, Green Solution BMPs sometimes provide superior removal efficiencies to many mechanical devices due to the additional treatment that soils and vegetation can provide through sorption, plant uptake and microbial transformation. Table 2-2 below summarizes the anticipated effectiveness of typical Green Solution BMPs. It is important to note that although infiltration types of BMPs are one of the most effective types, site constraints such as soil makeup can limit the use of these types of BMPs.

The table below shows which BMPs are best at treating targeted pollutants of concern.

Table 2-2. Anticipated BMP Effectiveness[3]

	Extended Detention Basin	Wet Ponds	Wetland Basins	Swales	Infiltration Basins & Trenches	Retention/ Irrigation Reuse	Bio-retention
Nutrients	L	M	M	L	H	H	L
Sediment	M	H	H	M	H	H	H
Metals	M	H	H	M	H	H	H
Pathogens	M	H	H	L	H	H	H
Organics	M	H	H	M	H	H	M
Toxicity	M	H	H	M	H	H	M
Trash	H	H	H	L	H	H	H

L= Low M= Medium H= High

Green Solution BMPs are categorized as BMPs which utilize natural treatment measures where possible and can also provide multiple community and public benefits such as active and passive recreation, water conservation, and wildlife habitat. Two main BMP categories are discussed within this report, distributed BMPs and regional BMPs.

2.2.1.1 Distributed BMPs

Distributed BMPs generally have smaller footprints and treat smaller areas compared to regional BMPs. Typically these would be located throughout a site and could treat on-site runoff as well as portions of off-site drainage. Since distributed BMPs are smaller and dispersed throughout a site, recreation opportunities tend to be more passive in nature rather than larger more active facilities associated with regional BMPs, but can provide green open space and habitat value.

Examples of Distributed BMPs include the following:

3. Source: California Stormwater Best Management Practices Handbook for New Development and redevelopment (CASQA, 2003)

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- Local Detention: Cisterns and Rain Barrels, On-Site Storage and Reuse
- Vegetated Treatment Systems: Filter Strips, Bioretention, Stormwater Planters
- Local Infiltration Systems: Permeable/Grass/Gravel Paving, Pervious Concrete & Crushed Stone, Infiltration Pits
- Catch Basin Inserts and Filters
- Street and Parking Lot Biofiltration Retrofits: Curb Extension Swales, Street Landscape Retrofits

Typical distributed BMPs that could be considered for Green Solution Projects include[4]:

Vegetated Swales - Vegetated swales are open, shallow channels, lined with vegetative cover that collect and slowly convey runoff to downstream discharge points. Typically the vegetative cover is comprised of low-lying grasses; however, thicker, denser ground cover may be used in certain circumstances. Pollutant removal is achieved through settling of particulate material, attachment to vegetative cover and plant uptake. Vegetated swales also reduce the effects of hydromodification by allowing for infiltration, evaporation, and reduced velocities. Effectiveness of vegetated swales is increased by maximizing the time in the swale which is accomplished with flat slopes and large longitudinal distances.

Rainwater Harvesting - Rainwater harvesting includes collecting and storing run off for non-potable uses, such as landscape irrigation, toilet flushing, and mechanical equipment such as cooling towers. Rainwater harvesting reduces stormwater discharge volumes while simultaneously reducing the demand for potable water. Rooftop runoff provides accessible locations for collection, in capture/reuse systems. Roof downspouts are redirected to collection containers such as rain barrels, which typically range from 55 to 120 gallons, or cisterns, which are generally much larger. Rain barrels are typically installed at outdoor residential locations; cisterns can be installed in residential and non-residential locations, either indoors or outdoors, and above or below grade. Rainwater harvesting can also be used as part of a treatment train by directing the overflow to a bioretention system to provide additional volume reduction and water quality treatment in instances where the quantity of runoff from a storm event exceeds the volume of the collection tank.

The County of Los Angeles published Draft Guidelines for the Installation and Pipeline Construction for Safe Reuse of Stormwater, Urban runoff and Non-potable cistern water. According to the guidelines unless the captured water has been treated to State Health and Safety guidelines (Title 22) for reclaimed water then the reuse water may only be applied in landscape areas via drip or sub-surface irrigation systems and not via spray irrigation systems.

Infiltration Basins and Trenches – Infiltration basins are generally shallow basins that are designed to infiltrate stormwater using the natural filtering ability of the soil to remove pollutants in stormwater runoff. Infiltration facilities store runoff until it gradually percolates through the soil and eventually into the water table. This allows high pollutant removal efficiency and can also help recharge groundwater. Site specific characteristics may limit the use of infiltration BMPs.

Infiltration trenches are long, narrow, rock-filled trenches with no outlet that receive stormwater runoff. Runoff is stored in the void space of the rocks and infiltrates through the bottom into the soil. Infiltration trenches perform well for removal of fine sediment and associated pollutants. Pretreatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench which can clog and render the trench ineffective.

Biofiltration Curb Inlets and Extensions– Biofiltration curb inlets offer substantial storage and pollutant removal through vegetated filtration and natural soil matrix processes. Biofiltration tree wells are common and are generally indistinguishable from standard tree wells. Biofiltration curb inlets are installed upstream of an existing catch basin. Low flow urban runoff and storm water runoff is intercepted from the gutter and flows enter the sump tree well where treatment occurs. Runoff is treated via filtration through the engineered soil media before discharging to the downstream existing catch basin. Larger flows, or instances when the tree well has reached its capacity, continue downstream in the gutter. Plants and soil slow the water down and help to filter contaminants. Similar to the biofiltration tree wells, traffic

4. Source of BMP Descriptions: California Stormwater Best Management Practices Handbook for New Development and redevelopment (CASQA, 2003)

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calming curb extensions use the same technology but generally with different plant materials due to traffic site-line requirements. Sub-drains may be utilized under biofiltration facilities to connect to an existing storm drain system.

Permeable/Porous Pavement or Removal of Impervious Surfaces - Pervious paving is used for light vehicle loading in parking areas. The term describes a system comprising a load-bearing, durable surface together with an underlying layered structure that infiltrates runoff. The surface can itself be porous such that water infiltrates across the entire surface of the material (e.g., grass and gravel surfaces, porous concrete and porous asphalt), or can be built of impermeable blocks separated by spaces and joints, through which the water can drain. This latter system is termed 'permeable' paving. Pervious pavements reduce runoff volume while providing treatment, and are unobtrusive resulting in a high level of acceptability. In locations where poor soil conditions exist and infiltration through the bedding material is unlikely, subdrain systems may be necessary.

2.2.1.2 Regional BMPs

While distributed BMPs are small-scale BMPs scattered throughout an area, regional BMPs generally have larger footprints to provide treatment for larger areas. Regional BMPs could treat on-site runoff as well as portions of runoff from off-site, surrounding areas. The large scale of regional BMPs is conducive to creating native habitat, natural open space, and active recreational facilities, such as sports fields, walkways/trails, outdoor educational facilities, and other multi-use components.

- Examples of Regional BMPs include the following:
- Dry Detention
- Infiltration
- Natural Treatment Systems (e.g. wetlands, wet ponds)
- Bioswales/Biofiltration

Typical regional BMPs that would be considered for Green Solution Projects include:

Biofiltration Systems - Biofiltration consists of a soil and plant-based filtration device that removes pollutants through physical, biological, and chemical treatment processes including a grass buffer strip, sand bed, ponding area, organic layer, planting soil, and plants. The buffer strip reduces the runoff's velocity and is dispersed along the ponding area. Over a period of time, the stored water in the biofiltration area will filter into the underlying soils.

Extended Detention Basins - A dry extended detention basin consists of a basin whose outlets have been designed to detain the stormwater runoff from a water quality design storm. Generally, the water is detained for a minimum of 48 hours to allow sediment and other pollutants to settle. They do not have a permanent pool and can be used to provide flood attenuation by including additional flood detention storage.

Capture/Storage/Reuse – Treated water can be stored underground in a large underground detention tank for later reuse. The underground detention tank could be plastic or concrete and can store pretreated stormwater. Underground detention tanks function similar to detention basins. However, since underground detention tanks are located below ground, the surface above these systems can be utilized for multi benefit uses (parking lots, sidewalks, landscaping adjacent to buildings, etc). Water may be controlled via a hydraulic control structure or mechanical means to regulate discharge. The objective of the system is to remove particulate pollutants and to reduce maximum runoff values associated with development to their pre-development levels. A number of pre-built, modular systems are commercially available. Once stored, the treated water may be sent through a recirculation system for further treatment/disinfection prior to reuse for non-potable uses. See Section 2.2.3 for discussion on regulations regarding stormwater reuse.
Wetland Basins – Wetland basins are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from wet ponds primarily in being shallower and having greater vegetation

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coverage. Constructed wetlands are among the most effective stormwater BMPs in terms of pollutant removal and they also offer aesthetic and habitat value. Runoff passes through the wetland and pollutant removal is achieved through settling and biological uptake within the wetland. Flow through the root systems allow the vegetation to remove nutrients and dissolved pollutants from the stormwater. A distinction should be made between using a wetland basin for storm water management and diverting storm water into a natural wetland. The latter practice is not recommended, natural wetlands should be protected from the adverse effects of development, including impacts from increased storm water runoff. This is especially important because natural wetlands provide storm water and flood control benefits on a regional scale.

Wet Ponds - Wet ponds (also referred to as stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year and differ from wetland basins primarily in having a greater average depth. Ponds treat incoming runoff by settling and biological uptake. The primary removal mechanism is settling as stormwater runoff resides in the pool, but pollutant uptake, particularly of nutrients, also occurs to some degree through biological activity in the pond. Wet ponds are among the most widely used stormwater BMPs, however their use is limited in Southern California due to the arid climate of the region. While there are several different versions of wet pond designs, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff and promote settling.

2.2.2 Identification of Water Quality Improvement Needs

In order to identify the water quality improvement needs of the ULAR Watershed, several assumptions were made regarding BMP design, parcel and land use suitability, hydrologic characteristics, as well as parcel and land use distribution throughout the watershed. The following subsections describe the approach used for estimating the BMP acreage needed for treating urban runoff and the treatment volume potentially treatable by public candidate parcels.

2.2.2.1 Effective Drainage Area

Some subwatersheds will generate more or less runoff in comparison to each other due to differences in impervious area. Impervious areas are defined as surfaces such as roof tops, streets, and parking lots where minimal absorption occurs. Conversely, pervious areas are defined as surfaces such as landscape and turf areas which absorb runoff. Based on these definitions the volume of runoff from a subwatershed is directly related to the amount of impervious area. Table 2-3 lists the primary land uses within the County and their imperviousness per the U.S. Geological Survey's National Land Cover Data 2001 impervious surface dataset.

Table 2-3. Land Use Imperviousness

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	% Impervious Cover			
	MEAN	MIN	MAX	STDDEV
Agricultural/Rangeland	17.12	0.00	65.87	15.14
Airports	37.99	0.00	77.15	24.48
Beach, Bay, Estuary	46.32	0.00	96.00	20.41
Colleges/Universities	48.63	2.00	87.96	20.62
Commercial/Industrial	55.47	0.00	97.19	28.29
Open Space - Developed	23.48	0.00	93.50	16.88
Open Space - Forest	16.31	0.00	68.00	16.26
Primary Schools	54.05	0.90	93.73	16.49
Public Facilities	59.98	0.00	97.21	23.17
Public Office Buildings	55.18	0.00	92.48	18.27
Residential	38.80	0.00	85.72	20.50
Transportation	54.69	0.00	94.77	17.64
Vacant	9.87	0.00	82.00	14.31

Exhibit C on the next page shows a map of the watershed along with the impervious data for each subwatershed.

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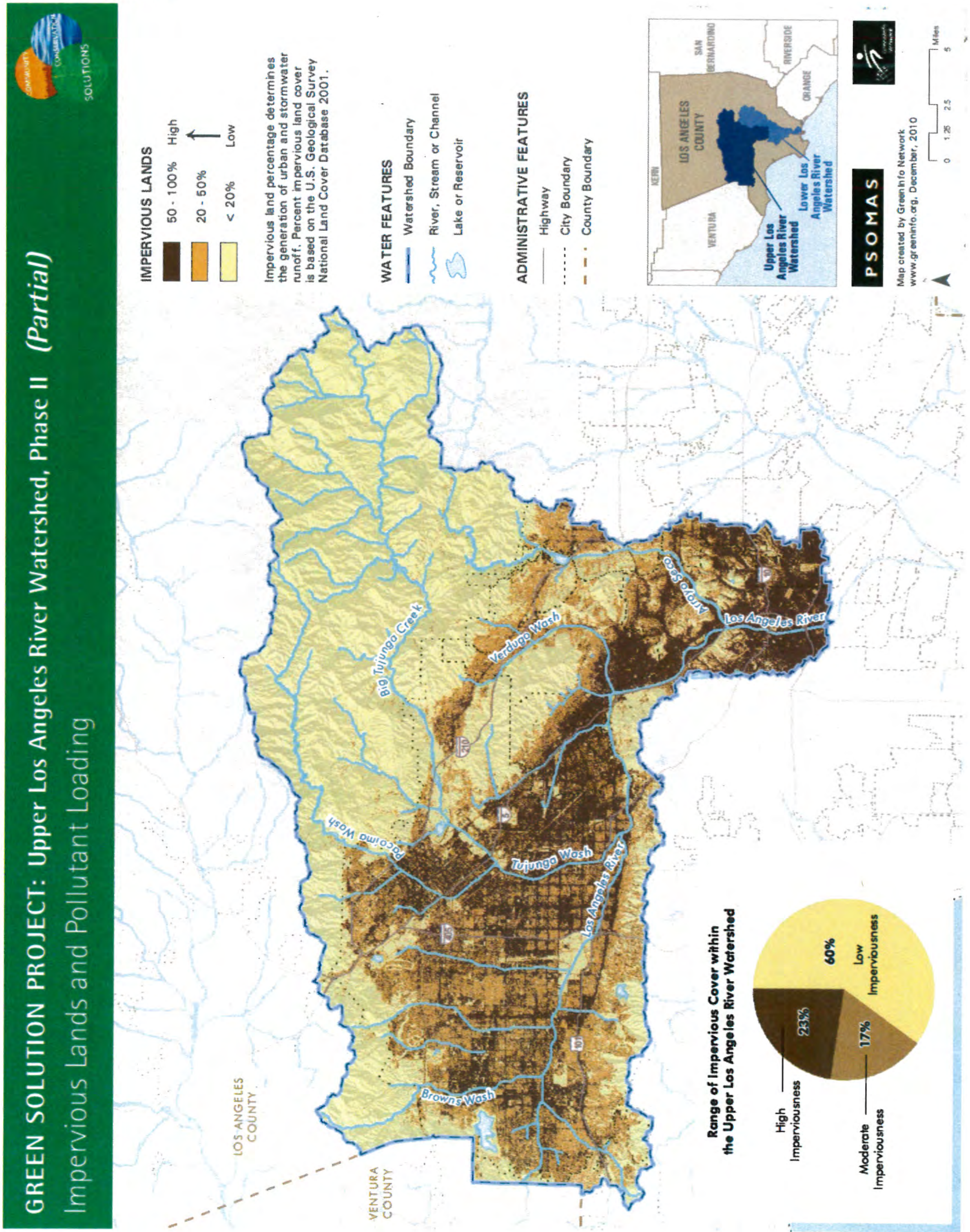

Exhibit C – Impervious Lands and Pollutant Loading

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The effective drainage area, or area contributing runoff, can be estimated using a runoff coefficient equation. Utilizing Table 2-2 and the following equation from the L.A. County Hydrology Manual and the L.A. County Standard Urban Stormwater Mitigation Plan (SUSMP) a developed runoff coefficient can be calculated for each subwatershed.

$C_D = (0.9 \times Imp) + (1.0 - Imp) \times C_U$

Where: C_D = Developed Runoff Coefficient
Imp = Percent Impervious
C_U = Undeveloped Runoff Coefficient

Throughout most of LA County, C_U is approximately 0.1 based on soil conditions and the typical low intensity targeted storms. The effective drainage area can then be calculated using the following equation which was derived from L.A. County's standard runoff equation:

$A_E = (0.9 \times A_T \times Imp) + [0.1 \times A_T \times (1 - Imp)]$

Where: A_E = Effective Drainage Area (acres)
A_T = Total Drainage Area (acres)
Imp = Percent Impervious

Each subwatershed's A_E was calculated and then summed on a watershed basis. Table 2-4 below shows the A_T of the watershed alongside the A_E.

Table 2-4. Watershed Effective Drainage Area for the Upper L.A. River Watershed

Watershed	Total Land Acres	Effective Drainage Area
Upper L.A. River	374,721	106,613

The concept and methodology of computing effective drainage area described in this report is consistent with the previously prepared GSP Phase I report.

2.2.2.2 Green BMP Sizing and Performance Assumptions

The BMP sizing and performance assumptions in this report are consistent with the GSP Phase I report. The concepts and assumptions are reiterated here for clarity:

The rainfall patterns within each watershed, the design volumes, and corresponding Green Solution BMP areas can be anticipated to vary. It is therefore expected that Green Solution BMP footprint areas will vary based on geography and the relative imperviousness of the subwatershed. Rainfall records from the National Climatic Data Center (NCDC) stations at LAX International Airport and Newhall Airport were consulted in order to capture the variations within the County. It is acknowledged that neither of these NCDC stations is within the watershed; however these two stations are the designated stations for Los Angeles County and are therefore applicable to all of the watersheds in the County. The charts produced by the NCDC provide a range of unit basin storage volume in inches for a target capture percentage. The California Stormwater Quality Association (CASQA) recommends volume based BMPs be designed for

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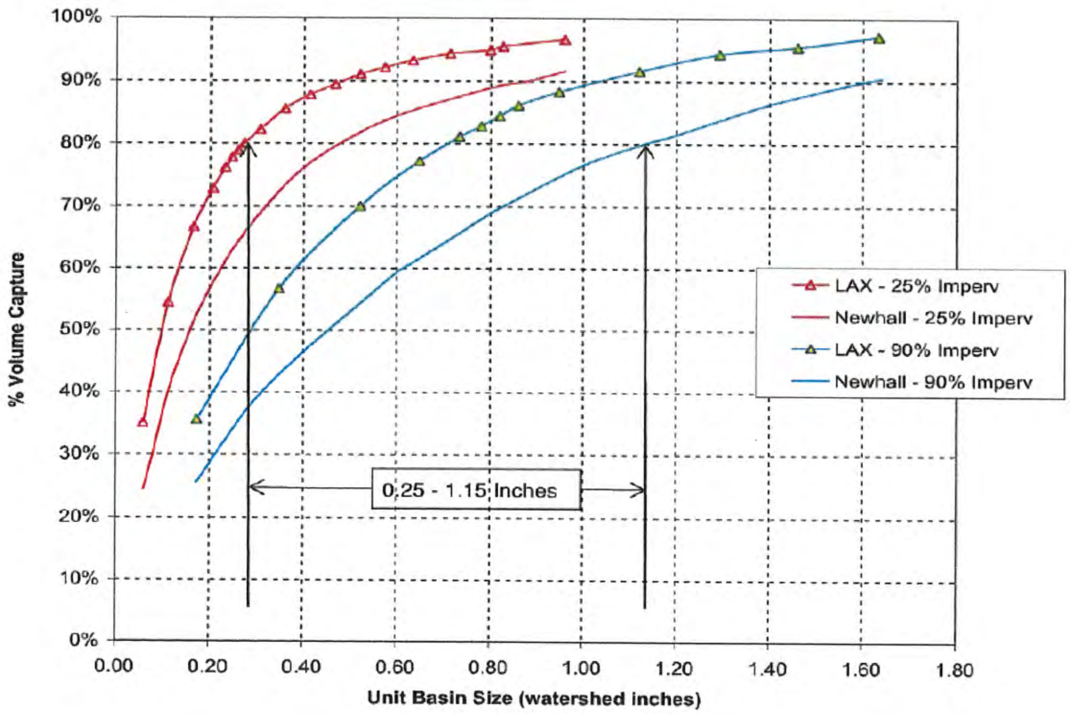
a drawdown time of no more than 48 hours. The Los Angeles Standard Urban Stormwater Management Plan (SUSMP) requires that treatment control BMPs treat "the volume of annual runoff based on unit basin storage water quality

volume, to achieve 80% or more volume treatment". Therefore based on 80% capture we arrive at a unit basin storage volume range of 0.25 to 1.15 inches based on the minimum and maximum expected runoff coefficients as shown on Figure 2-1.

Figure 2-1. Runoff Captured vs. Basin Size



Several Treatment Footprint (TF) Area design assumptions[5] were made in order to derive a relationship between the effective drainage area and the Treatment Footprint depth. The percent of effective drainage area needed is defined as the Treatment Footprint area divided by the effective drainage area. Figure 2-2 shows that the percentage of the effective drainage area drops as BMP depth increases.

5. For BMPs with a 1-foot depth, it was assumed they included 2:1 side slopes, no forebay, no freeboard, and a 1-foot top width buffer. For BMPs with a 2-4 foot depth, it was assumed they included 3:1 side slopes, 25% forebay, 2 feet of freeboard, and a 4 foot wide berm.

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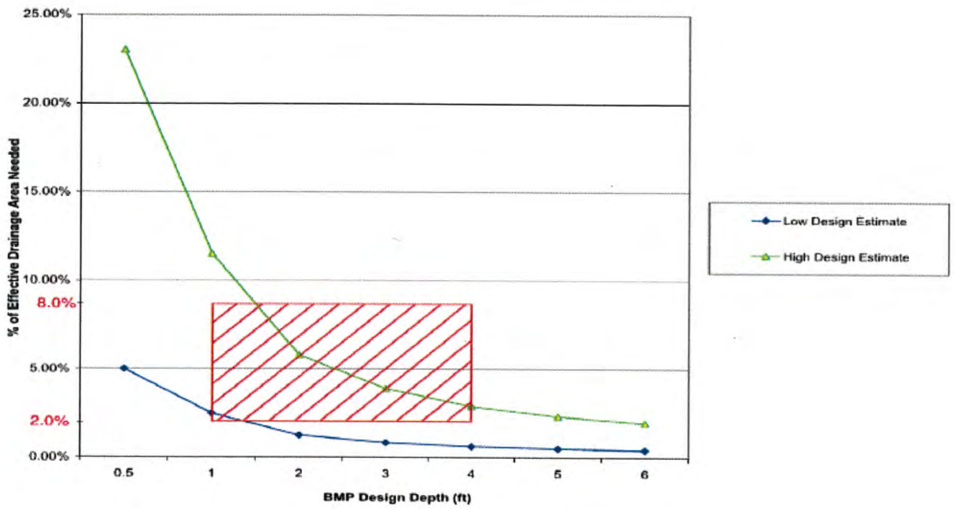
Figure 2-2. Effective Drainage Area vs. Treatment Footprint Depth



The High Design Estimate curve depicts a scenario with high imperviousness and a high intensity storm where as the Low Design Estimate curve depicts the scenario with a low imperviousness and a low intensity storm. Analyzing these curves indicates that Treatment Footprint Areas within the watershed would require 0.5% to 10% of their effective drainage areas with the majority falling in the 2% to 8% range. Using this range, a need for Treatment Footprint (TF) areas can be established for each subwatershed within the Upper LA River watershed, as shown in Table 2-5 below.

Table 2-5. Acres Needed for Treatment Footprint Areas for Upper L.A. River Watershed

			Acres Needed for TFA's		
Watershed	Total Land Acres	Effective Drainage Area	Low (2%)	Ave	High (8%)
Upper L.A. River	374,721	106,613	2,132	5,331	8,529

2.2.3 Identification of Opportunities for Runoff Treatment

Different opportunities exist on different land uses for treating urban runoff and storm water runoff. Within the context of this report, it is our assumption that the public land uses analyzed within this report can treat off-site drainage as well as on-site runoff. The following sections summarize how each public land use was analyzed in order to determine the appropriate treatment amounts for each category of land use.

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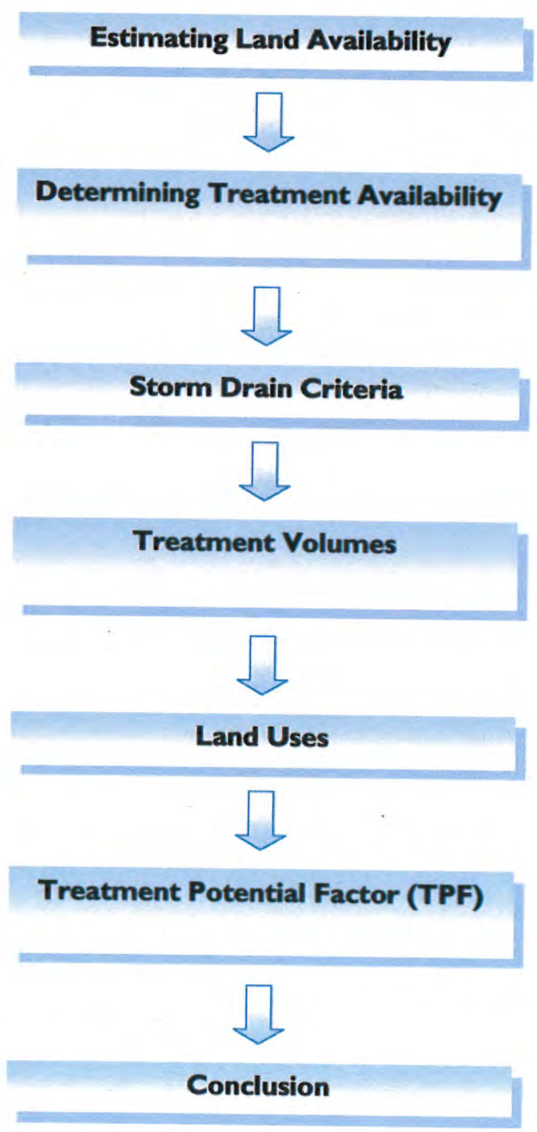
2.2.3.1 Target Land Uses and Parcel Screening

2.2.3.1.1 Public Land Uses

The GSP Phase I report focused on all of the publicly owned parcels within the county in order to establish the potential for multi-benefit Green Solution BMPs. This GSP Phase II (Partial) report focuses on four public land uses: elementary schools, senior/middle schools, colleges/universities, and vacant land within the Upper LA. River Watershed.

The GSP Phase II (Partial) screening process began with 1,029 parcels within the target land uses, and based on the screening criteria, 305 parcels totaling 5,300 acres in the Upper LA. River watershed were identified as potential candidate parcels.

This GSP Phase II (Partial) analysis modified the public land use screening process that was applied during GSP Phase I and included the following steps:



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Each step is described in detail below:

- Parcel Block Preparation: The process started with public parcels in the target land uses that were dissolved into parcel blocks based on ownership and screened as greater than 1/2 acre in size.
- Sub-Watershed Assignment: Each parcel block was then assigned to a sub-watershed. In cases where parcel blocks straddled sub-watershed boundaries, the parcel block was included in the sub-watershed which contained the majority of the parcel block.
- Land Use Screening: The parcel blocks were merged with the Los Angeles County land use data layer to isolate portions of parcel blocks overlaying target land uses: elementary schools, senior/middle schools, colleges, and vacant land.
- Minimum Parcel Size and Slope Filters: The next filter applied was for a minimum parcel size of ½ acre and contiguous flat area (slope < 10%) covering at least 25% of the parcel area. After reviewing these initial results, a more stringent size criterion was applied in order to better capture properties where Green Solutions Projects could realistically be implemented. Elementary, middle/senior schools and colleges were screened for a minimum of 2 acres in total parcel area. Vacant parcels were screened for a minimum of 1 acre in total parcel area.
- Storm Drain Criteria: Parcels were then screened for proximity to storm drains. Two different storm drain criteria were analyzed: parcels within 500' of a storm drain and parcels within 250' of a storm drain. All storm drains considered in the analysis have a minimum cross sectional area equal to or greater than a 36" diameter pipe. Since the cost of an additional 250' of storm drain to connect a parcel to an existing storm drain is relatively small, the team determined that the 500' criteria is the most appropriate. Based on previous project experience, the team agreed to exclude storm drains smaller than 36" in order to aid in future prioritization of public opportunity parcels which could be incorporated in future phases. Smaller storm drains could be utilized, but generally do not have enough dry weather flow to justify project and maintenance expenses. The exception to these criteria was for larger opportunity public parcels over 20 acres in size. These large parcels were additionally included if within 500 ft of a "no data" storm drain, i.e. a storm drain without reported information on cross-sectional area.

Exhibits D.1 through D.3 show the locations of all of the opportunity public parcels within the Upper LA River watershed.

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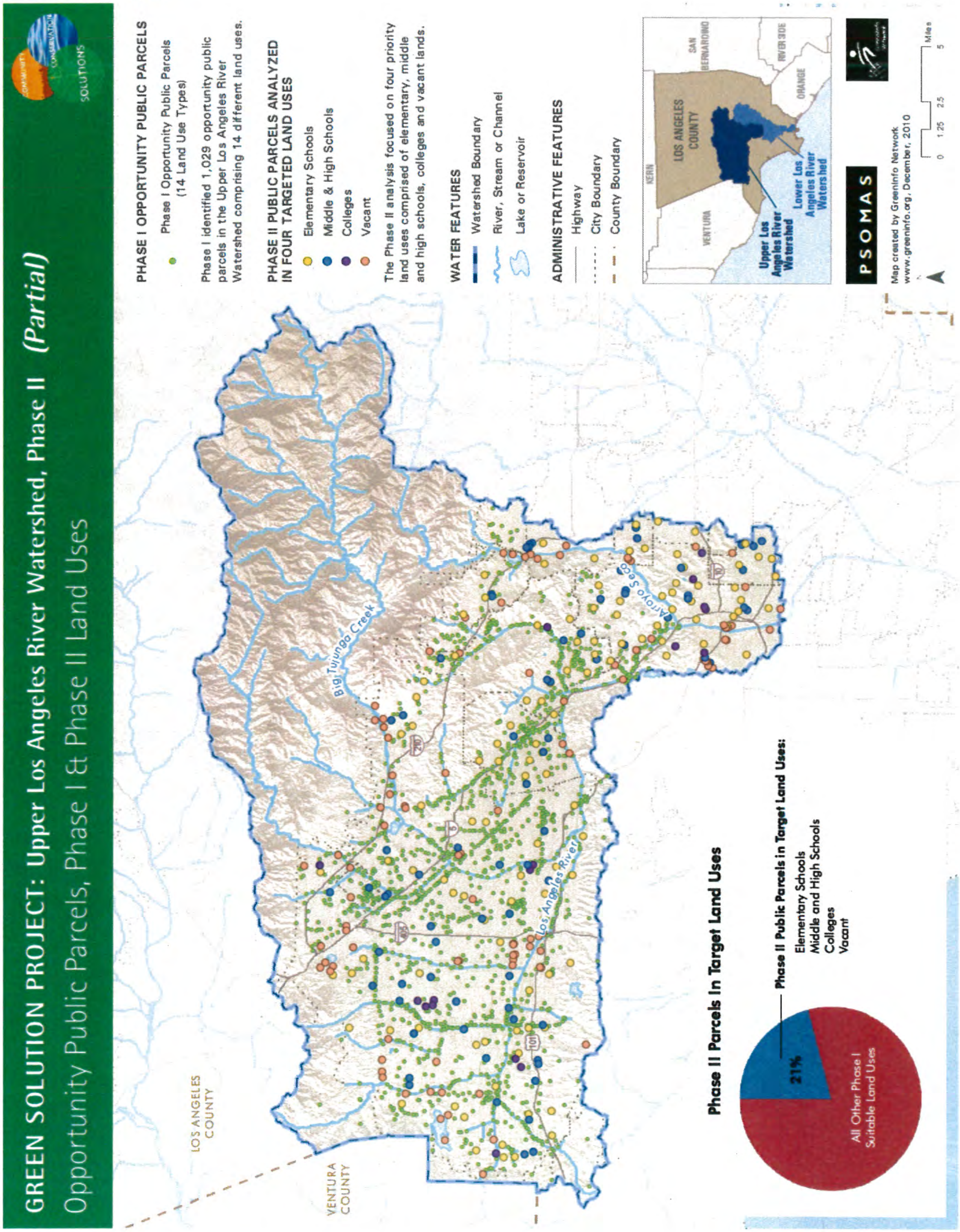

Exhibit D.1 – Opportunity Public Parcels, Phase I & Phase II Land Uses

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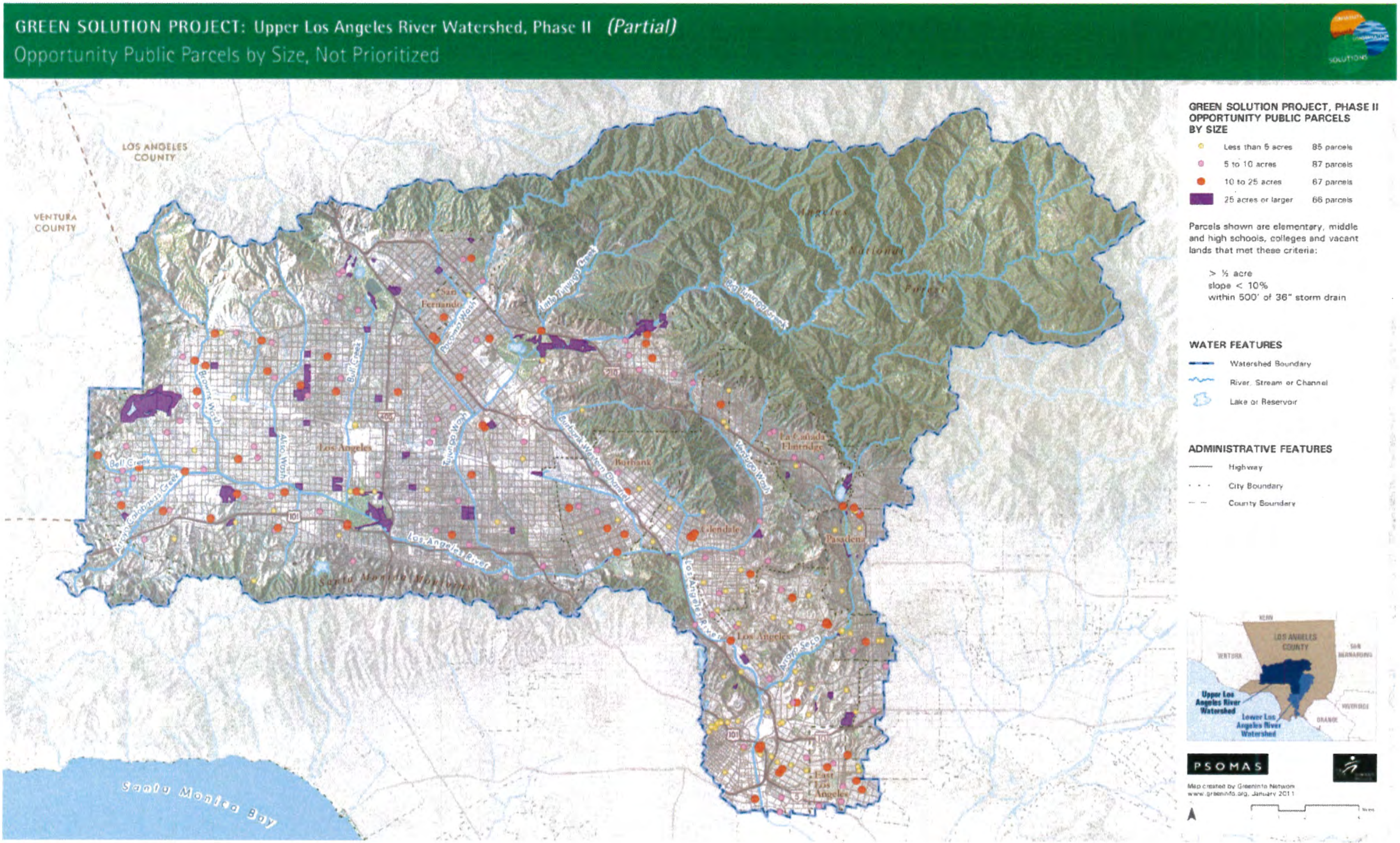

Exhibit D.2 – Opportunity Public Parcels by Size, Not Prioritized

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GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II (Partial)

Opportunity Public Parcels by Land Use, Not Prioritized

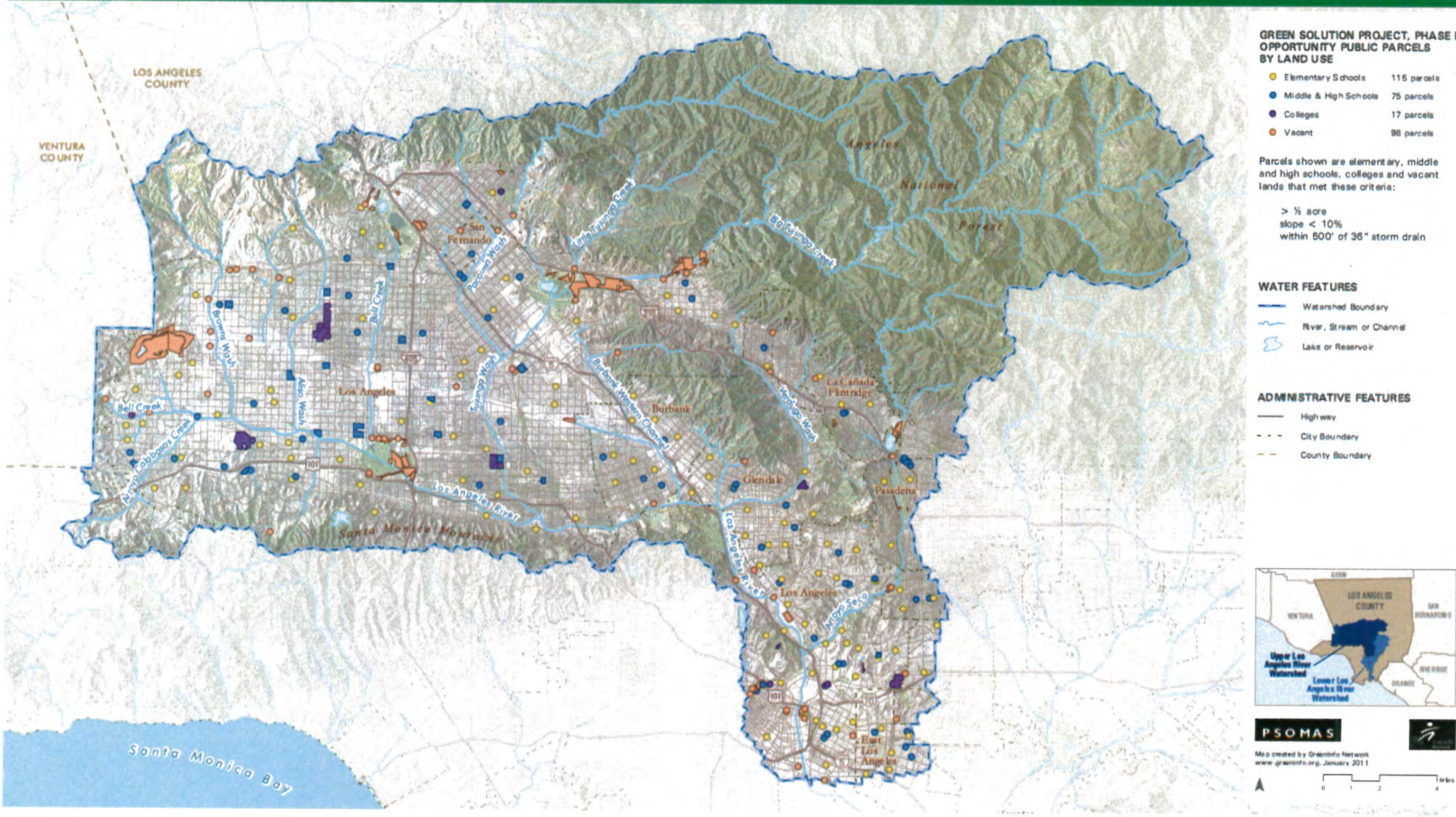

Exhibit D.3 – Opportunity Public Parcels by Land Use, Not Prioritized

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2.2.3.2 Land use Analysis

2.2.3.2.1 Public Land uses

The following describes the public land use analysis used for estimating available land for treatment:

Each step in the Public Land use Analysis is described below:

- Estimating Land Availability – Green Solution Project (GSP) Area vs. Treatment Footprint (TF) Area: The procedure for estimating land availability was conceptually held consistent with the GSP Phase I report. A distinction was made between GSP Area and Treatment Footprint Area. The GSP Area is defined as all of the project elements including pre-treatment facilities, vegetated swales, basins, wet ponds, trails, interpretive signs, parking and staging areas, etc. The Treatment Footprint Area is defined as the area over which a depth is computed, to generate a treatment volume (area x depth). The Treatment Footprint Area is included within the GSP Area; however, there is not a direct formulaic relationship between the two since the Treatment Footprint Area cannot be interpolated from GSP Area. The GSP Area for each land use was determined based on past project experiences by the team. The GSP Area is important for creation of multi-purpose park, recreation, habitat and other open space for public use, planning purposes, funding, and public involvement, while the statistically significant area for treatment potential is the Treatment Footprint Area.
- Determining Treatment Availability – Retrofit Area vs. Conversion Area: Two categories were established for determining the amount of available land for treatment on a parcel within a particular land use. The first category, retrofit area, is defined as pervious area that could be retrofitted with treatment facilities such as detention/ retention basins, wet ponds, infiltration facilities, etc. The footprint area for determining the appropriate treatment volume was held consistent with the GSP Phase I report. Fields were not a focus of this effort and only secondary practice fields or other miscellaneous fields not expected to be impacted by high usage were considered for retrofit areas.
- The second category, conversion area, is defined as impervious area that could be converted to pervious surfaces and/or installed with underground storage facilities. The previous GSP Phase I report did not include underground storage as a part of potential treatment area; however, it has been included herein as underground facilities are useful in providing multi-benefit facilities on the surface. Psomas concurred with the GSP Phase I report that stated not all of a land use's impervious area could be converted. Our estimates reflect the portions of typical parcels that, in our professional judgment, could be converted. For example, it was assumed that a maximum of half of the parking stalls in any land use could be converted to pervious pavement and it was also assumed that storage would only be installed under these areas. Storage was assumed to be placed adjacent to retrofit areas in order to maximize efficiency and to accommodate grade requirements. Similar to the retrofit treatment volumes an average depth of 2.5 feet was assumed for the conversion treatment volumes.

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Table 2-8 below indicates the suitable ranges of TF area and GSP area for the targeted land uses.

Table 2-8. Treatment Footprint and Green Solution Project Areas for Upper L.A. River Watershed (Green Solution Project Area includes Treatment Footprint Area)

Land Use	Treatment Footprint Area % Suitable of entire site	Green Solution Project Area % Suitable of entire site
Colleges	2-8%	10-25%
Elementary Schools	2-4%	10-20%
Senior & Middle Schools	3-11%	10-25%
Vacant	22-60%	50-80%

- Storm Drain Criteria: For both categories storm drain proximity was considered an essential element in determining whether an area would be considered GSP Area versus TF Area. Surface diversion of off-site runoff was not considered a governing criterion as a part of this analysis since a storm drain is still required near the treatment area for discharge purposes. It is noted that off-site surface diversion will be considered on a site specific basis in future phases. Some sites have the potential of substantially increasing their treatable area while others would have minimal potential.
- Treatment Volumes: Treatment volumes assume an average depth of 2.5 feet. Some opportunity parcels may have the potential for increased treatment depth. The treatment volume for particular parcels may be increased by increasing the storage depth if site constraints and budgets allow for it. This requires further analysis on a site specific basis.
- Land Uses: Specific parcels for each of the four selected land uses: elementary schools, middle/senior schools, colleges/universities, and vacant were randomly sampled and statistically analyzed to develop a refined percent range of the Treatment Footprint Area. The coefficient of variation of estimated percent of land availability was less than one for the sample size. The analysis was determined to be statistically valid.
- Treatment Potential Factor (TPF): The TPF is a value between 0 and 1 which is applied to the ratio of acres treatable by potential GSPs divided by the acres needing treatment. The TPF is applied to this ratio because:

  1. Suitable parcels are not always located where they are most needed.
  2. Suitable parcels are not always amenable to large BMP footprint areas
  3. Suitable parcels may have larger drainage areas than potentially treatable with the suitable public lands

<u>Background</u>

GSP Phase I introduced the concept of Treatment Area Ratio (TAR) in order to quantify the size of the treatable drainage area. The treatable drainage area was estimated by first comparing the upstream drainage area to the maximum effective tributary area that could be treated by a GSP BMP for a given site or site type. In some instances the upstream drainage area exceeded the maximum effective tributary area treatable by a site (BMP-area-limited condition). Conversely, there were instances when the effective tributary area treatable by a site exceeded the actual upstream tributary area (drainage-area-limited condition). The TAR concept was developed to account for these two potential conditions. The TAR was the ratio of the effective drainage area divided by the Green BMP footprint area and depends on both the type of BMP and the potential location within a watershed. The TAR can generally be much larger for regional BMPs than for distributed BMPs, but it depends on the location of the available land with respect to the drainage system.

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However this spatial variability versus land usage was not reflected in the numerical calculation of TAR.

Treatment Potential Factor (TPF) Development

In developing the TPF it was acknowledged that the BMP-area-limited condition and the drainage-area-limited condition needed to be addressed. TPF focuses on where a parcel is located within a watershed as opposed to land use. The basic principals of TPF account for the increased probability that a drainage-area-limited condition will occur in the upper reaches of a watershed, and that a BMP-area-limited condition will occur in the lower reaches of a watershed. There is a relatively equal probability of either condition occurring in the centroid of a watershed; therefore the weighted baseline factor for TPF is 50%. Based on our past project experience, we determined that it is appropriate to utilize a range based around the baseline factor. For the Upper LA. River Watershed, we believe that a 30% to 60% range is appropriate, as this applies a practicality factor based on the following:

- Spatial Distribution – Based on where a candidate parcel is located within the watershed the ratio of acres treatable/ acres needed may need a higher factor or a lower factor.
- Storm Drain Size – The size of the storm drain near potential parcels varies therefore too much or not enough water may be available.
- Distribution of Parcel Size – Different candidate parcel sizes are distributed through the upper and lower portions of the watershed.

The 0.3 to 0.6 TPF range is applied to the ratio (acres treatable/acres needed). It is also important to note that the acres treatable for each subwatershed has been capped at the acres needed. The reason for this limit is that this analysis focuses on the SUSMP treatment amount, and therefore does not address the possibility of over-treating a subwatershed. Furthermore, it is not good engineering practice to divert runoff from one subwatershed to another; it is cost prohibitive and other potential unforeseeable environmental harm could be caused to downstream habitats.

Land Use Analysis Summary

The land availability estimation process successfully defined the Treatment Footprint (TF) Area versus the Green Solution Project (GSP) Area. By separating these two types of areas, the results of this GSP Phase II (Partial) analysis more accurately convey the actual treatable drainage area as well as supplies estimates for the total project area so that the multi-benefit aspects can be evaluated. Sample parcels from each land use were reviewed in order to statistically validate an appropriate percent suitable range for TF Area and GSP Area. The TAR concept was reviewed from GSP Phase I and superseded with the TPF approach which estimates, within engineering reasoning, how much of a subwatershed could potentially be treated.

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2.2.4 Sub-watershed Prioritization Approach

Due to changes to the project scope and budget, the multiple-benefit factors were not integrated into a quantified scoring tool and the 305 identified public opportunity parcels were not ranked or prioritized based on these integrated factors. The individual factors which include community needs, conservation needs, storm water quantity and storm water quality for each public opportunity parcel have been identified with corresponding tables and are included in the appendix. Integration of these factors and scoring of the parcels would allow identification of those parcels, which could offer the greatest overall multiple benefits.

2.2.4.1 Non-Storm Water Factors

The non-storm water factors are related to community needs and conservation needs.

Community Needs

The components of the community needs factor are youth density, senior density, per capita income, housing tenure (rent verses own), and car access. This factor quantifies the needs of communities for park, recreation and natural open space amenities based on these demographics. The data source was the 2000 Census. Candidate parcels were evaluated based on proximity to census block groups with demographics that serve as key indicators of need for park, recreation and natural open space, as described below.

Youth density is defined as under the age of 18, and senior density is defined as 65 years of age or older. These age groups have a higher percent usage of parks, recreation and open space, so areas with high numbers of youth and seniors typically have a much greater need for public parks, recreation and natural open space than do other age groups.

The per capita income of each census block group was compared to the Los Angeles County average. Areas with below average per capita income generally have the highest needs for public park, recreation and natural open space amenities because low income levels make it difficult to access private facilities providing these amenities.

Areas with high numbers of renters generally are dominated by multi-family residential properties, high population numbers and land uses which have little or no available park, recreation or other natural open space, unlike single family residential properties. Lack of car access is also an indicator for a high need for easy access to public parks, recreation and natural open space that are within walking distance. Block groups were compared to the Los Angeles County average of car access.

Conservation Needs

The components of the conservation needs factor are open space deficit and proximity to existing rivers, habitat and trails. This factor quantifies the priority for creating parks, recreation, habitat and/or natural open space in a given area to meet per capita park and recreation goals for people, as well as to address the need for expanding wildlife corridors and restoring natural habitat to meet the needs of native wildlife species.

Park acreage per thousand residents was evaluated to determine the range of open space deficit, using park and open space data from the California Protected Areas Database (CPAD 2008) (www.calands.org) . Open space in mountain areas were not included. Habitat data was extracted from the Los Angeles County Significant Ecological Areas (SEA) and the California Natural Diversity Data Base (CNDDB) threatened and endangered species data from 2008. CNDDB data is based on species sightings, and represents the best available data on the presence of threatened and endangered species.

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2.2.4.2 Storm Water Factors

The two storm water factors are related to quantity and quality.

Quantitative

The quantitative factor is the availability of urban and storm water runoff for diversion and treatment. Because the Upper L.A. River watershed can generally be described as an urban watershed, much of the runoff can be described as polluted. It is important to have an adequate quantity of water to treat in order to maximize the return on investment of a treatment facility. Pipes smaller than 36 inches in diameter typically do not possess enough dry weather flow to justify major treatment facility projects, thus the screening criteria eliminated opportunity public parcels that did not meet this criteria. The proximity of an adequate quantity of water should be within 500 feet in order to ensure financial feasibility.

Qualitative

The qualitative aspect of storm water and urban runoff was eliminated from the scope of this report. Below is a description of the qualitative analysis that could be incorporated with later phases.

The quality of storm water runoff could be prioritized based on the Catchment Prioritization Index (CPI) as described in the Los Angeles County-Wide BMP Prioritization Methodology.[6] CPI is calculated by factoring the relative pollutant loadings estimated using available land use and rainfall data. Pollutant load indices would be based on an empirical load-estimating approach known as the simple method, where estimated runoff volumes would be multiplied by land use based concentrations.[7] For this analysis, runoff volumes for each land use could be estimated by multiplying the 85th percentile, 24-hour rainfall depth by land use area and land use based runoff coefficients. Load indices could then be estimated by multiplying the estimated runoff volume by characteristic land use event mean concentrations (EMCs). Subwatershed loading indices for several pollutant categories of concern could finally be estimated by summing the loads for each land use within the subwatershed. Pollutant index scores could then be calculated for each subwatershed and for each pollutant by normalizing by the maximum subwatershed load within the watershed and then ranking on a scale from 1 to 5, with 1 being a low priority and 5 being a high priority. The above described methodology is consistent with the previous GSP Phase I report.

6. GeoSyntec Consultants, (2006). Los Angeles County-wide Structural BMP Prioritization Methodology.
7. Schueler, T.R. (1987) *Controlling Urban Runoff: A Practical Manual for Planning & Designing Urban BMPs.* Pub # 87703, Metro Washington D.C. Governments.

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3. ANALYSIS OF NEEDS, OPPORTUNITIES, AND PRIORITIES

3.1 Preliminary Needs and Opportunities Assessment

The following sections summarize the results of the Upper L.A. River Watershed's water quality improvements needs and GSP opportunities assessment.

3.1.1 Estimated Gross-Scale Needs

The estimated acres needed for treatment per the SUSMP[8] requirements for each subwatershed is summarized in Table 4-1. The estimated acres are based on the 2-8% of the effective drainage area as described in Section 2.2.3.1. It is estimated that the Upper L.A. River Watershed will need between 2,132 and 8,259 acres of Treatment Footprint (TF) Areas in order to treat the targeted rainfall event for the watershed.

Table 3-1. Estimated Acres Needed for Treatment Footprint Area for Upper L.A. River Watershed

			Acres Needed for Treatment Footprint Areas		
Watershed	**Total Land Acres**	**Effective Drainage Area**	**Low (2%)**	**Ave**	**High (8%)**
Upper L.A. River	374,721	106,613	2,132	5,331	8,529

3.1.2 Potential Opportunities for Green BMPs

As described in Section 2.2.3.3.1, the public land use screening process was revised from the GSP Phase I analysis. Prior to the screening process, 1,029 potential public parcels in the selected land uses were identified; after the screening process, 305 candidate parcels totaling 5,300 acres were identified. Representative samples of each land use group were analyzed in order to determine appropriate ranges for TF areas and GSP areas to be implemented on the parcels. Table 3-2 gives the Treatment Footprint areas as well as the Green Solution Project areas.

Table 3-2. Treatment Footprint and Green Solution Project Areas for Upper L.A. River Watershed

Land Use	Treatment Footprint Area % Suitable of entire site	Green Solution Project Area % Suitable of entire site
Colleges	2-8%	10-25%
Elementary Schools	2-4%	10-20%
Senior & Middle Schools	3-11%	10-25%
Vacant	22-60%	50-80%

Vacant land has the highest percentage of land available for BMPs while Elementary Schools have the least. All of the

8. Los Angeles County Department of Public Works, (2002) *Development Planning for Storm Water Management.*

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candidate land uses' storage footprint areas within a subwatershed were summed so that a total area suitable for storage could be determined for the watershed.

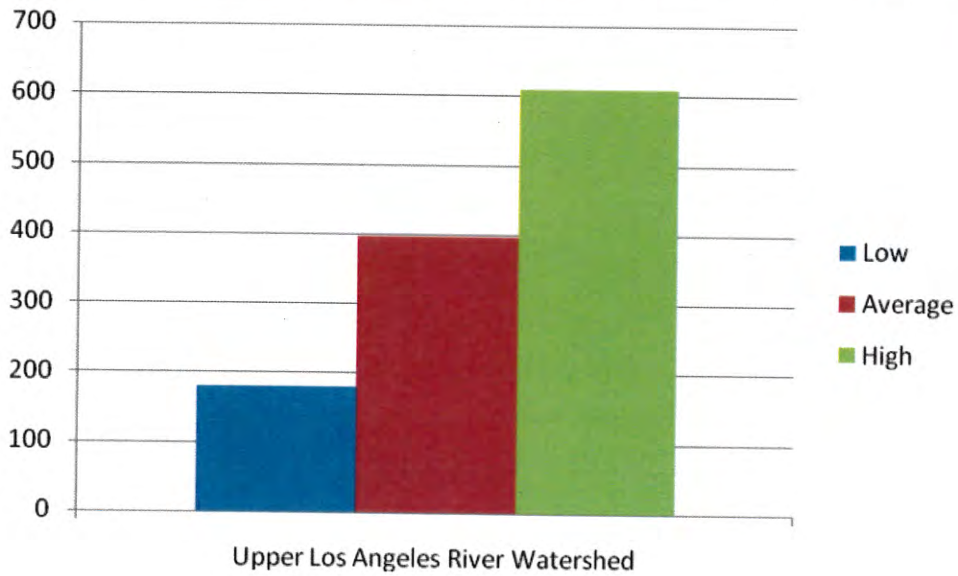
Utilizing the ranges discussed above, acreages for BMPs on each targeted land use were determined. Table 3-3 summarizes the total Treatment Footprint Area available in the watershed.

Table 3-3. Acres Suitable for Treatment Footprint Area for Upper L.A. River Watershed

			Acres Suitable for Treatment Footprint Areas		
Watershed	**Total Land Acres**	**Effective Drainage Area**	**Low**	**Ave**	**High**
Upper L.A. River	374,721	106,613	179	395	608

The histogram below highlights the lows and highs included in Table 3-3 above.

Figure 3-1. Acres Suitable for Treatment Footprint Areas for Upper L.A. River Watershed



RB-AR35608

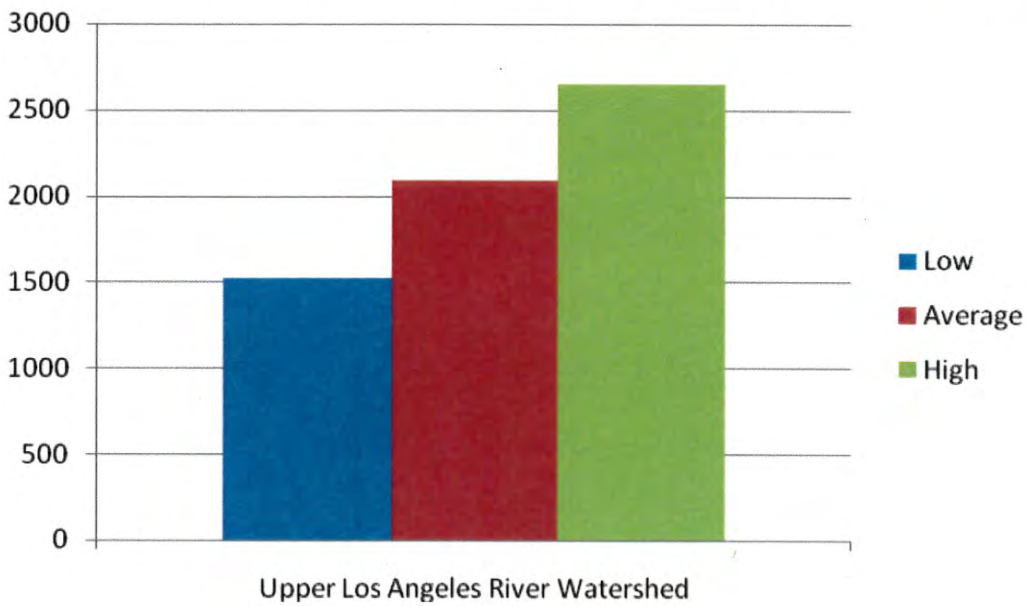
The multi-benefit aspects of GSPs bring additional value to areas that are lacking in parks, open space, and habitat. Table 3-4 shows the amount of GSP area available in the watershed.

Table 3-4. Acres Suitable for Green Solution Projects for Upper L.A. River Watershed

Watershed	Total Land Acres	Effective Drainage Area	Acres Suitable for Green Solution Project's		
			Low	Ave	High
Upper L.A. River	374,721	106,613	1,523	2,086	2,650

The histogram below highlights the lows and highs included in Table 3-4 above.

Figure 3-2. Acres Suitable for Green Solution Projects for Upper L.A. River Watershed



3.2 Water Quality Improvement Needs

Based on our design assumptions discussed in Section 2.2.3.1, the Upper L.A. River Watershed on average needs approximately 5,331 acres of public parcel land for Treatment Footprint Areas to treat its urban runoff. Approximately 395 acres on average, or 3%, of that need can be met by public parcels in the targeted land uses of this study. The percentage of the watershed's need that can be met by GSPs can be seen in Table 3-7.

It is also significant that the ratio of the acres suitable versus the acres needed was capped at 1.0, that is, the acres suitable cannot exceed the acres needed in a watershed. It is acknowledged that this potential excess treatment volume could over-treat the target watershed, treating 1.0+ inches versus the required 0.75 inch storm event. However the focus of this GSP Phase II (Partial) analysis is on treating the required treatment volumes from the L.A. SUSMP, therefore over-treatment was not considered and the percent need met cannot exceed 100% for a subwatershed. Furthermore, this ratio, also known as the percent need met, is where the Treatment Potential Factor as discussed in Section 2.2.3.4 is applied.

% need met = (acres suitable/acres needed)*TPF

Table 3-7. Ratio of Acres Suitable to Acres Needed for Upper L.A. River Watershed

			Ratio of Acres Suitable to Acres Needed		
Watershed	Total Land Acres	Effective Drainage Area	Low	Ave	High
Upper L.A. River	374,721	106,613	2%	3%	4%

3.2.1 Gross Green BMP Area Needs vs. Suitable Public Lands

Both the Suitable Acres on candidate parcels and the Acres Needed were reported with a low and high range. The purpose of this range is to allow for the variability of different site types within each land use category as well as to account for varied rainfall intensities and relative imperviousness throughout the watershed.

3.3 Water Quality Improvement Needs and Subwatershed Prioritization

The Water Quality Improvement Needs for each subwatershed were calculated based on the discussion in Section 3.2.

3.3.1 Prioritization Factors

Parcel prioritization based on integration of the multiple benefit factors described below was removed from the scope of this report due to budget cuts. If conducted at a later date, the prioritization scoring would incorporate storm drain size, CPI score, Parks and Open Space, Habitat Proximity and Community Needs, as discussed in Section 2.2.4. These factors were quantified individually and applied to each opportunity public parcel.

3.3.1.1 Community Needs

The Community Needs factor evaluates the human need of the community proximate to each candidate parcel for parks, recreation and natural open space lands, based on the key demographic indicators of youth density, senior density, per capita income, housing tenure (percent renters), and car access. This is an important numeric measure of the needs of residents throughout the Upper L.A. River Watershed for the types of new park, recreation and natural open space that Green Solution projects create, and contributes to the overall prioritization of candidate parcels for project implementation.

RB-AR35610

3.3.1.2 Conservation Needs

Open Space Deficit

The Conservation Needs factor integrates important conservation indicators for open space deficit, natural habitat needs and river, trail and habitat connectivity potential. This factor evaluates: the human need of the community proximate to each candidate parcel for creating new park, recreation and open space opportunities to address serious park and open space deficiencies; the conservation need for creating and restoring native habitat and natural open space to address the needs of wildlife species, including birds, mammals, insects, reptiles and amphibians; and the need for establishing connectivity to existing trails and river parkways to create networks of green open space in urban areas. This an important numeric measure of comprehensive conservation needs throughout the Upper LA River Watershed for the types of new park, habitat, greenways and natural open space lands that Green Solution projects create.

Park acreage per thousand residents is a measure used throughout the U.S. to compare the amount of parks available in different communities and to evaluate park needs, particularly in urban communities. The national standard established by the National Park and Recreation Association is six to ten acres of easily accessible park and recreation land per thousand residents. Many communities in the Upper L.A. River Watershed are far below this national standard, and Green Solution projects provide a unique and important opportunity to address these park and open space deficits by creating new park, recreation and open space lands. Existing trails, rivers and greenways provide connectivity opportunities, and Green Solution projects can expand these amenities and contribute to local and regional open space and greening goals by helping to create networks of green open space and trails throughout the watershed. Similarly, linking Green Solution projects to existing native habitat, and providing connectivity to these important sites, assists in addressing the need to restore viable habitat, particularly for threatened and endangered species, in urbanized areas of the Upper L.A. River Watershed.

3.3.2 Water Quality Prioritization vs. Improvement Needs Potentially Met

Future phases could integrate the multiple benefit factors as discussed in Section 3.3.1, into a tiered ranking system in order to identify the most desirable projects which are located in the areas which have the largest need.

<u>Concept Site Design Examples</u>

The concept site examples are intended to represent typical BMPs that could be implemented on some of the specific land use types evaluated in this study. For example, vacant sites typically allow for regional types of BMPs where as Elementary schools typically allow for distributed BMPs. However, this is not always the case. It is important to note that every site is different and that these concepts are not intended to be applied universally. Due to budget cuts, concept site design examples were prepared for two of the four land use types analyzed.

3.3.3 Public Land Uses: Middle/Senior School, Vacant

Concept sites were selected to be analyzed based on the project team's local knowledge.

RB-AR35611

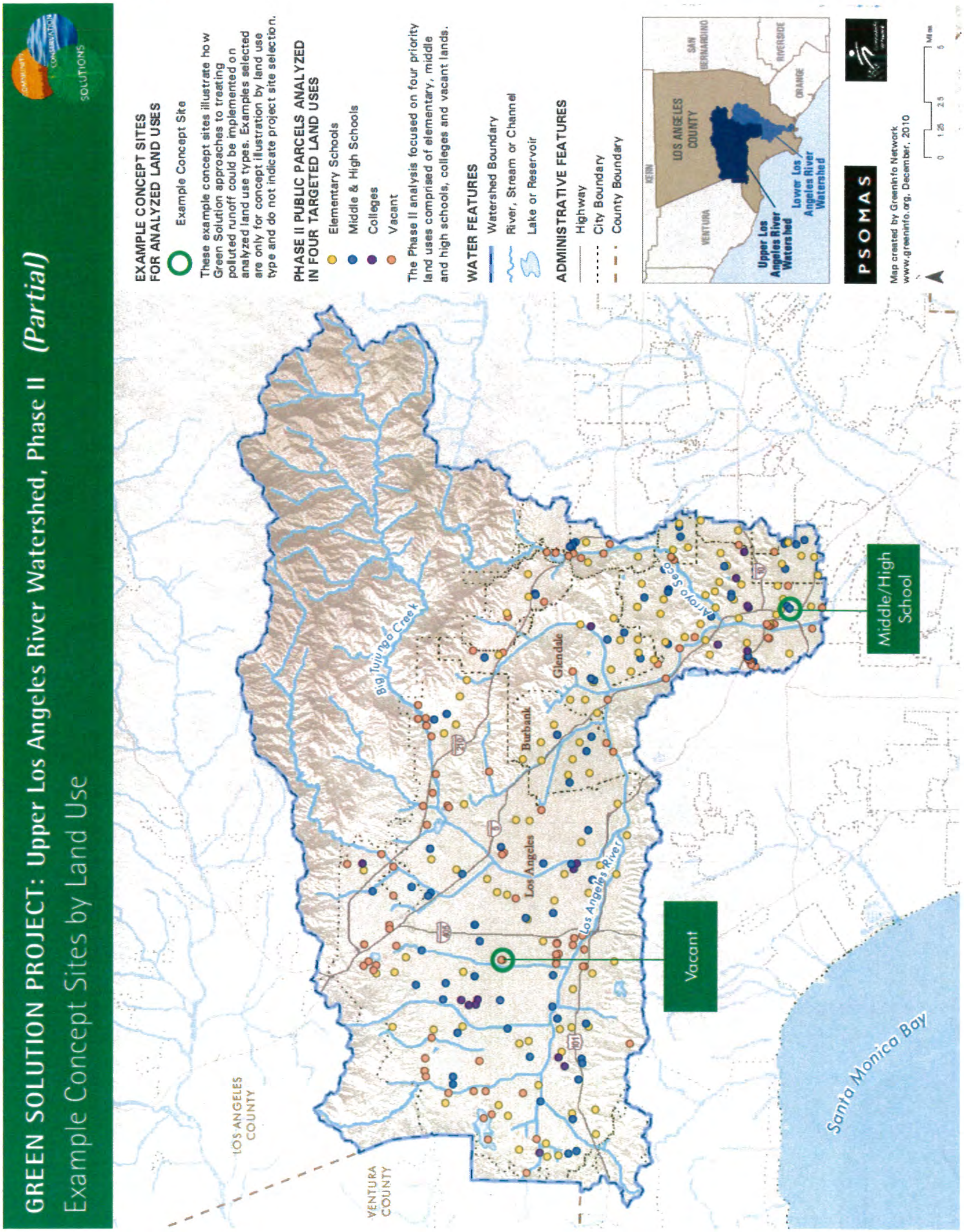


Exhibit E.1 – Example Concept Sites by Land Use

RB-AR35612

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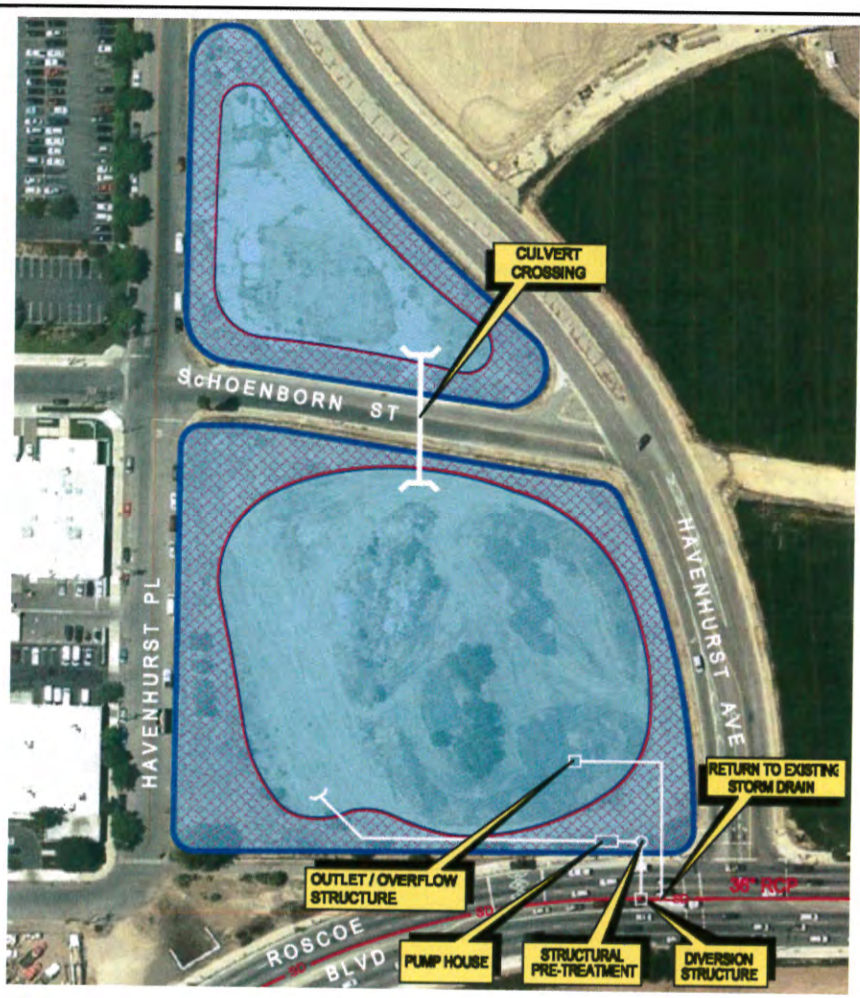
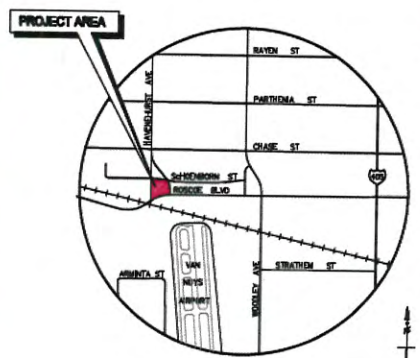
RB-AR35613



LEGEND

SD 51" RCP	EXISTING STORM DRAIN, MATERIAL & SIZE
	PROPOSED STORM DRAIN
	PARCEL BOUNDARY
	DIVERSION STRUCTURE
	STRUCTURAL PRE-TREATMENT
	PUMP HOUSE
	RETENTION/ DETENTION BASIN
	RETROFIT AREA



VICINITY MAP
NOT TO SCALE

GRAPHIC SCALE 100' 50' 0' 100'
Note: For reduced sized prints, original scale is in inches

Site Characteristics

Site Area (Ac):	5.16 Ac
Total Amount of Site Used for Green Solution Project:	100%
Off-Site Treatment	
Storage Volume Available:	7.3 Ac-Ft
Approximate Treatable Area:	159.0 Ac
On-Site Treatment	
Existing Impervious:	0.0 Ac
Proposed Impervious:	0.0 Ac

Project Setting and Characteristics

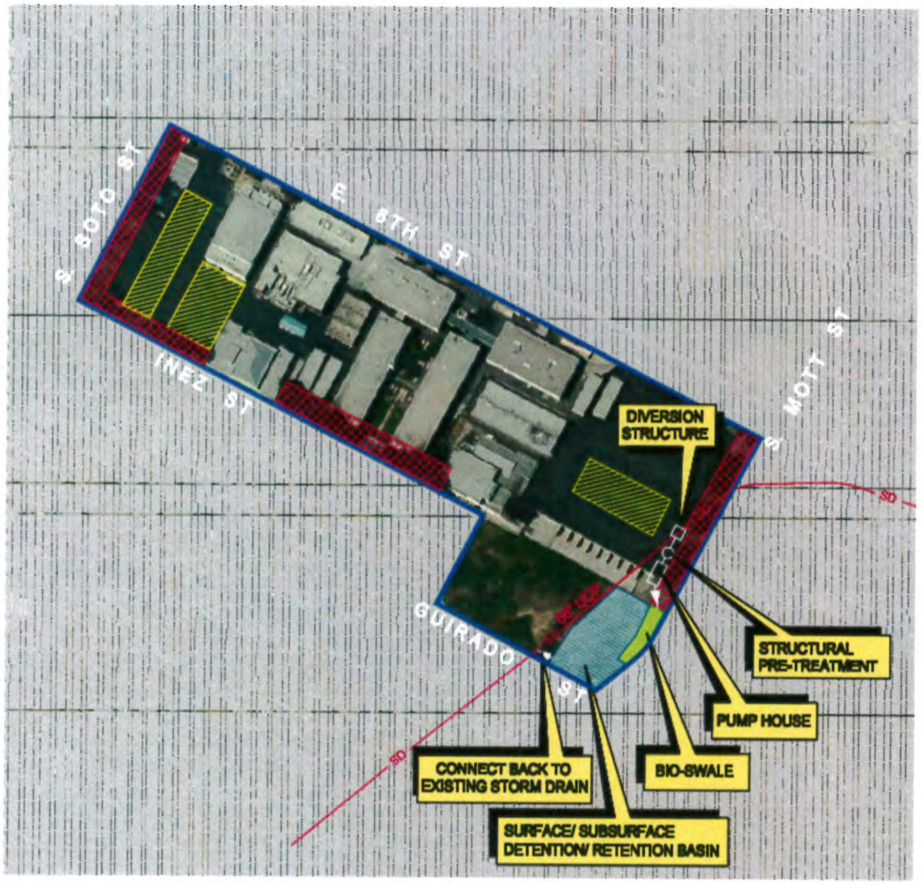
- The primary purpose of this concept plan is to identify Green BMPs which could treat off-site urban runoff.
- The parcel is located near the Van Nuys airport in the City of Los Angeles and is representative of most vacant land in the watershed.
- On the ground distance to storm drain: 60'
- Approximate storm drain size: 36"
- The surrounding potential contributing area contains industrial parcels associated with the airport as well as commercial and residential parcels. (Assumed 75% Impervious)
- The concept site examples are intended to represent typical BMPs that could be implemented on the specific land use types evaluated in this study. For example, vacant sites typically allow for regional types of BMPs whereas Elementary schools typically allow for distributed BMPS. However, this is not always the case. It is important to note that every site is different and that these concepts are not intended to be applied universally.

Concept Site Design for a Vacant Lot Upper Los Angeles River Parcel 1

PSOMAS

DATE: 5-19-2010 REVISED ON:
JOB No:1CCI010101
SHEET 1 OF 8
CCI-101-02

Exhibit E.2 – Concept Site Design for a Vacant Lot, Upper Los Angeles River



200' 100' 0' 200'
GRAPHIC SCALE
Note: For reduced sized prints, original scale is in inches

LEGEND

SD 51" RCP	EXISTING STORM DRAIN, MATERIAL & SIZE
	PROPOSED STORM DRAIN
	PARCEL BOUNDARY
	DIVERSION STRUCTURE
	STRUCTURAL PRE-TREATMENT
	PUMP HOUSE
	SUBSURFACE DETENTION/ RETENTION BASIN
	CONVERSION AREA
	RETROFIT AREA
	BIO-SWALE

VICINITY MAP
NOT TO SCALE

Site Characteristics

Site Area (Ac):	11.09 Ac
Total Amount of Site Used for Green Solution Project:	17%
Off-Site Treatment	
Storage Volume Available:	1.0 Ac-Ft
Approximate Treatable Area:	24.0 Ac
On-Site Treatment	
Existing Impervious:	8.7 Ac
Proposed Impervious:	7.9 Ac

Project Setting and Characteristics

- The primary purpose of this concept plan is to identify BMPs which could treat off-site urban runoff. Additional site BMPs such as directing roof runoff to landscape areas, upgrading irrigation facilities, etc. could be utilized with further site analysis.
- The parcel is located in the Boyle Heights community of the City of Los Angeles and is representative of most senior/middle schools in the watershed.
- On the ground distance to storm drain: 150'
- Approximate storm drain size: 66"
- It is our assumption that only secondary play fields could be used for BMPs. Depending on the level of usage these BMPs could be surface or subsurface.
- The surrounding potential contributing area is primarily residential with some commercial parcels. (Assumed 70% Impervious)
- The concept site examples are intended to represent typical BMPs that could be implemented on the specific land use types evaluated in this study. For example, vacant sites typically allow for regional types of BMPs whereas Elementary schools typically allow for distributed BMPS. However, this is not always the case. It is important to note that every site is different and that these concepts are not intended to be applied universally.

Concept Site Design
for a
Senior / Middle School
Upper Los Angeles River
Parcel 2

PSOMAS

DATE: 5-19-2010 REVISED ON:
JOB No:1CCI010101
SHEET 1 OF #
CCI-101-02

Exhibit E.3 – Concept Site Design for Senior/Middle School, Upper Los Angeles

RB-AR35614

RB-AR35615

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Study Results

The analysis successfully identified 305 candidate public parcels within the Upper L.A. River Watershed on which GSPs could potentially be constructed. Utilizing an integrated scoring of the community needs, conversation needs, storm water quantity and storm water quality, candidate parcels could be reviewed, scored, prioritized and ranked to identify for implementation the candidate public parcels that could provide the greatest multiple benefits. This scoring and prioritization process allows the public opportunity parcels to be compared in a quantified manner to establish the greatest multiple benefits.

Ranges of land area needs for target land uses for GSPs in Upper L.A. River watershed were estimated utilizing spatial analysis methods and experience with regional urban water quality issues and BMP sizing requirements. About 3% of the watersheds' needed Treatment Footprint (TF) Area can be met through the implementation of Green Solution Projects (GSPs) on the target land uses. These treatment footprint areas could potentially treat up to 15,000 acres within the Upper L.A. River Watershed. This is a significant portion considering that this study only analyzed four public land uses of the 19 identified in GSP Phase I; that urban watersheds generally have limited space for BMPs and that often larger tributary drainage areas are not adjacent to prime candidate parcels.

The results of this study indicate that if GSPs were constructed on candidate land uses they would have the potential to improve water quality within the watershed. Approximately 11,200 acres on average could be treated by the 305 candidate opportunity public parcels identified in this report.

Table 4-1. Treatable Area for Upper L.A. River Watershed

Watershed	Total Land Acres	Potential Acres Treatable		
		Low	Ave	High
Upper L.A. River	374,721	9,400	11,200	15,000

4.2 Recommended Next Steps for Additional Study

This GSP Phase II (Partial) study honed the analysis completed in the GSP Phase I study. However, integration of the multiple benefit factors and prioritization and ranking of the opportunity public parcels was removed from the scope of this report. It is recommended that these tasks be completed in order to prioritize and rank the opportunity public parcels identified in this partial Phase II so that the highest value sites can be quantified for potential implementation. Approximately 11,000 acres on average could be treated by the 305 candidate opportunity parcels identified in this report. In addition, private lands and public rights-of-way have the potential to treat additional runoff.

RB-AR35616

1. GSP Phase I – Identified potentially suitable opportunity public parcels from all land uses that could be used to naturally capture and treat polluted runoff, including:

   - identified areas in each watershed with the highest clean-up needs
   - quantified contributing area
   - quantified acreage needed for the treatment footprint area
   - analyzed the complete public parcel roll
   - evaluated and identified potentially suitable opportunity public parcels
   - utilized a Treatment Area Ratio (TAR) to quantify treatable area
   - quantified acres potentially suitable for GSP, and % need potentially met
   - identified sub-watersheds with greatest pollutant loading at general scale.

2. GSP Phase II (Partial) – Introduced water quality/quantity, conservation priorities and community needs; identified candidate opportunity public parcels within specific land uses and

   - refined potential land use selection/identification

   Additional Phase II Work Needed
   Revise Phase II analysis to include Catchment Prioritization Index scoring so that subwatersheds with the greatest pollutant loads can be identified and integrate the multiple benefit factors introduced in this report so that the candidate opportunity public parcels can be prioritized and ranked for potential implementation.

3. GSP Phase III –Could discuss a variety of alternatives including evaluating high priority land uses, site selections, concept reports or preliminary design reports for project implementation.

   - Ascertain site-specific treatability
   - Characterize most feasible sites
   - Prepare preliminary hydrology
   - Review BMP implementation
   - Present potential operation and maintenance
   - Provide rough order of magnitude opinion of probable cost

4.2.1 Obtain Additional Data and Refine Analysis

More specific site information such as upstream tributary areas, depths of existing storm drains and surrounding topography could allow for more aggressive treatment options by using larger BMP depths and incorporating surface interception.

4.2.2 Perform Detailed Analysis of Specific Priority Parcels

Specific Concept Reports (CRs) could be prepared for individual sites. CRs generally lay out specific concepts for a particular site, or Preliminary Design Reports (PDRs) could be prepared to move towards project implementation by identifying design parameters.

RB-AR35617

APPENDICES

RB-AR35618

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RB-AR35619

APPENDIX A

OPPORTUNITY PUBLIC PARCELS BY LAND USE, NOT PRIORITIZED INDEX AND LOCATOR MAPS

RB-AR35620

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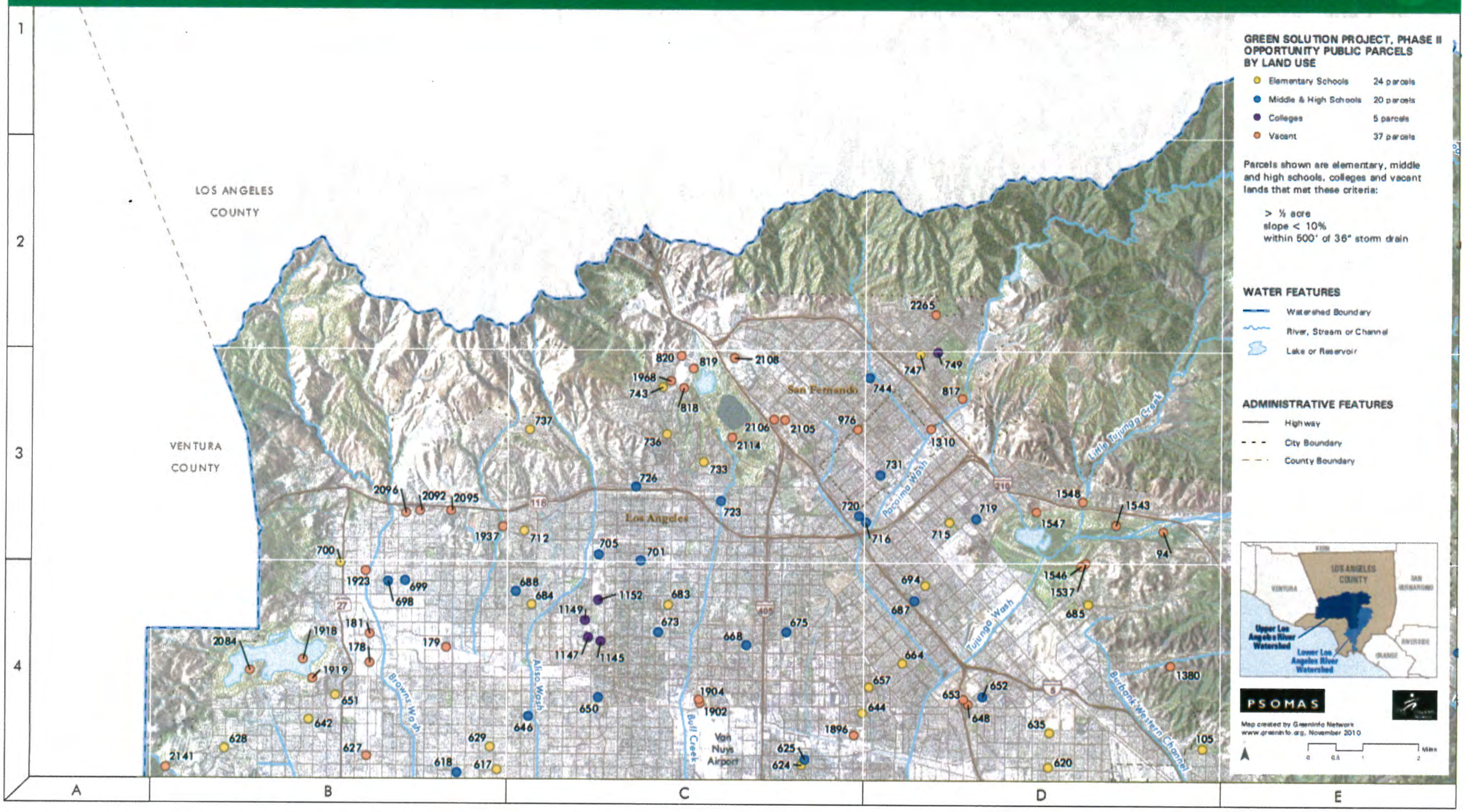
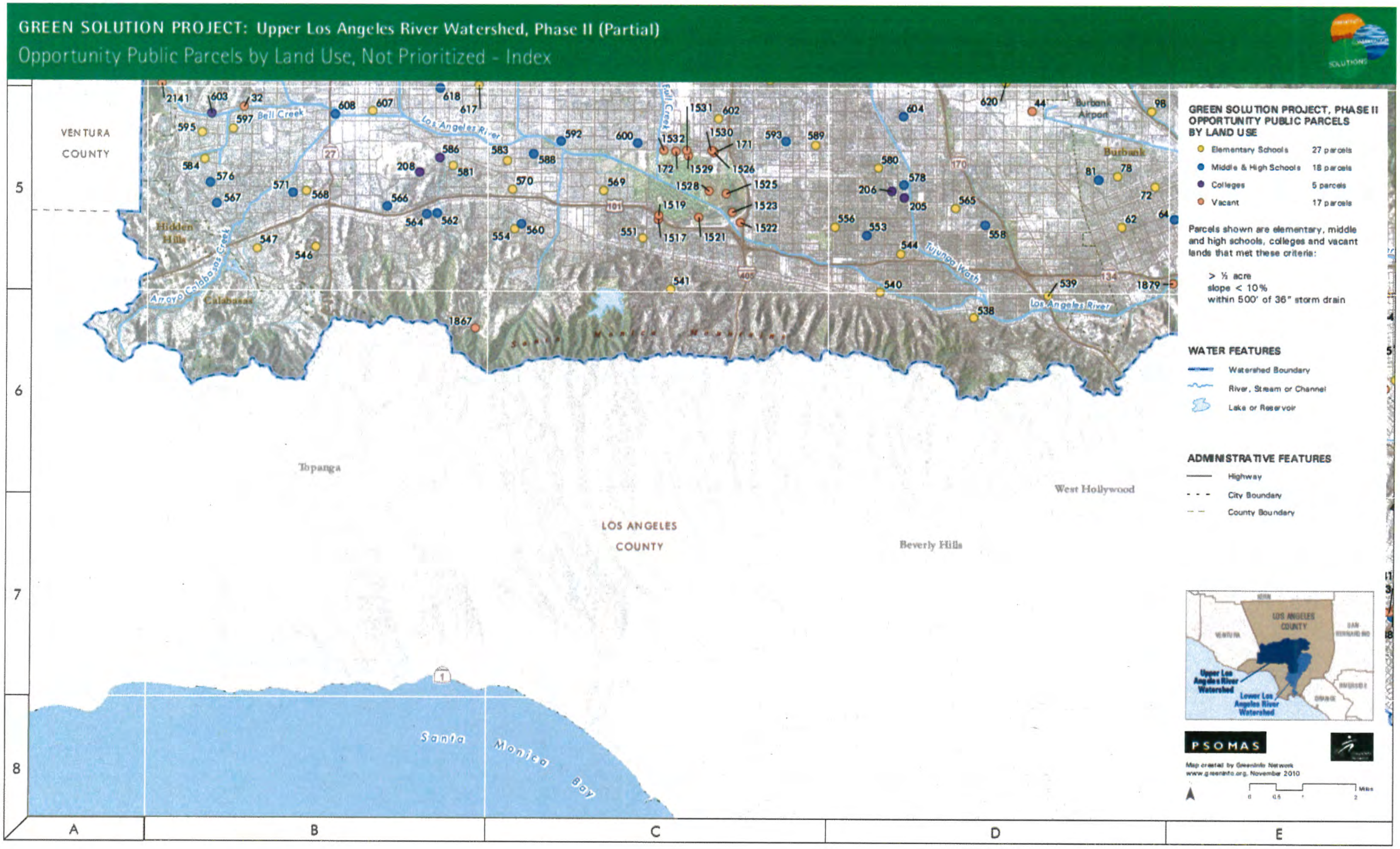
GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II (Partial)

Opportunity Public Parcels by Land Use, Not Prioritized - Index



Opportunity Public Parcels by Land Use, Not Prioritized – Index

RB-AR35621



Opportunity Public Parcels by Land Use, Not Prioritized – Index

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II (Partial)

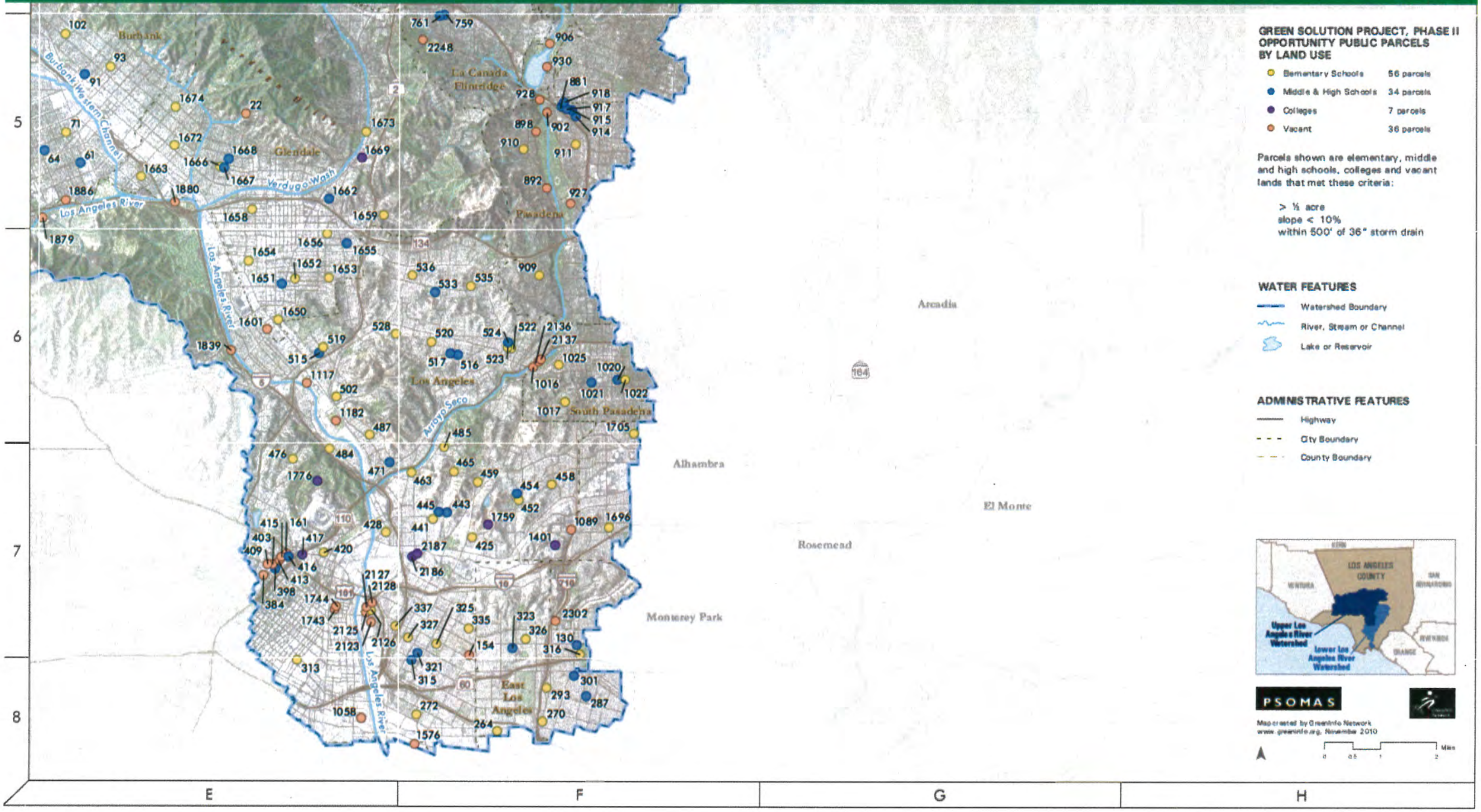
Opportunity Public Parcels by Land Use, Not Prioritized - Index

Opportunity Public Parcels by Land Use, Not Prioritized - Index

RB-AR35623

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II (Partial)

Opportunity Public Parcels by Land Use, Not Prioritized - Index



Opportunity Public Parcels by Land Use, Not Prioritized – Index

RB-AR35624

Opportunity Public Parcels by Land Use, Not Prioritized - Index, Page 1 of 5

Parcel ID	Land Use	Watershed	Owner Name	Acres	Index
22	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	1.65	E5
32	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	18.20	B5
44	Vacant	Upper Los Angeles River Watershed	BURBANK GLENDALE PASADENA AIRPORT AUTHORITY	25.01	D5
48	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	9.53	E4
61	Middle and High Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	14.42	E5
62	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	4.26	D5
64	Middle and High Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	17.39	E5
71	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	3.06	E5
72	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	6.93	D5
74	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	2.04	E4
78	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	7.03	D5
81	Middle and High Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	22.48	D5
91	Middle and High Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	16.24	E5
93	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	4.78	E5
94	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	203.65	D3
98	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	7.20	D5
102	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	7.94	E5
105	Elementary Schools	Upper Los Angeles River Watershed	BURBANK UNIFIED SCHOOL DISTRICT	6.44	D4
108	Middle and High Schools	Upper Los Angeles River Watershed	Unknown	20.71	E3
130	Middle and High Schools	Upper Los Angeles River Watershed	L A CO HOUSING AUTHORITY	3.26	F7
154	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	1.27	F7
161	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	1.31	E7
171	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	26.20	C5
172	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	13.72	C5
178	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	5.84	B4
179	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	2.40	B4
181	Vacant	Upper Los Angeles River Watershed	L A CO METROPOLITAN TRANSPORTATION AUTHORITY	15.91	B4
205	Colleges	Upper Los Angeles River Watershed	L A COMMUNITY COLLEGE DISTRICT	31.86	D5
206	Colleges	Upper Los Angeles River Watershed	L A COMMUNITY COLLEGE DISTRICT	72.67	D5
208	Colleges	Upper Los Angeles River Watershed	L A COMMUNITY COLLEGE DISTRICT	374.55	B5
264	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.53	F8
270	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.07	F8
272	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.45	F8
287	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.67	F8
293	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.52	F8
301	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	12.82	F8
313	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.70	E8
315	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	11.69	F8
316	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.07	F7
321	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	23.70	F7
323	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	12.06	F7
325	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.18	F7
326	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.30	F7
327	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.45	F7
335	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.53	F7
337	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.92	E7
384	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	1.38	E7
398	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.65	E7
403	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	1.98	E7
409	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.20	E7
413	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.39	E7
415	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.32	E7
416	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.92	E7
417	Colleges	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.53	E7
420	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.58	E7
425	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.93	F7
428	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.62	E7
441	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.07	F7
443	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	10.41	F7
445	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.73	F7
452	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.75	F7
454	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.75	F7
458	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.85	F7
459	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.18	F7
463	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.87	F7
465	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.28	F7
471	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.85	E7
476	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.63	E7
484	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.26	E7
485	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.62	F7
487	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.46	E6

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Opportunity Public Parcels by Land Use, Not Prioritized - Index, Page 2 of 5

Parcel ID	Land Use	Watershed	Owner Name	Acres	Index
502	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.33	E6
515	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	9.28	E6
516	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	9.94	F6
517	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.46	F6
519	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.30	E6
520	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.50	F6
522	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	14.46	F6
523	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	14.46	F6
524	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	14.46	F6
528	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.64	E6
533	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	24.18	F6
535	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.17	F6
536	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.31	F6
538	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.83	D6
539	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.65	D6
540	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.00	D5
541	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.92	C5
544	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.19	D5
546	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.39	B5
547	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.01	B5
551	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.23	C5
553	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	18.99	D5
554	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.95	C5
556	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.90	D5
558	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	25.37	D5
560	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	18.44	C5
562	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.88	B5
564	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	29.82	B5
565	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.40	D5
566	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	18.98	B5
567	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.96	B5
568	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.56	B5
569	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.77	C5
570	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.81	C5
571	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.72	B5
576	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	20.80	B5
578	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	32.34	D5
580	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.95	D5
581	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.43	B5
583	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.39	C5
584	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.04	B5
586	Colleges	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	20.03	B5
588	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	21.53	C5
589	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	4.13	C5
592	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	29.16	C5
593	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.88	C5
595	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.24	B5
597	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.54	B5
600	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	108.83	C5
602	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.78	C5
603	Colleges	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.20	B5
604	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.37	D5
607	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.89	B5
608	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	24.78	B5
617	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.48	B4
618	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	23.42	B5
620	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	3.72	D4
624	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	35.77	C4
625	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	35.77	C4
627	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	2.22	B4
628	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.83	B4
629	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.94	B4
635	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.86	D4
642	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.56	B4
644	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.68	C4
646	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	37.21	C4
648	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	13.37	D4
650	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.12	C4
651	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.12	B4
652	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	37.15	D4
[illegible]	Vacant	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	[illegible]	[illegible]

Opportunity Public Parcels by Land Use, Not Prioritized - Index, Page 3 of 5

Parcel ID	Land Use	Watershed	Owner Name	Acres	Index
657	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.32	D4
664	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.89	D4
668	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	35.52	C4
673	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	21.44	C4
675	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	22.78	C4
681	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.90	E4
683	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.14	C4
684	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.64	C4
685	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.41	D4
687	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	23.70	D4
688	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.99	C4
691	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.45	E4
694	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.35	D4
695	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.07	E4
698	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.52	B4
699	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	35.70	B4
700	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	5.74	B4
701	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	16.70	C3
703	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	22.63	E3
704	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.24	E3
705	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	32.85	C3
712	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.87	C3
715	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.97	D3
716	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	10.70	D3
719	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	18.96	D3
720	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	23.09	C3
723	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	27.77	C3
726	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.73	C3
731	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	19.00	D3
733	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.22	C3
736	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.67	C3
737	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	6.94	C3
743	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	7.24	C3
744	Middle and High Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	30.42	D3
747	Elementary Schools	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	8.95	D3
749	Colleges	Upper Los Angeles River Watershed	L A UNIFIED SCHOOL DISTRICT	21.56	D3
759	Middle and High Schools	Upper Los Angeles River Watershed	LA CANADA UNIFIED SCHOOL DIST	8.77	F5
761	Middle and High Schools	Upper Los Angeles River Watershed	LA CANADA UNIFIED SCHOOL DIST	4.83	F5
762	Elementary Schools	Upper Los Angeles River Watershed	LA CANADA UNIFIED SCHOOL DIST	7.18	F4
763	Elementary Schools	Upper Los Angeles River Watershed	LA CANADA UNIFIED SCHOOL DIST	8.85	F4
764	Elementary Schools	Upper Los Angeles River Watershed	LA CANADA UNIFIED SCHOOL DIST	9.37	E4
817	Vacant	Upper Los Angeles River Watershed	METROPOLITAN WATER DISTRICT	9.86	D3
818	Vacant	Upper Los Angeles River Watershed	METROPOLITAN WATER DISTRICT	188.85	C3
819	Vacant	Upper Los Angeles River Watershed	METROPOLITAN WATER DISTRICT	188.85	C3
820	Vacant	Upper Los Angeles River Watershed	METROPOLITAN WATER DISTRICT	188.85	C3
881	Middle and High Schools	Upper Los Angeles River Watershed	PASADENA AREA COMMUNITY COLLEGE DISTRICT	2.03	F5
892	Vacant	Upper Los Angeles River Watershed	PASADENA CITY	29.59	F5
898	Vacant	Upper Los Angeles River Watershed	PASADENA CITY	316.70	F5
902	Vacant	Upper Los Angeles River Watershed	PASADENA CITY	316.70	F5
906	Vacant	Upper Los Angeles River Watershed	PASADENA CITY	120.99	F5
909	Elementary Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	3.16	F6
910	Elementary Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	4.94	F5
911	Elementary Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	3.98	F5
914	Middle and High Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	18.06	F5
915	Middle and High Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	5.32	F5
917	Middle and High Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	4.76	F5
918	Middle and High Schools	Upper Los Angeles River Watershed	PASADENA UNIFIED SCHOOL DISTRICT	15.66	F5
927	Vacant	Upper Los Angeles River Watershed	PASADENA WATER DEPT	52.84	F5
928	Vacant	Upper Los Angeles River Watershed	PASADENA WATER DEPT	10.66	F5
930	Vacant	Upper Los Angeles River Watershed	PASADENA WATER DEPT	100.53	F5
976	Vacant	Upper Los Angeles River Watershed	SAN FERNANDO CITY	1.83	C3
1016	Vacant	Upper Los Angeles River Watershed	SOUTH PASADENA CITY	48.56	F6
1017	Elementary Schools	Upper Los Angeles River Watershed	SOUTH PASADENA UNIFIED SCHOOL DISTRICT	8.53	F6
1020	Middle and High Schools	Upper Los Angeles River Watershed	SOUTH PASADENA UNIFIED SCHOOL DISTRICT	4.35	F6
1021	Middle and High Schools	Upper Los Angeles River Watershed	SOUTH PASADENA UNIFIED SCHOOL DISTRICT	10.54	F6
1022	Elementary Schools	Upper Los Angeles River Watershed	SOUTH PASADENA UNIFIED SCHOOL DISTRICT	4.40	F6
1025	Elementary Schools	Upper Los Angeles River Watershed	SOUTH PASADENA UNIFIED SCHOOL DISTRICT	3.72	F6
1058	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF	19.45	E8
1089	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF	1.80	F7
1117	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF	13.44	E6
[illegible]	Colleges	Upper Los Angeles River Watershed	STATE OF CALIF	[illegible]	[illegible]

Opportunity Public Parcels by Land Use, Not Prioritized - Index, Page 4 of 5

Parcel ID	Land Use	Watershed	Owner Name	Acres	Index
1147	Colleges	Upper Los Angeles River Watershed	STATE OF CALIF	150.70	C4
1149	Colleges	Upper Los Angeles River Watershed	STATE OF CALIF	17.38	C4
1152	Colleges	Upper Los Angeles River Watershed	STATE OF CALIF	135.28	C4
1182	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF DEPT OF PARKS AND RECREATION	40.31	E6
1310	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF MTNS RECREATION AND CONSERVATION AUTHORITY	1.89	D3
1380	Vacant	Upper Los Angeles River Watershed	STATE OF CALIF SANTA MONICA MTNS CONSERVANCY	1.25	D4
1401	Colleges	Upper Los Angeles River Watershed	TRUSTEES OF THE CALIF STATE UNIVERSITY AND COLLEGES	101.87	F7
1517	Vacant	Upper Los Angeles River Watershed	U S GOVT	17.74	C5
1519	Vacant	Upper Los Angeles River Watershed	U S GOVT	10.01	C5
1521	Vacant	Upper Los Angeles River Watershed	U S GOVT	241.83	C5
1522	Vacant	Upper Los Angeles River Watershed	U S GOVT	241.83	C5
1523	Vacant	Upper Los Angeles River Watershed	U S GOVT	241.83	C5
1525	Vacant	Upper Los Angeles River Watershed	U S GOVT	339.48	C5
1526	Vacant	Upper Los Angeles River Watershed	U S GOVT	339.48	C5
1528	Vacant	Upper Los Angeles River Watershed	U S GOVT	888.63	C5
1529	Vacant	Upper Los Angeles River Watershed	U S GOVT	888.63	C5
1530	Vacant	Upper Los Angeles River Watershed	U S GOVT	2.34	C5
1531	Vacant	Upper Los Angeles River Watershed	U S GOVT	2.86	C5
1532	Vacant	Upper Los Angeles River Watershed	U S GOVT	2.05	C5
1537	Vacant	Upper Los Angeles River Watershed	U S GOVT	3.41	D4
1543	Vacant	Upper Los Angeles River Watershed	U S GOVT	114.37	D3
1546	Vacant	Upper Los Angeles River Watershed	U S GOVT	1,232.21	D4
1547	Vacant	Upper Los Angeles River Watershed	U S GOVT	1,232.21	D3
1548	Vacant	Upper Los Angeles River Watershed	U S GOVT	15.11	D3
1576	Vacant	Upper Los Angeles River Watershed	VERNON CITY REDEVELOPMENT AGENCY	8.07	F8
1601	Vacant	Upper Los Angeles River Watershed	GLENDALE CITY	7.23	E6
1640	Vacant	Upper Los Angeles River Watershed	GLENDALE CITY	1.37	E4
1650	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.64	E6
1651	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	6.83	E6
1652	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	4.26	E6
1653	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.60	E6
1654	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.81	E6
1655	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	23.75	E6
1656	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.46	E6
1658	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	5.70	E5
1659	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	7.31	E5
1662	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	9.87	E5
1663	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.98	E5
1666	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	14.36	E5
1667	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	14.36	E5
1668	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	18.52	E5
1669	Colleges	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	58.21	E5
1672	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.58	E5
1673	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	6.06	E5
1674	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	3.87	E5
1680	Elementary Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	4.09	E4
1682	Middle and High Schools	Upper Los Angeles River Watershed	GLENDALE UNIFIED SCHOOL DISTRICT	13.29	E4
1696	Elementary Schools	Upper Los Angeles River Watershed	ALHAMBRA CITY SCHOOL DISTRICT	6.28	F7
1705	Elementary Schools	Upper Los Angeles River Watershed	ALHAMBRA CITY SCHOOL DISTRICT	6.54	F6
1743	Vacant	Upper Los Angeles River Watershed	L A CITY	4.01	E7
1744	Vacant	Upper Los Angeles River Watershed	L A CITY	6.80	E7
1759	Colleges	Upper Los Angeles River Watershed	L A CITY	88.23	F7
1776	Colleges	Upper Los Angeles River Watershed	L A CITY	180.11	E7
1839	Vacant	Upper Los Angeles River Watershed	L A CITY	8.48	E6
1867	Vacant	Upper Los Angeles River Watershed	L A CITY	3.72	B6
1879	Vacant	Upper Los Angeles River Watershed	L A CITY	63.58	E5
1880	Vacant	Upper Los Angeles River Watershed	L A CITY	25.23	E5
1886	Vacant	Upper Los Angeles River Watershed	L A CITY	10.20	E5
1896	Vacant	Upper Los Angeles River Watershed	L A CITY	6.17	C4
1902	Vacant	Upper Los Angeles River Watershed	L A CITY	3.76	C4
1904	Vacant	Upper Los Angeles River Watershed	L A CITY	1.42	C4
1918	Vacant	Upper Los Angeles River Watershed	L A CITY	412.94	B4
1919	Vacant	Upper Los Angeles River Watershed	L A CITY	412.94	B4
1923	Vacant	Upper Los Angeles River Watershed	L A CITY	15.13	B4
1936	Vacant	Upper Los Angeles River Watershed	L A CITY	8.26	E3
1937	Vacant	Upper Los Angeles River Watershed	L A CITY	23.04	B3
1945	Vacant	Upper Los Angeles River Watershed	L A CITY	68.98	E3
1968	Vacant	Upper Los Angeles River Watershed	L A CITY	7.93	C3
2084	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	740.68	B4
2092	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	1.74	B3
[illegible]	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	[illegible]	[illegible]

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Opportunity Public Parcels by Land Use, Not Prioritized - Index, Page 5 of 5

Parcel ID	Land Use	Watershed	Owner Name	Acres	Index
2096	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	14.61	B3
2098	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	19.16	E3
2101	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	99.58	E3
2102	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	79.30	E3
2105	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	70.34	C3
2106	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	70.34	C3
2108	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	36.61	C3
2114	Vacant	Upper Los Angeles River Watershed	L A CITY DEPARTMENT OF WATER AND POWER	1,260.60	C3
2123	Vacant	Upper Los Angeles River Watershed	L A CITY HOUSING AUTHORITY	4.76	E7
2125	Vacant	Upper Los Angeles River Watershed	L A CITY HOUSING AUTHORITY	2.44	E7
2126	Elementary Schools	Upper Los Angeles River Watershed	L A CITY HOUSING AUTHORITY	15.04	E7
2127	Vacant	Upper Los Angeles River Watershed	L A CITY HOUSING AUTHORITY	15.04	E7
2128	Vacant	Upper Los Angeles River Watershed	L A CITY HOUSING AUTHORITY	17.42	E7
2136	Vacant	Upper Los Angeles River Watershed	L A CITY PARK	1.73	F6
2137	Vacant	Upper Los Angeles River Watershed	L A CITY PARK	1.64	F6
2141	Vacant	Upper Los Angeles River Watershed	L A CITY PARK	10.63	B4
2186	Colleges	Upper Los Angeles River Watershed	L A CO	4.15	F7
2187	Colleges	Upper Los Angeles River Watershed	L A CO	2.30	F7
2248	Vacant	Upper Los Angeles River Watershed	L A CO	26.02	F5
2265	Vacant	Upper Los Angeles River Watershed	L A CO	96.55	D2
2302	Vacant	Upper Los Angeles River Watershed	L A CO FLOOD CONTROL DISTRICT	11.27	F7

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APPENDIX B

DATA SUMMARY INDEX

RB-AR35632

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RB-AR35633

PSOMAS

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*
Data Summary Table

Parcel ID	Acres	Land Use Group	Watershed	WATER FACTORS: Distance (in ft) to storm drain ≥ 36" diam	WATER FACTORS: Distance (in ft) to storm drain with no size data	COMMUNITY FACTORS: Habitat Distance	River/Trail Distance	Youth Density (mi^2)	Senior Density (mi^2)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
22	1.29	Vacant	Upper Los Angeles River Watershed	191.5	N/A		Half Mile	504	381	$44,149	4.6	3.1	1.66	Yes
32	2.08	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile		1,359	743	$30,083	13.4	2.3	0.00	No
44	25.01	Vacant	Upper Los Angeles River Watershed	23.7	N/A	Half Mile		3,882	677	$12,021	65.4	15.9	0.00	No
48	4.55	Vacant	Upper Los Angeles River Watershed	292.4	N/A	Half Mile	Qtr Mile	944	548	$52,425	20.9	6.1	0.27	No
61	12.20	Senior and Middle Schools	Upper Los Angeles River Watershed	20.0	N/A	Half Mile	One Mile	1,604	922	$23,396	64.7	12.0	4.16	No
62	4.23	Elem Schools	Upper Los Angeles River Watershed	177.8	N/A	One Mile	Half Mile	1,582	1,046	$29,107	45.7	8.9	1.01	No
64	17.39	Senior and Middle Schools	Upper Los Angeles River Watershed	36.8	N/A	Half Mile	One Mile	1,535	982	$27,917	51.0	9.5	1.56	No
71	2.65	Elem Schools	Upper Los Angeles River Watershed	357.7	N/A	Half Mile	Half Mile	1,712	1,023	$25,957	57.4	10.9	2.33	No
72	6.64	Elem Schools	Upper Los Angeles River Watershed	342.0	N/A	Half Mile	Qtr Mile	1,616	944	$25,079	44.6	9.2	0.00	No
74	1.78	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile	Half Mile	1,068	533	$31,587	11.6	2.7	2.95	No
78	6.96	Elem Schools	Upper Los Angeles River Watershed	73.3	N/A	One Mile	Half Mile	1,806	854	$22,236	43.1	8.8	1.99	No
81	21.16	Senior and Middle Schools	Upper Los Angeles River Watershed	72.9	N/A	One Mile	Half Mile	2,216	880	$21,240	49.8	10.1	1.97	No
91	16.24	Senior and Middle Schools	Upper Los Angeles River Watershed	61.5	N/A	Half Mile	One Mile	2,071	1,202	$25,732	67.1	11.6	1.45	No
93	4.76	Elem Schools	Upper Los Angeles River Watershed	404.3	N/A	Half Mile	One Mile	2,628	1,556	$26,818	67.5	10.6	0.61	No
94	192.43	Vacant	Upper Los Angeles River Watershed	N/A	0.0	Half Mile	Qtr Mile	289	185	$26,502	29.0	4.9	39.74	Yes
98	7.10	Elem Schools	Upper Los Angeles River Watershed	20.5	N/A	One Mile		1,508	731	$24,213	49.0	6.3	0.24	No
102	7.94	Elem Schools	Upper Los Angeles River Watershed	38.4	N/A	Half Mile		1,477	832	$30,403	50.4	7.9	3.55	No
105	6.38	Elem Schools	Upper Los Angeles River Watershed	24.9	N/A	Half Mile	One Mile	860	544	$29,639	28.0	4.0	6.32	Yes
108	19.88	Senior and Middle Schools	Upper Los Angeles River Watershed	41.0	N/A	Half Mile	Half Mile	1,214	530	$21,652	35.4	6.1	11.90	No
130	3.00	Senior and Middle Schools	Upper Los Angeles River Watershed	328.9	N/A	Half Mile		3,127	1,286	$12,056	64.2	27.2	4.90	No
154	1.27	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	6,552	1,608	$8,700	64.6	24.9	0.00	No
161	1.31	Vacant	Upper Los Angeles River Watershed	498.6	N/A	Half Mile		4,534	1,754	$11,118	85.6	33.4	0.13	No
171	6.03	Vacant	Upper Los Angeles River Watershed	88.6	N/A	Half Mile	Qtr Mile	2,183	593	$23,518	70.6	12.3	15.65	No
172	10.96	Vacant	Upper Los Angeles River Watershed	137.3	N/A	Half Mile	Qtr Mile	1,597	479	$25,022	61.1	10.5	37.24	No
178	5.83	Vacant	Upper Los Angeles River Watershed	331.7	N/A	One Mile	One Mile	2,026	597	$25,068	62.2	11.5	0.17	No
179	1.10	Vacant	Upper Los Angeles River Watershed	91.9	N/A			827	395	$20,079	30.6	4.8	0.00	No
181	5.83	Vacant	Upper Los Angeles River Watershed	315.5	N/A	Half Mile	One Mile	1,625	532	$26,305	59.9	8.2	0.00	No
205	31.15	Colleges	Upper Los Angeles River Watershed	N/A	81.8	One Mile	Qtr Mile	2,370	1,403	$25,495	58.9	9.1	0.48	No
206	72.67	Colleges	Upper Los Angeles River Watershed	47.8	N/A	One Mile	Qtr Mile	2,620	1,297	$24,672	57.8	9.3	0.44	No
208	168.75	Colleges	Upper Los Angeles River Watershed	0.0	N/A		Qtr Mile	1,292	634	$27,439	45.1	8.7	0.00	No
264	5.53	Elem Schools	Upper Los Angeles River Watershed	10.2	N/A	Half Mile		3,867	681	$8,850	67.9	21.4	0.62	No
270	5.07	Elem Schools	Upper Los Angeles River Watershed	217.7	N/A	Half Mile		5,178	1,067	$8,781	67.5	22.3	0.46	No
272	5.12	Elem Schools	Upper Los Angeles River Watershed	188.0	N/A	Half Mile	Qtr Mile	3,147	693	$10,458	70.1	25.6	1.17	No
287	19.67	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		4,855	1,311	$10,320	63.8	22.3	0.74	No
293	5.37	Elem Schools	Upper Los Angeles River Watershed	161.5	N/A	Half Mile		5,707	1,248	$9,043	68.8	23.5	0.00	No
301	12.82	Senior and Middle Schools	Upper Los Angeles River Watershed	251.3	N/A	Half Mile		4,607	1,333	$11,078	63.3	21.9	2.72	No
313	2.70	Elem Schools	Upper Los Angeles River Watershed	43.3	N/A	Half Mile		525	389	$14,090	96.9	78.1	0.06	No
315	11.69	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	5,333	1,325	$9,476	76.2	31.9	1.77	No
316	3.04	Elem Schools	Upper Los Angeles River Watershed	284.4	N/A	Half Mile		3,686	1,358	$10,468	65.3	27.1	4.31	No
321	23.70	Senior and Middle Schools	Upper Los Angeles River Watershed	150.0	N/A	Half Mile	Qtr Mile	6,002	1,460	$8,911	75.3	31.4	1.38	No
323	12.06	Senior and Middle Schools	Upper Los Angeles River Watershed	35.9	N/A	Half Mile		5,694	1,274	$9,769	63.3	21.1	0.49	No
325	4.11	Elem Schools	Upper Los Angeles River Watershed	37.0	N/A	Half Mile	Half Mile	7,504	2,026	$8,107	75.6	33.2	0.26	No
326	5.23	Elem Schools	Upper Los Angeles River Watershed	468.5	N/A	Half Mile		5,073	1,225	$10,372	62.9	21.8	1.19	No
327	2.45	Elem Schools	Upper Los Angeles River Watershed	46.1	N/A	Half Mile	Half Mile	6,971	1,845	$8,319	83.5	38.5	1.09	No
335	5.37	Elem Schools	Upper Los Angeles River Watershed	111.2	N/A	Half Mile		7,471	1,678	$8,697	70.5	28.1	0.09	No
337	3.92	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Half Mile	5,865	1,435	$8,586	86.4	39.5	1.39	No
384	1.34	Vacant	Upper Los Angeles River Watershed	322.4	N/A	Half Mile		6,617	1,529	$11,578	93.6	46.3	0.07	No
398	3.27	Senior and Middle Schools	Upper Los Angeles River Watershed	58.0	N/A	Half Mile		4,293	1,746	$11,663	90.2	39.7	0.37	No
403	1.76	Vacant	Upper Los Angeles River Watershed	450.2	N/A	Half Mile		5,047	1,296	$11,610	89.1	36.1	0.00	No
409	2.20	Vacant	Upper Los Angeles River Watershed	294.5	N/A	Half Mile		5,972	1,246	$11,806	89.9	37.0	0.11	No
413	3.39	Vacant	Upper Los Angeles River Watershed	86.8	N/A	Half Mile		4,498	1,619	$11,941	86.9	33.8	0.28	No
415	3.32	Vacant	Upper Los Angeles River Watershed	417.6	N/A	Half Mile		4,609	1,641	$11,903	85.9	32.7	0.20	No
416	2.92	Senior and Middle Schools	Upper Los Angeles River Watershed	374.8	N/A	Half Mile		4,133	1,977	$11,526	86.1	34.3	0.63	No
417	2.27	Colleges	Upper Los Angeles River Watershed	483.3	N/A	Half Mile		3,441	2,280	$10,299	88.1	41.9	0.91	No
420	2.58	Elem Schools	Upper Los Angeles River Watershed	87.1	N/A	Half Mile		2,409	2,201	$13,573	89.4	47.0	1.60	Yes
425	4.73	Elem Schools	Upper Los Angeles River Watershed	21.7	N/A	Half Mile	One Mile	2,321	818	$11,648	55.7	18.6	5.09	No
428	2.91	Elem Schools	Upper Los Angeles River Watershed	32.4	N/A	Half Mile	One Mile	3,284	865	$15,514	82.9	31.4	1.74	No

COMMUNITY CONSERVATION SOLUTIONS

RB-AR35634

COMMUNITY CONSERVATION SOLUTIONS

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*
Data Summary Table

				WATER FACTORS		COMMUNITY FACTORS								
Parcel ID	Acres	Land Use Group	Watershed	Distance (in ft) to storm drain ≥ 36" diam.	Distance (in ft) to storm drain with no size data	Habitat Distance	River/Trail Distance	Youth Density (mi²)	Senior Density (mi²)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
441	4.07	Elem Schools	Upper Los Angeles River Watershed	250.9	N/A	Half Mile	Half Mile	5,257	1,813	$8,788	75.4	27.2	2.40	No
443	9.17	Senior and Middle Schools	Upper Los Angeles River Watershed	27.8	N/A	Half Mile	Half Mile	3,491	1,055	$10,369	68.0	25.8	1.52	No
445	7.28	Senior and Middle Schools	Upper Los Angeles River Watershed	30.3	N/A	Half Mile	Qtr Mile	3,528	1,045	$10,201	69.8	26.3	1.03	No
452	4.08	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		3,610	1,043	$12,615	50.4	17.0	1.82	No
454	17.76	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	3,002	970	$12,862	51.4	16.0	1.82	No
458	3.67	Elem Schools	Upper Los Angeles River Watershed	94.0	N/A	Half Mile	One Mile	3,172	1,164	$28,223	47.3	11.3	0.00	No
459	4.18	Elem Schools	Upper Los Angeles River Watershed	44.0	N/A	Half Mile	One Mile	2,392	777	$12,662	50.5	21.2	3.86	No
463	2.83	Elem Schools	Upper Los Angeles River Watershed	316.4	N/A	Half Mile	Qtr Mile	4,115	940	$10,221	67.6	24.8	0.72	Yes
465	3.06	Elem Schools	Upper Los Angeles River Watershed	26.0	N/A	Half Mile	Qtr Mile	2,361	721	$13,298	53.5	21.1	4.47	No
471	8.82	Senior and Middle Schools	Upper Los Angeles River Watershed	351.3	N/A	Half Mile	Qtr Mile	3,106	873	$11,852	62.2	23.5	2.88	Yes
476	2.59	Elem Schools	Upper Los Angeles River Watershed	22.8	N/A	Half Mile	One Mile	1,999	549	$22,816	59.6	15.4	6.66	No
484	3.26	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	1,547	627	$15,069	51.3	12.2	10.60	Yes
485	2.58	Elem Schools	Upper Los Angeles River Watershed	37.1	N/A	Half Mile	Qtr Mile	2,448	670	$16,529	60.6	20.4	7.86	Yes
487	3.46	Elem Schools	Upper Los Angeles River Watershed	61.0	N/A	Half Mile	Half Mile	3,562	1,022	$13,364	51.7	19.7	1.68	No
502	3.30	Elem Schools	Upper Los Angeles River Watershed	319.7	N/A	Half Mile	Half Mile	2,775	728	$13,234	54.9	13.0	3.12	No
515	9.28	Senior and Middle Schools	Upper Los Angeles River Watershed	34.3	N/A	Half Mile	One Mile	2,747	811	$16,632	59.6	14.1	1.90	No
516	9.93	Senior and Middle Schools	Upper Los Angeles River Watershed	192.4	N/A	Half Mile	One Mile	4,566	1,095	$14,941	59.7	16.9	0.00	No
517	8.15	Senior and Middle Schools	Upper Los Angeles River Watershed	365.1	N/A	Half Mile	One Mile	4,586	1,117	$14,974	59.6	16.9	0.00	No
519	3.30	Elem Schools	Upper Los Angeles River Watershed	88.0	N/A	Half Mile	One Mile	3,320	552	$15,406	70.5	20.9	1.70	No
520	3.50	Elem Schools	Upper Los Angeles River Watershed	241.1	N/A	Half Mile		4,099	1,223	$13,874	47.2	11.9	0.17	No
522	2.93	Elem Schools	Upper Los Angeles River Watershed	23.9	N/A	Half Mile	Half Mile	4,077	1,113	$16,521	58.8	13.9	8.41	Yes
523	2.82	Elem Schools	Upper Los Angeles River Watershed	21.2	N/A	Half Mile	Half Mile	4,245	1,128	$15,573	58.8	14.4	8.41	Yes
524	8.71	Senior and Middle Schools	Upper Los Angeles River Watershed	250.4	N/A	Half Mile	Half Mile	3,390	1,474	$24,458	55.4	12.7	8.41	Yes
528	3.08	Elem Schools	Upper Los Angeles River Watershed	349.3	N/A	Half Mile		2,958	1,120	$18,427	54.6	13.5	0.00	No
533	19.43	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		2,597	1,100	$20,473	47.9	10.4	0.49	No
535	2.13	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	2,331	1,029	$23,142	39.9	11.8	0.13	No
536	5.22	Elem Schools	Upper Los Angeles River Watershed	28.9	N/A	Half Mile		1,851	819	$24,028	46.1	8.3	0.66	No
538	5.44	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A		Qtr Mile	785	786	$59,502	50.8	4.1	0.87	No
539	6.37	Elem Schools	Upper Los Angeles River Watershed	383.6	N/A	Half Mile	One Mile	1,017	950	$42,737	71.0	5.8	1.37	No
540	4.91	Elem Schools	Upper Los Angeles River Watershed	38.8	N/A	Half Mile		1,218	579	$49,107	62.0	5.4	0.00	No
541	5.79	Elem Schools	Upper Los Angeles River Watershed	141.5	N/A			569	1,030	$65,048	10.8	2.1	0.00	Yes
544	6.15	Elem Schools	Upper Los Angeles River Watershed	32.5	N/A	Half Mile	One Mile	1,529	1,268	$36,599	56.5	5.8	0.00	No
546	3.39	Elem Schools	Upper Los Angeles River Watershed	29.1	N/A		Half Mile	919	545	$39,229	19.5	3.4	0.04	Yes
547	7.01	Elem Schools	Upper Los Angeles River Watershed	1.8	N/A		Half Mile	895	589	$46,406	17.9	2.0	0.00	Yes
551	4.23	Elem Schools	Upper Los Angeles River Watershed	92.0	N/A		One Mile	652	880	$53,333	29.5	2.8	10.70	No
553	18.99	Senior and Middle Schools	Upper Los Angeles River Watershed	31.2	N/A	Half Mile	One Mile	1,607	1,266	$32,635	58.6	7.0	0.00	No
554	6.95	Elem Schools	Upper Los Angeles River Watershed	409.4	N/A			1,076	797	$46,810	46.8	7.6	0.00	Yes
556	6.88	Elem Schools	Upper Los Angeles River Watershed	28.8	N/A	Half Mile	One Mile	1,788	1,203	$29,521	61.4	8.3	8.13	No
558	21.60	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	37.9	Half Mile		2,652	1,241	$25,468	75.3	11.7	4.63	No
560	18.29	Senior and Middle Schools	Upper Los Angeles River Watershed	376.1	N/A		One Mile	1,359	1,020	$43,739	52.9	8.6	0.00	Yes
562	2.88	Senior and Middle Schools	Upper Los Angeles River Watershed	218.0	N/A			773	520	$42,774	41.0	5.8	0.00	Yes
564	29.82	Senior and Middle Schools	Upper Los Angeles River Watershed	34.3	N/A		One Mile	656	519	$44,940	37.3	4.2	0.57	Yes
565	4.29	Elem Schools	Upper Los Angeles River Watershed	383.6	N/A	Half Mile	One Mile	2,946	2,011	$22,838	76.7	11.3	0.00	No
566	18.98	Senior and Middle Schools	Upper Los Angeles River Watershed	117.4	N/A		One Mile	719	622	$35,477	53.3	5.4	0.45	No
567	27.96	Senior and Middle Schools	Upper Los Angeles River Watershed	40.3	N/A		One Mile	920	585	$48,997	11.8	1.8	0.00	No
568	6.56	Elem Schools	Upper Los Angeles River Watershed	57.4	N/A			1,003	878	$34,369	52.0	6.8	2.21	No
569	5.72	Elem Schools	Upper Los Angeles River Watershed	25.0	N/A		Half Mile	1,352	1,440	$32,311	53.3	9.0	7.31	No
570	4.81	Elem Schools	Upper Los Angeles River Watershed	49.5	N/A		Half Mile	1,947	1,086	$33,165	56.4	8.0	0.74	No
571	19.72	Senior and Middle Schools	Upper Los Angeles River Watershed	28.3	N/A			1,035	816	$34,671	45.6	5.9	1.09	No
576	20.72	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	52.2			1,069	661	$42,857	10.8	2.1	0.00	No
578	31.48	Senior and Middle Schools	Upper Los Angeles River Watershed	39.7	N/A		Half Mile	2,591	1,333	$23,024	58.7	9.7	0.51	No
580	7.95	Elem Schools	Upper Los Angeles River Watershed	16.0	N/A		Half Mile	3,280	1,169	$19,782	61.1	11.0	0.58	No
581	7.40	Elem Schools	Upper Los Angeles River Watershed	420.0	N/A		Qtr Mile	1,232	688	$30,478	30.5	6.7	0.00	No
583	8.39	Elem Schools	Upper Los Angeles River Watershed	366.3	N/A		Qtr Mile	2,280	1,221	$26,782	52.1	9.7	0.04	No
584	7.04	Elem Schools	Upper Los Angeles River Watershed	235.6	N/A		One Mile	1,210	740	$36,345	10.9	2.5	0.00	No
586	20.01	Colleges	Upper Los Angeles River Watershed	N/A	8.4		Qtr Mile	1,360	673	$28,192	35.0	8.1	0.00	No

RB-AR35635

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*
Data Summary Table

				WATER FACTORS		COMMUNITY FACTORS								
Parcel ID	Acres	Land Use Group	Watershed	Distance (in ft) to storm drain ≥ 36" diam.	Distance (in ft) to storm drain with no size data	Habitat Distance	River/Trail Distance	Youth Density (mi²)	Senior Density (mi²)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
589	4.13	Elem Schools	Upper Los Angeles River Watershed	220.9	N/A		Half Mile	6,047	790	$11,802	83.3	19.5	0.24	No
592	28.80	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	0.0		Half Mile	2,543	1,190	$19,759	53.9	10.7	3.09	No
593	27.68	Senior and Middle Schools	Upper Los Angeles River Watershed	45.2	N/A		Half Mile	4,206	1,048	$15,895	74.9	16.8	0.07	No
595	7.24	Elem Schools	Upper Los Angeles River Watershed	292.5	N/A		One Mile	1,236	700	$34,337	10.9	2.4	0.26	No
597	7.54	Elem Schools	Upper Los Angeles River Watershed	425.7	N/A			1,320	746	$31,167	13.2	2.8	0.07	No
600	88.02	Senior and Middle Schools	Upper Los Angeles River Watershed	79.5	N/A		Qtr Mile	1,395	612	$24,333	41.8	6.8	37.93	No
602	5.78	Elem Schools	Upper Los Angeles River Watershed	292.7	N/A	One Mile	One Mile	2,962	750	$17,894	73.0	13.3	0.00	No
603	7.15	Colleges	Upper Los Angeles River Watershed	35.1	N/A		One Mile	1,287	658	$33,412	11.7	2.5	0.28	No
604	19.37	Senior and Middle Schools	Upper Los Angeles River Watershed	97.9	N/A			3,531	1,029	$14,753	62.1	12.7	0.00	No
607	6.61	Elem Schools	Upper Los Angeles River Watershed	353.2	N/A		Half Mile	2,930	695	$18,169	67.8	13.9	0.35	No
608	23.22	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	One Mile	Half Mile	2,336	926	$22,100	63.5	12.2	0.00	No
617	6.29	Elem Schools	Upper Los Angeles River Watershed	50.1	N/A			2,728	1,013	$18,057	41.1	7.5	0.00	No
618	23.42	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	9.3		One Mile	3,075	1,015	$18,713	44.3	8.6	0.62	No
620	3.72	Elem Schools	Upper Los Angeles River Watershed	25.2	N/A	Half Mile		5,078	891	$10,777	62.5	15.0	0.00	No
624	8.02	Elem Schools	Upper Los Angeles River Watershed	18.7	N/A	One Mile		4,375	974	$13,366	74.8	17.4	0.00	No
625	22.39	Senior and Middle Schools	Upper Los Angeles River Watershed	396.0	N/A	One Mile		4,574	934	$13,087	75.2	18.0	0.00	No
627	2.22	Vacant	Upper Los Angeles River Watershed	30.5	N/A			4,622	819	$14,187	74.1	15.7	0.00	No
628	7.78	Elem Schools	Upper Los Angeles River Watershed	334.5	N/A	One Mile	One Mile	995	446	$38,449	8.3	1.8	4.72	No
629	6.94	Elem Schools	Upper Los Angeles River Watershed	255.0	N/A			2,872	939	$18,636	43.9	8.2	0.00	No
635	5.86	Elem Schools	Upper Los Angeles River Watershed	23.0	N/A	Half Mile		3,756	670	$11,977	54.5	13.8	0.32	No
642	6.56	Elem Schools	Upper Los Angeles River Watershed	37.5	N/A	Half Mile	One Mile	1,895	816	$27,791	39.4	7.7	0.89	No
644	5.68	Elem Schools	Upper Los Angeles River Watershed	273.7	N/A	Half Mile		5,201	988	$13,311	62.6	16.6	0.45	No
646	37.21	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	6.3			2,705	796	$17,870	50.5	9.5	0.00	No
648	2.09	Vacant	Upper Los Angeles River Watershed	0.0	N/A			1,483	564	$14,517	27.5	6.8	2.30	No
650	27.12	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	31.9			2,237	833	$21,982	49.0	8.6	0.00	No
651	7.12	Elem Schools	Upper Los Angeles River Watershed	350.0	N/A		Half Mile	2,220	797	$26,560	54.4	10.9	3.82	No
652	37.15	Senior and Middle Schools	Upper Los Angeles River Watershed	20.5	N/A			2,198	614	$14,061	33.1	8.2	2.25	No
653	5.71	Vacant	Upper Los Angeles River Watershed	451.2	N/A			2,005	678	$14,721	25.9	6.8	2.70	No
657	8.30	Elem Schools	Upper Los Angeles River Watershed	24.9	N/A	Half Mile		5,480	1,130	$13,455	57.2	16.5	0.43	No
664	8.89	Elem Schools	Upper Los Angeles River Watershed	218.4	N/A	One Mile		3,526	960	$14,420	31.6	10.2	1.14	No
668	35.52	Senior and Middle Schools	Upper Los Angeles River Watershed	83.1	N/A	Half Mile		3,189	796	$20,515	48.5	14.3	0.64	No
673	21.44	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	243.9			1,104	750	$33,118	28.1	4.6	2.01	No
675	21.35	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	16.8	Half Mile		4,980	945	$16,815	60.0	17.4	0.00	No
681	5.90	Elem Schools	Upper Los Angeles River Watershed	167.1	N/A		One Mile	1,117	466	$23,900	38.1	7.3	0.53	No
683	7.14	Elem Schools	Upper Los Angeles River Watershed	218.5	N/A			1,375	902	$30,587	30.8	5.6	0.00	No
684	7.37	Elem Schools	Upper Los Angeles River Watershed	7.1	N/A		One Mile	1,037	756	$33,246	41.3	5.6	0.00	No
685	5.37	Elem Schools	Upper Los Angeles River Watershed	40.0	N/A	One Mile	One Mile	214	121	$27,231	25.9	4.9	14.24	Yes
687	23.67	Senior and Middle Schools	Upper Los Angeles River Watershed	48.6	N/A			3,952	815	$11,411	33.7	9.9	0.00	No
688	19.99	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A		One Mile	957	712	$36,096	30.0	4.2	0.00	No
691	6.22	Elem Schools	Upper Los Angeles River Watershed	55.8	N/A		One Mile	1,535	519	$23,219	52.5	8.7	0.21	No
694	4.16	Elem Schools	Upper Los Angeles River Watershed	413.4	N/A			4,709	922	$9,686	37.7	10.4	0.00	No
695	4.94	Elem Schools	Upper Los Angeles River Watershed	26.9	N/A		Qtr Mile	1,872	771	$22,257	39.0	6.8	0.18	No
698	19.52	Senior and Middle Schools	Upper Los Angeles River Watershed	344.5	N/A	Half Mile		1,128	574	$27,654	40.3	4.4	0.00	No
699	35.70	Senior and Middle Schools	Upper Los Angeles River Watershed	28.2	N/A	Half Mile		1,106	580	$27,814	37.5	4.0	0.93	No
700	5.74	Elem Schools	Upper Los Angeles River Watershed	40.7	N/A	Half Mile		924	476	$31,833	39.8	4.6	4.50	No
701	16.70	Senior and Middle Schools	Upper Los Angeles River Watershed	14.0	N/A			1,544	821	$25,871	45.8	6.4	0.00	No
703	22.63	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	0.0	One Mile	One Mile	1,719	600	$22,169	46.9	7.2	0.12	No
704	5.96	Elem Schools	Upper Los Angeles River Watershed	30.0	N/A	Half Mile	One Mile	1,156	575	$22,910	35.4	6.5	2.08	No
705	32.85	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	24.3			1,310	752	$27,064	43.2	5.5	2.09	No
712	6.87	Elem Schools	Upper Los Angeles River Watershed	24.0	N/A		Half Mile	952	636	$38,220	7.9	2.0	8.10	No
715	6.95	Elem Schools	Upper Los Angeles River Watershed	67.9	N/A	Half Mile	One Mile	4,078	667	$9,987	43.3	13.3	0.52	No
716	10.22	Senior and Middle Schools	Upper Los Angeles River Watershed	31.4	N/A	Half Mile		2,965	713	$13,553	36.6	10.6	3.90	No
719	16.31	Senior and Middle Schools	Upper Los Angeles River Watershed	52.4	N/A	Half Mile	Half Mile	3,558	550	$10,019	44.7	13.0	7.19	Yes
720	23.09	Senior and Middle Schools	Upper Los Angeles River Watershed	19.6	N/A	Half Mile		2,856	720	$13,817	38.4	11.3	3.47	No
723	27.58	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		1,272	713	$25,432	22.7	4.6	0.48	No
726	6.73	Senior and Middle Schools	Upper Los Angeles River Watershed	209.6	N/A			1,038	560	$30,805	18.4	2.7	0.00	Yes
731	19.00	Senior and Middle Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		3,291	671	$12,417	41.1	11.3	1.98	No

PSOMAS

COMMUNITY CONSERVATION SOLUTIONS

RB-AR35636

COMMUNITY CONSERVATION SOLUTIONS

Data Summary Table

				WATER FACTORS		COMMUNITY FACTORS								
Parcel ID	Acres	Land Use Group	Watershed	Distance (in ft) to storm drain ≥ 36" diam.	Distance (in ft) to storm drain with no size data	Habitat Distance	River/Trail Distance	Youth Density (mi^2)	Senior Density (mi^2)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
733	7.22	Elem Schools	Upper Los Angeles River Watershed	209.6	N/A	Half Mile		816	484	$31,269	11.9	2.4	0.00	No
736	7.58	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		747	440	$35,317	8.4	1.8	0.00	No
737	6.54	Elem Schools	Upper Los Angeles River Watershed	285.7	N/A			607	260	$40,701	7.9	0.9	12.05	Yes
743	7.24	Elem Schools	Upper Los Angeles River Watershed	437.1	N/A	One Mile	One Mile	400	223	$36,748	8.7	1.2	19.83	Yes
744	30.42	Senior and Middle Schools	Upper Los Angeles River Watershed	39.7	N/A	Half Mile		3,211	656	$14,887	34.3	8.7	1.35	No
747	8.95	Elem Schools	Upper Los Angeles River Watershed	26.9	N/A	One Mile	One Mile	2,413	531	$17,042	34.8	7.5	0.00	No
749	21.37	Colleges	Upper Los Angeles River Watershed	37.1	N/A	Half Mile	One Mile	1,741	418	$17,752	29.2	5.9	0.23	Yes
759	7.28	Senior and Middle Schools	Upper Los Angeles River Watershed	293.6	N/A	Half Mile	One Mile	824	378	$53,314	17.3	4.0	11.34	No
761	2.67	Senior and Middle Schools	Upper Los Angeles River Watershed	0.2	N/A	Half Mile	One Mile	847	330	$51,589	11.5	3.9	17.18	No
762	5.08	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Half Mile	856	404	$50,951	20.7	4.6	5.90	No
763	8.68	Elem Schools	Upper Los Angeles River Watershed	17.8	N/A	Half Mile	One Mile	717	326	$46,960	8.7	3.0	0.11	No
764	7.52	Elem Schools	Upper Los Angeles River Watershed	455.0	N/A	Half Mile	Qtr Mile	942	496	$47,593	25.9	6.3	0.51	No
817	4.59	Vacant	Upper Los Angeles River Watershed	262.4	N/A	One Mile	Half Mile	1,080	374	$16,870	16.8	5.6	0.00	Yes
818	11.22	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	380	206	$35,549	11.6	1.7	34.54	No
819	10.84	Vacant	Upper Los Angeles River Watershed	235.7	N/A	Half Mile	Half Mile	356	123	$31,220	17.9	2.4	34.54	Yes
820	17.40	Vacant	Upper Los Angeles River Watershed	62.2	N/A	Half Mile	Qtr Mile	386	156	$32,278	14.5	1.8	34.54	Yes
881	2.03	Senior and Middle Schools	Upper Los Angeles River Watershed	15.0	N/A	Half Mile	Qtr Mile	3,102	553	$39,247	49.8	14.5	3.78	Yes
892	12.17	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	626	358	$60,846	28.9	8.5	129.10	Yes
898	1.02	Vacant	Upper Los Angeles River Watershed	89.0	N/A	Half Mile	Qtr Mile	326	370	$59,809	10.7	2.7	194.20	Yes
902	3.97	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	1,748	452	$60,775	25.1	4.8	194.20	Yes
906	34.90	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	1,008	373	$33,223	20.9	6.2	40.46	Yes
909	3.00	Elem Schools	Upper Los Angeles River Watershed	21.6	N/A	Half Mile	Half Mile	562	644	$75,376	8.5	1.5	17.62	No
910	4.91	Elem Schools	Upper Los Angeles River Watershed	18.8	N/A	Half Mile	Half Mile	250	258	$76,106	7.1	1.5	117.20	Yes
911	3.98	Elem Schools	Upper Los Angeles River Watershed	14.9	N/A	Half Mile	Qtr Mile	1,895	501	$23,087	40.4	12.1	18.84	Yes
914	18.06	Senior and Middle Schools	Upper Los Angeles River Watershed	28.0	N/A	Half Mile	Half Mile	2,196	666	$26,046	41.9	12.6	6.49	Yes
915	5.31	Senior and Middle Schools	Upper Los Angeles River Watershed	192.1	N/A	Half Mile	Half Mile	1,996	625	$26,814	38.4	11.6	7.71	Yes
917	4.76	Senior and Middle Schools	Upper Los Angeles River Watershed	42.1	N/A	Half Mile	Qtr Mile	1,488	653	$24,786	28.4	9.8	13.24	Yes
918	7.57	Senior and Middle Schools	Upper Los Angeles River Watershed	8.0	N/A	Half Mile	Qtr Mile	1,733	560	$29,434	34.3	10.8	10.93	Yes
927	1.85	Vacant	Upper Los Angeles River Watershed	165.2	N/A	Half Mile	Qtr Mile	674	430	$52,084	26.8	9.3	56.85	Yes
928	5.45	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	959	420	$41,935	24.2	8.0	40.73	Yes
930	28.87	Vacant	Upper Los Angeles River Watershed	8.7	N/A	Half Mile	Qtr Mile	1,061	416	$35,755	20.8	6.2	33.15	Yes
976	1.79	Vacant	Upper Los Angeles River Watershed	162.9	N/A	Half Mile		3,835	662	$13,007	35.6	10.7	0.12	No
1016	3.86	Vacant	Upper Los Angeles River Watershed	129.5	N/A	Half Mile	Qtr Mile	2,484	844	$26,703	60.0	8.8	3.40	Yes
1017	5.76	Elem Schools	Upper Los Angeles River Watershed	292.1	N/A	Half Mile	One Mile	2,232	859	$26,582	54.1	7.3	0.73	No
1020	4.35	Senior and Middle Schools	Upper Los Angeles River Watershed	290.1	N/A	Half Mile		1,798	797	$32,331	57.3	5.3	1.00	No
1021	10.37	Senior and Middle Schools	Upper Los Angeles River Watershed	5.3	N/A	Half Mile	One Mile	1,967	872	$31,082	58.1	5.7	0.63	No
1022	4.35	Elem Schools	Upper Los Angeles River Watershed	21.6	N/A	Half Mile		1,853	783	$33,773	53.8	4.7	0.90	No
1025	3.58	Elem Schools	Upper Los Angeles River Watershed	28.6	N/A	Half Mile	Qtr Mile	1,833	934	$30,836	53.8	5.6	5.21	Yes
1058	15.72	Vacant	Upper Los Angeles River Watershed	5.7	N/A	Half Mile	One Mile	1,057	199	$15,370	83.6	29.4	0.00	No
1089	1.46	Vacant	Upper Los Angeles River Watershed	312.8	N/A	Half Mile		1,639	920	$16,273	37.0	9.6	0.00	No
1117	4.82	Vacant	Upper Los Angeles River Watershed	19.0	N/A	Half Mile	Qtr Mile	2,699	645	$11,066	61.6	14.4	6.63	No
1145	8.67	Colleges	Upper Los Angeles River Watershed	497.7	N/A			1,165	664	$27,974	57.0	7.1	0.00	No
1147	134.64	Colleges	Upper Los Angeles River Watershed	0.0	N/A			1,295	742	$27,210	53.6	6.9	0.00	No
1149	17.38	Colleges	Upper Los Angeles River Watershed	22.5	N/A			1,119	727	$26,877	54.2	6.3	0.19	No
1152	110.47	Colleges	Upper Los Angeles River Watershed	0.0	N/A			1,188	722	$27,949	50.5	6.2	2.37	No
1182	40.26	Vacant	Upper Los Angeles River Watershed	18.4	N/A	Half Mile	Qtr Mile	2,376	679	$15,915	52.2	14.3	3.40	No
1310	1.89	Vacant	Upper Los Angeles River Watershed	12.0	N/A	Half Mile		2,666	442	$12,583	35.5	7.0	0.39	No
1380	1.01	Vacant	Upper Los Angeles River Watershed	18.1	N/A	One Mile	Half Mile	163	112	$24,733	21.5	3.0	9.02	Yes
1401	99.90	Colleges	Upper Los Angeles River Watershed	380.0	N/A	Half Mile		2,142	915	$15,791	42.8	12.5	0.00	No
1517	4.16	Vacant	Upper Los Angeles River Watershed	423.7	N/A		Qtr Mile	374	553	$44,287	30.6	2.8	51.74	No
1519	3.35	Vacant	Upper Los Angeles River Watershed	0.0	N/A		Qtr Mile	313	474	$42,095	31.7	2.7	65.13	No
1521	24.39	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile	Qtr Mile	578	532	$39,754	49.0	5.6	245.70	No
1522	22.06	Vacant	Upper Los Angeles River Watershed	N/A	0.0	One Mile	Qtr Mile	995	674	$33,576	59.1	6.5	245.70	No
1523	56.98	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile	Qtr Mile	880	577	$33,234	57.8	6.6	245.70	No
1525	44.95	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	1,228	504	$30,152	63.3	8.9	303.90	No
1526	12.62	Vacant	Upper Los Angeles River Watershed	188.6	N/A	Half Mile	Qtr Mile	2,058	563	$24,121	70.3	11.9	303.90	No
1528	95.03	Vacant	Upper Los Angeles River Watershed	5.1	N/A	Half Mile	Qtr Mile	1,145	436	$31,376	61.8	8.7	117.70	No

RB-AR35637

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*
Data Summary Table

				WATER FACTORS		COMMUNITY FACTORS								
Parcel ID	Acres	Land Use Group	Watershed	Distance (in ft) to storm drain ≥ 36" diam.	Distance (in ft) to storm drain with no size data	Habitat Distance	River/Trail Distance	Youth Density (mi²)	Senior Density (mi²)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
1529	22.39	Vacant	Upper Los Angeles River Watershed	211.0	N/A	Half Mile	Qtr Mile	1,603	407	$25,607	66.5	11.3	117.70	No
1530	2.34	Vacant	Upper Los Angeles River Watershed	38.6	N/A	Half Mile	Qtr Mile	2,427	392	$23,670	71.2	13.9	13.77	No
1531	2.86	Vacant	Upper Los Angeles River Watershed	102.1	N/A	Half Mile	Qtr Mile	2,028	365	$25,678	67.5	11.2	22.98	No
1532	2.05	Vacant	Upper Los Angeles River Watershed	209.9	N/A	One Mile	Qtr Mile	1,182	337	$26,554	56.1	7.0	56.21	No
1537	3.22	Vacant	Upper Los Angeles River Watershed	20.3	N/A	Half Mile	Qtr Mile	286	117	$26,245	31.6	5.3	217.60	Yes
1543	111.15	Vacant	Upper Los Angeles River Watershed	21.2	N/A	Half Mile	Qtr Mile	376	147	$24,874	23.3	3.4	178.20	Yes
1546	181.89	Vacant	Upper Los Angeles River Watershed	149.9	N/A	Half Mile	Qtr Mile	578	173	$21,815	28.6	5.0	280.50	Yes
1547	11.96	Vacant	Upper Los Angeles River Watershed	5.4	N/A	Half Mile	Qtr Mile	1,765	287	$12,754	37.3	8.3	280.50	Yes
1548	9.67	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	606	174	$19,357	29.2	4.4	99.33	Yes
1576	4.42	Vacant	Upper Los Angeles River Watershed	429.9	N/A	Half Mile	One Mile	1,273	191	$10,086	89.7	29.2	1.20	No
1601	2.10	Vacant	Upper Los Angeles River Watershed	28.6	N/A	Half Mile	One Mile	1,202	673	$17,209	63.2	13.7	0.00	No
1640	1.30	Vacant	Upper Los Angeles River Watershed	25.3	N/A	Half Mile	One Mile	2,218	735	$27,604	45.0	6.7	4.74	No
1650	3.64	Elem Schools	Upper Los Angeles River Watershed	75.5	N/A	Half Mile	One Mile	1,228	745	$16,778	74.7	19.7	0.02	No
1651	5.91	Senior and Middle Schools	Upper Los Angeles River Watershed	53.2	N/A	One Mile		3,968	2,031	$16,242	81.6	21.9	0.13	No
1652	4.26	Elem Schools	Upper Los Angeles River Watershed	22.2	N/A	One Mile		6,638	3,254	$13,658	86.8	24.4	0.19	No
1653	3.52	Elem Schools	Upper Los Angeles River Watershed	0.5	N/A	Half Mile		5,376	2,656	$17,696	75.5	16.8	0.11	No
1654	3.68	Elem Schools	Upper Los Angeles River Watershed	461.8	N/A		One Mile	1,956	834	$14,623	84.3	20.1	0.32	No
1655	23.69	Senior and Middle Schools	Upper Los Angeles River Watershed	N/A	239.3	Half Mile		3,232	1,973	$23,278	73.3	16.0	0.11	No
1656	3.38	Elem Schools	Upper Los Angeles River Watershed	23.6	N/A	Half Mile		5,410	3,068	$16,420	84.3	17.2	0.05	No
1658	5.70	Elem Schools	Upper Los Angeles River Watershed	377.5	N/A		One Mile	3,104	2,272	$19,291	74.6	15.4	0.39	No
1659	5.02	Elem Schools	Upper Los Angeles River Watershed	26.2	N/A	Half Mile	One Mile	1,345	882	$33,813	58.9	9.5	0.54	Yes
1662	9.86	Senior and Middle Schools	Upper Los Angeles River Watershed	25.0	N/A	Half Mile		2,391	1,854	$29,293	71.4	14.9	0.21	No
1663	3.98	Elem Schools	Upper Los Angeles River Watershed	24.6	N/A	Half Mile	Qtr Mile	1,991	789	$14,198	76.0	12.5	11.26	No
1666	5.50	Elem Schools	Upper Los Angeles River Watershed	170.8	N/A		One Mile	2,113	1,375	$25,387	61.8	9.2	1.27	No
1667	8.69	Senior and Middle Schools	Upper Los Angeles River Watershed	37.0	N/A		One Mile	2,156	1,411	$25,729	62.8	9.3	1.27	No
1668	18.24	Senior and Middle Schools	Upper Los Angeles River Watershed	18.9	N/A		One Mile	1,986	1,368	$28,719	61.2	9.0	0.03	No
1669	39.55	Colleges	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	783	651	$39,162	38.8	5.7	7.57	Yes
1672	3.58	Elem Schools	Upper Los Angeles River Watershed	25.8	N/A	One Mile	One Mile	3,333	1,492	$19,189	72.3	12.6	0.41	No
1673	3.78	Elem Schools	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	One Mile	731	500	$36,235	42.4	8.2	10.79	Yes
1674	3.82	Elem Schools	Upper Los Angeles River Watershed	47.8	N/A	Half Mile	One Mile	2,242	1,286	$29,947	45.9	8.2	1.03	No
1680	4.09	Elem Schools	Upper Los Angeles River Watershed	43.1	N/A	Half Mile	One Mile	2,282	772	$27,846	40.0	6.4	4.94	No
1682	11.37	Senior and Middle Schools	Upper Los Angeles River Watershed	5.0	N/A	Half Mile	One Mile	1,504	609	$30,311	21.9	3.8	0.83	No
1696	6.28	Elem Schools	Upper Los Angeles River Watershed	41.0	N/A	One Mile		1,864	1,219	$18,888	43.7	9.8	1.63	No
1705	6.49	Elem Schools	Upper Los Angeles River Watershed	232.0	N/A	Half Mile		2,867	1,357	$21,061	68.0	9.2	0.95	No
1743	3.24	Vacant	Upper Los Angeles River Watershed	271.7	N/A	Half Mile		483	891	$18,565	91.4	59.3	0.59	No
1744	3.97	Vacant	Upper Los Angeles River Watershed	339.4	N/A	Half Mile		460	800	$18,278	91.2	57.9	0.61	No
1759	7.91	Colleges	Upper Los Angeles River Watershed	143.1	N/A	Half Mile	One Mile	2,923	914	$11,392	56.6	20.8	1.05	No
1776	8.38	Colleges	Upper Los Angeles River Watershed	294.3	N/A	Half Mile	Half Mile	1,953	681	$18,601	68.5	22.9	44.35	Yes
1839	1.30	Vacant	Upper Los Angeles River Watershed	41.9	N/A	Half Mile	Qtr Mile	1,274	969	$23,221	62.6	8.9	14.13	No
1867	3.72	Vacant	Upper Los Angeles River Watershed	0.0	N/A		Half Mile	365	238	$68,954	3.6	1.1	14.91	Yes
1879	1.87	Vacant	Upper Los Angeles River Watershed	242.1	N/A		Qtr Mile	183	190	$37,142	61.0	9.2	45.54	Yes
1880	1.42	Vacant	Upper Los Angeles River Watershed	376.4	N/A		Qtr Mile	325	177	$10,332	52.1	6.2	142.30	Yes
1886	9.86	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile	Qtr Mile	776	543	$29,530	59.8	9.1	42.18	No
1896	4.72	Vacant	Upper Los Angeles River Watershed	12.9	N/A	Half Mile		3,598	623	$12,580	59.7	14.9	0.00	No
1902	3.76	Vacant	Upper Los Angeles River Watershed	42.5	N/A			465	335	$21,714	28.6	5.1	0.00	No
1904	1.42	Vacant	Upper Los Angeles River Watershed	474.2	N/A			562	389	$22,193	28.3	4.4	0.00	No
1918	200.35	Vacant	Upper Los Angeles River Watershed	N/A	426.4	Half Mile	Qtr Mile	831	389	$35,530	37.7	6.9	130.10	Yes
1919	158.38	Vacant	Upper Los Angeles River Watershed	465.8	N/A	Half Mile	Qtr Mile	1,090	446	$32,976	45.1	8.3	130.10	Yes
1923	4.67	Vacant	Upper Los Angeles River Watershed	44.4	N/A	Half Mile		1,957	857	$25,516	50.8	5.1	0.00	No
1936	7.85	Vacant	Upper Los Angeles River Watershed	129.0	N/A	Half Mile	Qtr Mile	819	435	$23,506	33.9	6.9	7.55	Yes
1937	3.80	Vacant	Upper Los Angeles River Watershed	259.8	N/A		Qtr Mile	732	627	$40,730	6.2	1.9	18.26	No
1945	68.97	Vacant	Upper Los Angeles River Watershed	72.5	N/A	Half Mile	Qtr Mile	630	331	$20,828	28.8	5.7	45.61	Yes
1968	4.19	Vacant	Upper Los Angeles River Watershed	0.0	N/A	One Mile	One Mile	298	169	$36,494	10.3	1.2	23.86	Yes
2084	632.09	Vacant	Upper Los Angeles River Watershed	68.2	N/A	Half Mile	Qtr Mile	534	294	$35,175	16.5	2.8	94.90	Yes
2092	1.25	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	645	215	$38,248	7.3	2.0	0.00	No
2095	5.34	Vacant	Upper Los Angeles River Watershed	3.3	N/A	One Mile	Qtr Mile	588	351	$39,338	7.7	2.2	10.41	No
2096	12.02	Vacant	Upper Los Angeles River Watershed	71.3	N/A	Half Mile	Qtr Mile	570	302	$37,125	18.9	3.1	2.57	No

COMMUNITY CONSERVATION SOLUTIONS

GREEN SOLUTION PROJECT: Upper Los Angeles River Watershed, Phase II *(Partial)*
Data Summary Table

				WATER FACTORS		COMMUNITY FACTORS									
Parcel ID	Acres	Land Use Group	Watershed	Distance (in ft) to storm drain ≥ 36" diam	Distance (in ft) to storm drain with no size data	Habitat Distance	River/Trail Distance	Youth Density (mi^2)	Senior Density (mi^2)	Per Capita Income	% of Renters	% No Car Access	Park acres/ 1,000 Residents	Rim of the Valley
2098	9.56	Vacant	Upper Los Angeles River Watershed	393.9	N/A	Half Mile	Qtr Mile	670	341	$20,565	23.2	4.5	77.24	Yes
2101	99.58	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	409	211	$20,420	21.6	3.5	103.60	Yes
2102	61.49	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile	Qtr Mile	214	103	$22,208	14.9	0.9	132.20	Yes
2105	24.11	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		1,603	379	$20,329	30.4	9.0	0.28	No
2106	37.92	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		1,282	314	$22,836	31.1	8.7	0.28	No
2108	7.40	Vacant	Upper Los Angeles River Watershed	225.1	N/A	Half Mile	One Mile	568	130	$24,854	29.7	5.3	0.00	No
2114	29.59	Vacant	Upper Los Angeles River Watershed	N/A	469.0	Half Mile		624	338	$30,947	16.8	3.7	0.03	No
2123	3.10	Vacant	Upper Los Angeles River Watershed	460.4	N/A	Half Mile	One Mile	2,476	847	$12,167	89.3	38.0	1.24	No
2125	2.44	Vacant	Upper Los Angeles River Watershed	33.6	N/A	Half Mile	One Mile	2,113	737	$13,747	89.8	38.2	0.52	No
2126	6.16	Elem Schools	Upper Los Angeles River Watershed	60.4	N/A	Half Mile	One Mile	2,556	830	$14,908	86.2	40.6	1.30	No
2127	8.88	Vacant	Upper Los Angeles River Watershed	60.0	N/A	Half Mile	One Mile	2,368	840	$15,008	87.5	43.6	1.30	No
2128	17.36	Vacant	Upper Los Angeles River Watershed	93.6	N/A	Half Mile	One Mile	2,763	914	$14,841	86.4	41.0	0.61	No
2136	1.67	Vacant	Upper Los Angeles River Watershed	46.7	N/A	Half Mile	Qtr Mile	2,534	917	$26,448	60.5	8.5	4.39	Yes
2137	1.26	Vacant	Upper Los Angeles River Watershed	11.2	N/A	Half Mile	Qtr Mile	2,491	946	$26,491	60.3	8.2	5.04	Yes
2141	8.22	Vacant	Upper Los Angeles River Watershed	18.9	N/A	One Mile	Qtr Mile	836	352	$28,332	6.6	1.8	14.81	Yes
2186	4.05	Colleges	Upper Los Angeles River Watershed	66.0	N/A	Half Mile		3,202	915	$13,095	78.9	30.3	1.07	No
2187	2.20	Colleges	Upper Los Angeles River Watershed	73.0	N/A	Half Mile		3,507	1,040	$11,405	78.3	30.6	2.39	No
2248	12.41	Vacant	Upper Los Angeles River Watershed	33.5	N/A	Half Mile	Qtr Mile	725	405	$49,080	27.7	5.6	47.21	Yes
2265	14.44	Vacant	Upper Los Angeles River Watershed	60.8	N/A	Half Mile	One Mile	999	208	$17,663	20.0	3.7	19.27	Yes
2302	10.87	Vacant	Upper Los Angeles River Watershed	0.0	N/A	Half Mile		3,092	1,113	$14,895	54.4	19.1	0.20	No

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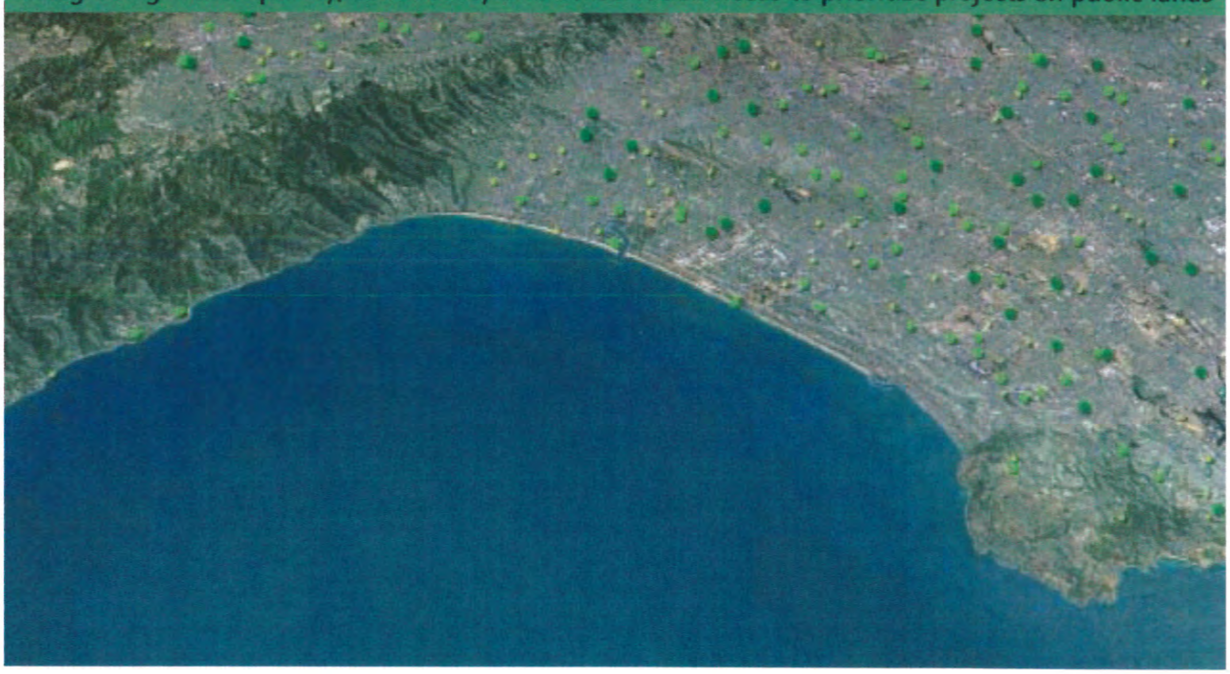
THE GREEN SOLUTION PROJECT

SANTA MONICA BAY WATERSHED, Phase II

EXECUTIVE SUMMARY & MAPS

Strategic & Prioritized Approach to Naturally Cleaning Polluted Runoff

Integrating water quality, community and conservation needs to prioritize projects on public lands



Coastal Conservancy

bay restoration commission
STEWARDS OF SANTA MONICA BAY

ABOUT Community Conservation Solutions

COMMUNITY CONSERVATION SOLUTION'S MISSION is to tackle the most complex and challenging problems created when people and nature intersect. Community Conservation Solutions (CCS) does this by developing creative, practical and lasting solutions that unite diverse communities and interests and leverage investments of public funds. CCS has successfully crafted innovative solutions to serious environmental problems affecting California's natural and human communities by integrating the protection and restoration of natural lands and waters with compatible community uses, economic benefits and permanent public benefits.

Community Conservation Solutions works on diverse projects in urban and rural areas that help both natural habitats and people. Our projects range from parks and beaches to wilderness and watersheds, and from recreational sites to mixed-use developments. CCS is a 501(c)(3) non-profit, tax-exempt organization.

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ABOUT The Green Solution Project

COMMUNITY CONSERVATION SOLUTIONS' GREEN SOLUTION PROJECT is a major paradigm shift in how we clean up polluted runoff on a regional watershed scale. The Green Solution Project is a quantified, prioritized and practical approach to identifying public lands that can be converted to naturally capture and clean polluted runoff while creating new parks, wildlife habitat and recreation lands. The Green Solution Project uses cutting-edge digital technology to integrate hydrology with water quality, community and conservation needs. This provides cities and counties throughout California with a strategic road map to meet their runoff clean-up needs through conversion of lands already in public ownership to "smart," designed green open space that can clean, store and reuse runoff. CCS' Green Solution Project challenges conventional assumptions about the role that "green approaches" can play in naturally cleaning up polluted runoff throughout California and beyond. CCS' Green Solution Project is being considered as a solution to growing water pollution problems affecting California's rivers, lakes, wetlands, bays, beaches and ocean waters.

ABOUT The Project Team

CCS' GREEN SOLUTION PROJECT TEAM includes **PSOMAS** and **GreenInfo Netwok**. Psomas is a leading consulting engineering firm serving clients in the water/wastewater, transportation, public, institutional and private land development markets, and is committed to the advancement and implementation of sustainable stormwater solutions. GreenInfo Network is a non profit organization providing Geographic Information System (GIS) and related technology, data analysis and support to a wide range of water, land conservation and many other types of projects throughout California and the United States.

For a complete copy of this report, go to
www.conservationsolutions.org/greensolution.html

For more information, contact us at:
2554 Lincoln Boulevard, Suite 223 Los Angeles, CA 90291 (310) 398-8584

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THE GREEN SOLUTION PROJECT

SANTA MONICA BAY WATERSHED, Phase II

EXECUTIVE SUMMARY & MAPS

Strategic & Prioritized Approach to Naturally Cleaning Polluted Runoff

Integrating water quality, community and conservation needs to prioritize projects on public lands

Technical Report, Analysis and Mapping By

PSOMAS

GreenInfo Network

To view the Technical Report go to:
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STEWARDS OF SANTA MONICA BAY

FEBRUARY 2011

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LIST OF MAPS

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EXECUTIVE SUMMARY

Green Solution Projects improve water quality by using soil and plants to capture, filter and clean polluted urban and stormwater runoff, while creating new parks, natural habitat, recreation and other open space lands.

This Executive Summary summarizes the results of Community Conservation Solutions' (CCS) Green Solution Project Phase II analysis for the Santa Monica Bay Watershed and presents our findings and conclusions. This study expanded our innovative Phase I findings on the use of existing public lands to naturally treat polluted runoff while creating a network of new, green open space lands. We are pleased to present this prioritization of public parcels for potential project implementation for use in efforts to improve water quality in Santa Monica Bay and in rivers, streams and lakes throughout the Santa Monica Bay Watershed.

The project team included Community Conservation Solutions, Psomas, who provided engineering support and prepared the Technical Report, and GreenInfo Network, who provided Geographic Information System (GIS) data analysis and mapping.

The Phase I Green Solution Project analysis presented an innovative and ground-breaking approach to cleaning up polluted runoff by identifying existing public lands suitable for conversion and retrofit of impervious lands to "smart" green spaces that can act as natural filters and treatment areas, while also providing badly-needed new parks, natural habitat and open space. This Phase II analysis focused on prioritizing public lands in selected land uses for future project implementation by integrating hydrology, water quality, pollutant loading, community needs and conservation priorities.

Polluted stormwater and urban (dry weather) runoff contaminates all of Santa Monica Bay, beaches, Marina del Rey harbor, including over 130 miles of rivers, creeks and coastline and over 800 acres of lakes and wetlands in the Santa Monica Bay Watershed. All of Santa Monica Bay and most of its' contributing waters are in violation of the U.S. Clean Water Act, with pollutant loads above state and federal standards developed to protect human health and marine and aquatic life. Local governments are under increasing pressure to improve water quality in these water bodies.

Pollutants in Santa Monica Bay Watershed in violation of the U.S. Clean Water Act include: DDT, PCBs (Polychlorinated biphenyls), bacteria, heavy metals (including copper, lead, zinc, and selenium), toxic substances, chlordane, PAHs (Polycyclic Aromatic Hydrocarbons), trash, sediment and cyanide.

By focusing on existing public lands, Community Conservation Solutions' Green Solution Project analysis provides a practical,

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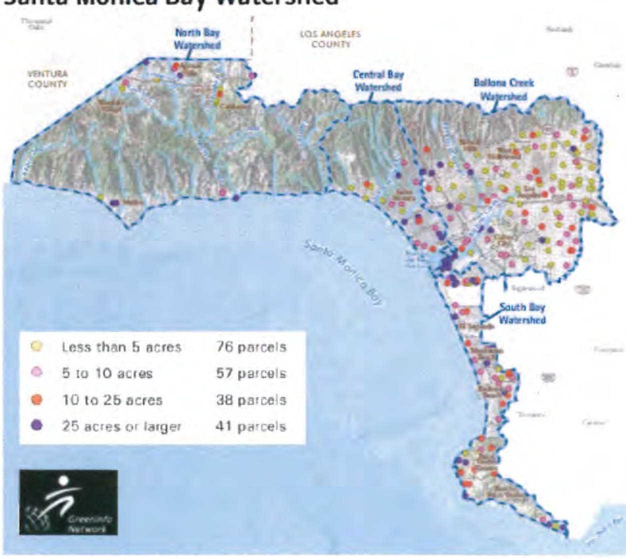
quantified strategy to help public agencies solve these serious water quality problems, clean up polluted runoff on a regional watershed scale, meet L.A. Regional Water Quality Control Board requirements, and create multiple benefits through creation of new park, habitat and green open space lands in communities with tremendous need for these amenities.

By focusing on existing public lands, Community Conservation Solution's Green Solution Project analysis provides a practical, quantified strategy to.....clean up polluted runoff on a regional watershed scale.

The results of our analysis are exciting, and show that there are over 200 high-priority sites comprising over 3,000 acres that are suitable for Green Solution projects in the selected land uses (schools, colleges and vacant lands). This strategic and prioritized Green Solution approach to cleaning up polluted runoff could significantly improve water quality in the Santa Monica Bay Watershed and create networks of green open space. Implementing Green Solution projects on these sites could treat polluted runoff from up to 13,000 acres – equal to four times the area of downtown Los Angeles - while providing badly-needed new parks, habitat and open space, particularly in densely-populated, park-poor communities.

Prioritized Opportunity Public Parcels
Santa Monica Bay Watershed



Implementing Green Solution Projects on prioritized public parcels could treat polluted runoff from up to 13,000 acres.

Polluted stormwater and urban runoff contaminates all of Santa Monica Bay, beaches and Marina del Rey harbor.

Our analysis demonstrates how Green Solution projects can be implemented to safeguard public health and safety, using strict guidelines for site design, operations and maintenance.

Green Solutions include:

- Prioritizing projects by integrating water quality, conservation and community needs
- Converting impervious areas to "smart" green spaces
- Using soils and plants to naturally capture and filter pollutants from runoff
- Creating new parks, habitat and open space lands
- Improving water quality in polluted creeks, rivers, beaches, bays and ocean waters

The CCS Team analysis demonstrates that solving polluted runoff problems can be readily achieved through a comprehensive approach that combines Green Solutions projects on public lands, roads, and certain suitable private land uses. Strategically, conversion of existing public lands – emphasizing prioritization of sites - is the most important because these sites can capture and treat the highest volumes of runoff from surrounding, impervious areas – and can provide other significant public benefits through creating parks, habitat and open space that can be used by the public.

Other exciting results of this analysis show that roadways and private lands can also be effectively used for Green Solutions, and have the potential to treat thousands of acres of runoff. Some of the most heavily polluted runoff – that which flows on public streets and roads – can be captured and treated by using Green Solution projects that convert center medians and curb-side parkways to landscaped greenways that help green urban areas. Green Solutions on private lands can only treat runoff from that particular site, and are most practical on land uses which typically have large, paved areas and can generate high pollutant loads, such as regional shopping centers, office buildings and large apartment complexes.

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What is a Green Solution?

Green Solution projects are prioritized and provide a strategic "road map" so that the best projects are implemented. The CCS Team's quantified approach integrates cutting-edge technology, engineering and strategic site selection to create "smart" green spaces that naturally capture, filter and clean polluted runoff. The CCS team developed a unique methodology to integrate hydrology, pollutant loading, conservation and community needs in order to evaluate and prioritize existing public lands for future project implementation.

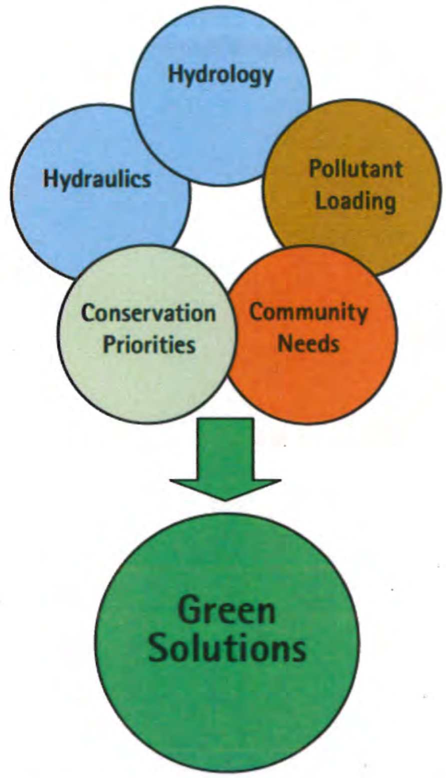
Green Solutions effectively utilize natural treatment processes which take advantage of the natural functions of soils and plants to filter, treat and reduce the volume of runoff. These natural processes include:

- **Biofiltration:** the filtration of pollutants through vegetation and soil
- **Bio-uptake:** biological processes such as the assimilation of pollutants such as nitrogen and phosphorous, which soil and plants can convert for their beneficial use
- **Infiltration:** the process by which water on the ground moves into the soil
- **Evapotranspiration:** the process of transferring moisture from the earth to the atmosphere by evaporation and transpiration from plants
- **Other:** biological, physical, and biochemical processes

Natural treatment processes can also be more cost effective than other types of structural Best Management Practices because they are passive systems and require little energy, operations and maintenance.

Integrating Multiple Benefit Factors: Unique Methodology of the CCS Team

CCS' Green Solution Project provides a rational, quantified approach to identifying and prioritizing opportunity parcels for water quality improvement projects. This technical methodology can be applied in any region with polluted runoff problems. The CCS Team integrated the following multiple benefit factors to rank and prioritize over 200 opportunity public parcels in the Santa Monica Bay Watershed:



A state-of-the-art Green Solution Project. *The Sun Valley Watershed Project in Los Angeles County uses underground vaults and a surface park, habitat and recreation area to naturally capture and treat polluted runoff from surrounding urban areas. New open space benefits this park-poor community, and the project recharges the San Fernando Groundwater Basin.*

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A Prioritized Green Solution Project Approach is Essential to Cleaning Up Polluted Runoff

The CCS Team's Green Solution integrated methodology is essential to help public agencies meet water quality improvement goals and strict clean-up timelines for the Santa Monica Bay Watershed.

The Green Solution prioritizes specific projects for implementation based on integrated multiple benefits, including watershed hydrology, pollutant loading, community needs and conservation priorities, and ensures that public funds are invested wisely in sites that provide the highest overall benefit. This prioritized and analysis-based Green Solution Project strategy is critical to achieving water quality improvement goals because it:

- Helps implement projects that can provide the highest overall benefit
- Ensures cost effective investment of public funds
- Allows treatment of offsite runoff
- Focuses on existing public lands to make best use of existing resources
- Maximizes natural treatment of polluted runoff while providing greatest multiple benefits
- Focuses on high pollutant loading areas
- Helps meet conservation priorities
- Provides new green open space in communities with the greatest needs

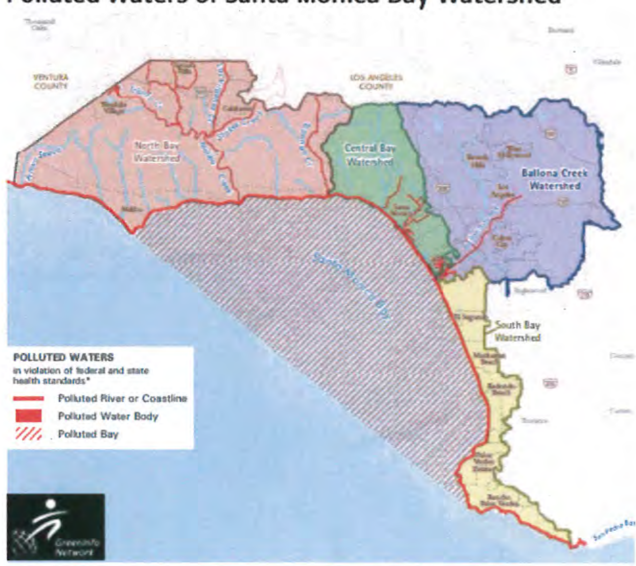
This prioritized, analytical Green Solutions approach provides a strategic "road map" for conversion of lands already in public ownership to new, "smart" green spaces that naturally clean up polluted runoff, can help recycle and reuse stormwater and re-charge groundwater supplies. The Green Solution Project focus on existing public lands offers a cost-effective and readily available solution not only to the increasingly serious water quality problems in Los Angeles County, but also to the demand to make communities healthier and more livable by creating a green network of park, habitat, recreation and open space lands. Moreover, to the growing need to address drought and global warming by conserving and recycling our increasingly precious water resources.

The Urgency: Polluted Runoff Problems in the Santa Monica Bay Watershed

There is an urgent need to clean up polluted runoff to improve water quality in Santa Monica Bay, Ballona Creek, creeks throughout the watershed and at world-renowned beaches along the coast. Polluted urban and stormwater runoff is a serious problem here, where extensive urbanization has resulted in vast areas of paved surfaces and high daily volumes of contaminated runoff. Nearly all of the natural habitat in the developed areas of the Santa Monica Bay Watershed has been destroyed by over 100 years of urban growth, and these areas have some of the greatest park and open space deficits in California.

Nearly all properties in the watershed produce runoff that flows - untreated in any way - through county and city storm drains every day, even in dry weather. Dry weather runoff generates a total of 30 million gallons of water every day[1] – enough to

Polluted Waters of Santa Monica Bay Watershed



All of Santa Monica Bay and most of its' contributing waters are in violation of the U.S. Clean Water Act, with pollutant loads above the state and federal standards developed to protect human health and marine and aquatic life.

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Dry weather runoff from sprinklers, yards, car washing and hosing down driveways generates 30 million gallons of water every day – enough to fill the Rose Bowl in less than 3 days.

fill the Rose Bowl in less than three days. When it rains, the problem is far worse, as the high volumes of stormwater carry huge amounts of trash and pollutants through the county's drainage system very quickly.

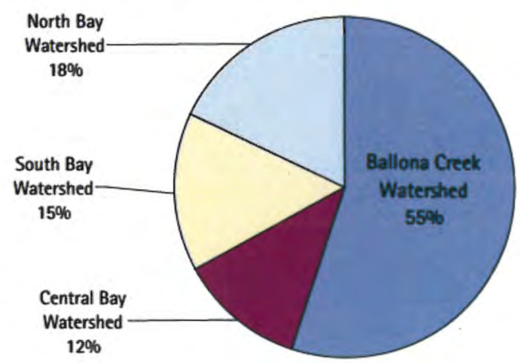
Many pollutants in waters of the Santa Monica Bay Watershed are significantly above federal and state public health standards and in violation of the U.S. Clean Water Act, which sets water quality standards intended to protect human health and marine and aquatic life. These pollutants include infection-causing bacteria, toxic metals, pesticides, household and industrial chemicals, trash, oil, oxygen-choking fertilizers and other toxins. To enforce federal standards, the L.A. Regional Water Quality Control Board has established six different Total Maximum Daily Loads (TMDL) limits – with more anticipated - for runoff flowing into Santa Monica Bay beaches and Ballona Creek, and cities and the county are required to meet these TMDL limits.

Polluted runoff endangers the health of people, animals and the aquatic and marine life dependent on river and ocean waters for survival, and contaminates ocean waters around the world.[2] Millions of tons of trash end up on Santa Monica Bay beaches every year – and this does not count the additional millions of tons carried by ocean currents and accumulating in huge floating "rafts" of plastic trash in the Pacific Ocean between California and Japan. Trash chokes one million seabirds worldwide every year; plastic is found in the stomachs of seabirds, turtles and marine mammals around the worlds, and toxic pollutants and bacteria from runoff can be fatal to marine mammals. Low oxygen "dead zones" are spreading due to increasing fertilizer use and growing coastal populations.[3] UCLA and Stanford University scientists found that up to 1.5 million people get sick each year from infections and gastrointestinal illnesses caused by bacteria at L.A. County beaches.[4] Pollution associated with stormwater and daily urban runoff can only be solved by addressing the generation of pollutants throughout the watershed. This includes taking full advantage of all opportunities for conversion of paved, impervious surfaces to pervious surfaces that allow soil and plants to naturally capture, infiltrate and clean runoff and installing "smart", engineered Green Solutions that can act as natural filters and treatment areas.

The CCS Team's Green Solution Project: Prioritization Findings

By using state-of-the-art technology and engineering, the CCS team developed a unique methodology to integrate hydrology, pollutant loading, conservation and community needs in order to evaluate and prioritize existing public lands for future project implementation. The result is a strategic road map to selecting project sites that ensures cost-effective use of public funds and implementation of projects that can maximize both natural capture and clean-up of runoff and creation of new "smart" parks, habitat and green open space for public use.

Contribution of Runoff from Santa Monica Bay Watersheds



We evaluated the Central Bay, Ballona Creek, North Bay and South Bay watersheds of the Satan Monica Bay Watershed. The amount of runoff produced in the watershed depends on the extent of imperviousness in each area.

Pollutants of concern in the Santa Monica Bay Watershed that can be addressed by Green Solutions are:

- Bacteria
- Nitrates and other fertilizer-based chemicals
- Heavy metals, including lead and copper
- Oil and grease
- Oxygen-demanding substances
- Sediment
- Trash and debris

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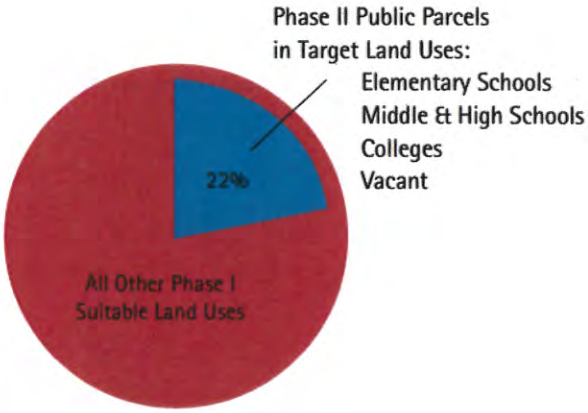
Green Solutions on Existing Public Lands: Schools, Colleges and Vacant Lands

This Phase II analysis focused on four of the fourteen land uses identified as suitable in Phase I: elementary, middle and high schools, colleges and vacant lands.

Parcels in Target Land Use



Overturning conventional assumptions about the limited role that green approaches might play in naturally cleaning up polluted runoff in developed areas, our Phase I study identified up to 9,700 acres of public lands suitable for Green Solution Projects in the Santa Monica Bay Watershed. The four targeted land uses analyzed in Phase II represent approximately one quarter of the Phase I suitable parcels in all public land uses.

The purpose of the Phase II analysis was to expand the Phase I study and evaluate these four particular land uses at a detailed level, so as to provide a strategic, quantified approach to prioritizing the parcels for project implementation. This rigorous analysis included screening for parcel size, slope, level of pollutant loading in surrounding area, and portion of parcels suitable for runoff capture and treatment. Parcels less than ½ acres were not included, and all parcels had to be within 500 feet of a storm drain at least 36" in diameter. Hydrology, pollutant loading, community needs and conservation priorities were integrated into a matrix, and all parcels were then evaluated and scored on a one to five scale, with five being the highest priority.

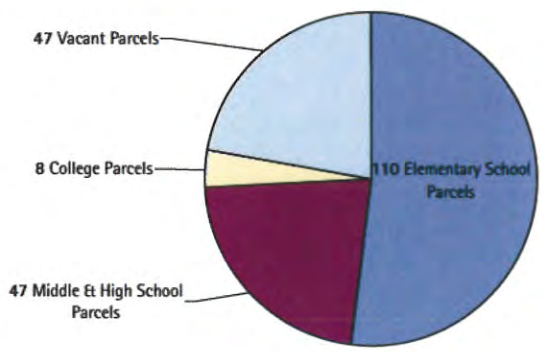
The factors evaluated and integrated by the team included:

- **Hydrology of the watershed:** rainfall and runoff volume, storm drain locations and size, runoff flow
- **Pollutant loading:** concentration of polluted runoff
- **Community needs:** open space deficit, youth and senior density, income, access to car, percent renters
- **Conservation priorities:** proximity to existing parks, trails, rivers and habitat.

Over 200 Project Sites Identified

The CCS Team identified 212 opportunity public parcels in these specific four public land uses, comprising a total area of over 3,000 acres.

Green Solution Opportunity Public Parcels by Land Use



These parcels passed the rigorous screening and evaluation for suitability. Based on the analysis, which took into account actual area potentially available in each land use for conversion

Table 1. Potential Green Solution Projects (GSP): Parcels & Acres Suitable in Target Land Uses

	Number of Opportunity Parcels	Total Acreage of Opportunity Parcels	Avg. Suitable Acres for GSP	Max. Suitable Acres for GSP
Ballona Creek Watershed	116	1,696	480	613
Central Bay Watershed	21	246	46	64
South Bay Watershed	56	857	317	402
North Bay Watershed	19	260	110	139
TOTAL	**212**	**3,060**	**953**	**1,217**

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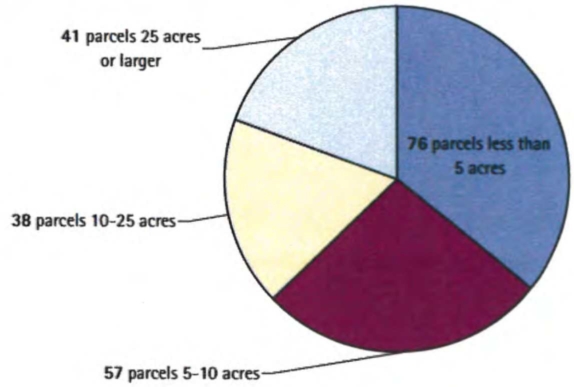
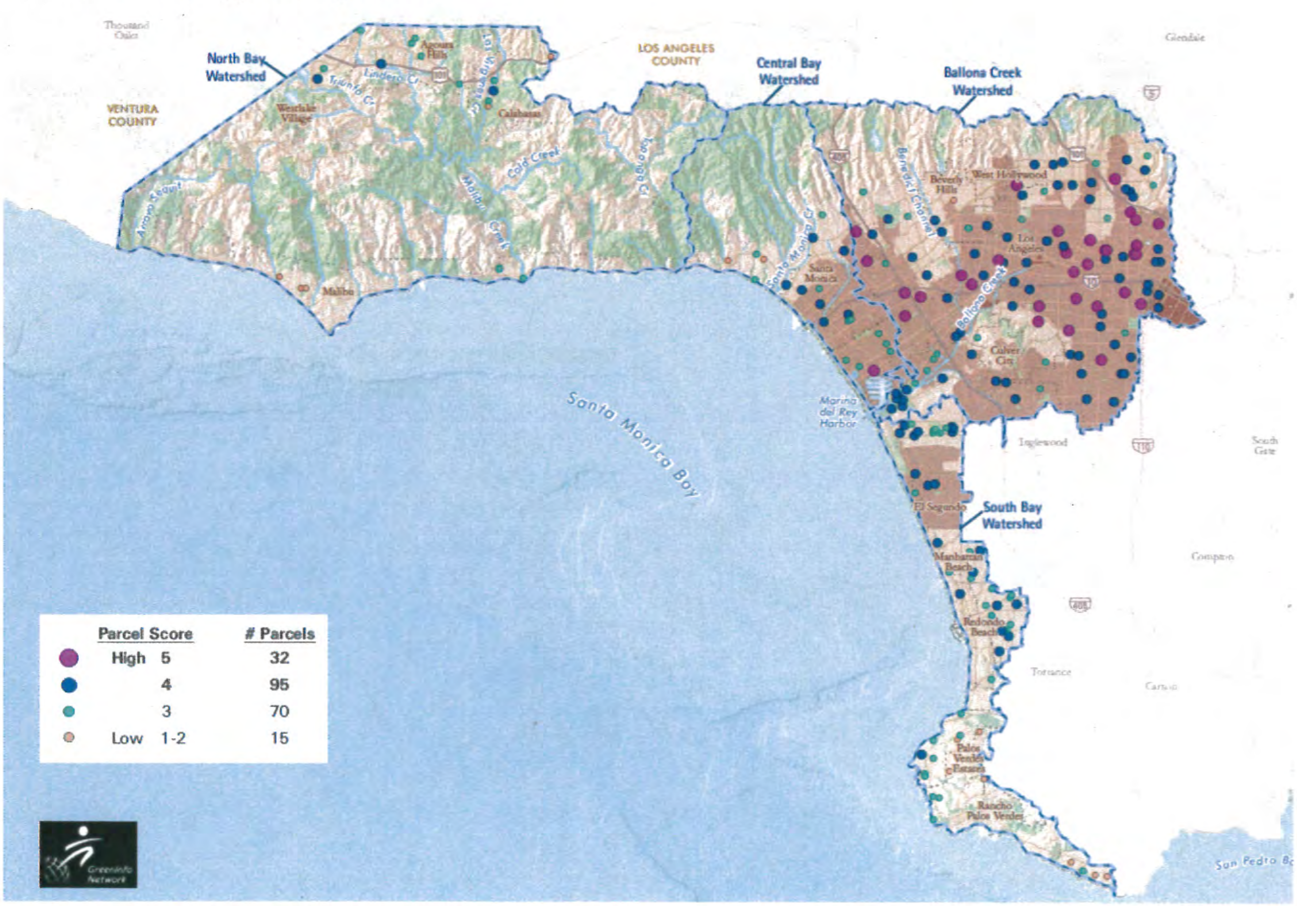
or retrofit for use as runoff treatment and park, habitat or other green open space, these 212 parcels have a net of up to 1,200 acres of land that are suitable for Green Solution projects. Table 1 shows the number of opportunity public parcels and acres of public lands suitable for Green Solution projects, by watershed.

The map below shows the distribution of prioritized public opportunity parcels throughout the watershed, by score and by intensity of pollutant loading in the watershed. There are 127 top priority sites with scores of four and five, making up 65% of the suitable acreage. These top priority sites comprise 2,000 acres and, if implemented as Green Solution projects, could potentially treat polluted runoff from 8,000 acres of the Santa Monica Bay Watershed. (For detail by watershed, see Opportunity Public Parcel maps at end of this Executive Summary.)

Green Solution Opportunity Public Parcels by Size



Prioritized Public Opportunity Parcels



Over 200 priority public parcels provide 1,200 acres suitable for Green Solution Projects. There are 127 top priority sites (scores four and five). These sites could treat runoff from 8,000 acres of the Santa Monica Bay Watershed.

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If implemented as Green Solution projects, these 212 priority opportunity public parcels could treat polluted runoff from up to 13,000 acres of the Santa Monica Bay Watershed - an area equal to four times the size of downtown Los Angeles. Table 2 shows the acres treatable, by watershed, if these high-priority opportunity public parcels were implemented as Green Solution projects.

Table 2. Acres of Watershed Treated by Prioritized Public Opportunity Parcels

	Avg. Acres Treated	Max. Acres Treated
Ballona Creek Watershed	2,400	3,250
Central Bay Watershed	870	1,150
South Bay Watershed	2,700	3,450
North Bay Watershed	4,000	5,000
TOTAL	**9,970**	**12,850**

Green Solution Potential on Example Roads and Rights-of-Way

The CCS team identified 40 miles of example roads and rights-of-way in the Santa Monica Bay Watershed that have the potential to be used as Green Solutions to treat runoff from surrounding areas. These examples include 26 miles of roads with medians and parkways (landscaped strip near the curb), and fourteen miles of roads with insufficient median widths that therefore could only treat runoff in the parkways. If the medians and/or parkways were retrofitted to engineered, landscaped Green Solutions that naturally capture, filter and treat polluted runoff, these example roads could treat up to 2,600 acres of polluted runoff in the Santa Monica Bay Watershed - an area approximately the size of Los Angeles International Airport (LAX). This treatment capacity assumes that the roads are treating only runoff carried by that particular road, and not additional runoff diverted from storm drains.

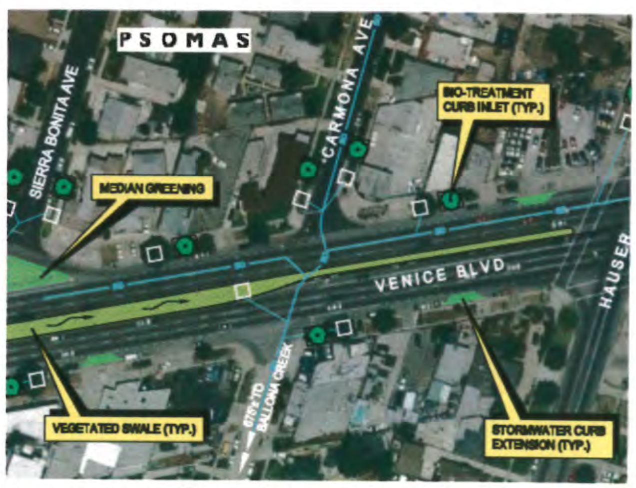
These example roads were selected based on visual inspection of aerial maps, professional knowledge and expertise, as limited GIS data was available. The team's focus was on candidate roadways in the Santa Monica Bay Watershed that would have high treatment potential because they include medians and/or parkways adjacent to the curb that could be converted to catch, filter and treat runoff using Green Solution approaches. The amount of potential runoff capture and treatment varies with the type of roadway, as shown in Table 3.

Table 3. Acres of Watershed Treated by Road Type

Roadway Type	Acres Treatable per 1,000-ft. of road
Arterial streets with median and parkway	10-18
Arterial streets with median only	8-16
Arterial and non-arterial streets with parkway only	0.6-1.1

This runoff treatment capacity by roads is very significant because roads collect the most polluted runoff in the Santa Monica Bay Watershed, in both dry and wet weather. Road runoff has very high concentrations of heavy metals and oils from vehicles, sediment, and other toxins, so treating this runoff before it gets into the storm drain system is extremely important, and can lessen the overall treatment need by removing problem pollutants throughout the watershed. Converting and retrofitting medians and parkways to Green Solutions in roadways also creates important linear greenways that contribute to urban greening.

While data was not available on miles of roadways in the Santa Monica Bay Watershed, our 40 example miles indicate that this portion of Green Solutions is certainly significant and worthy of further delineation. There are approximately 6,500 miles of roadways in the City of Los Angeles alone; some percentage of roadways in the Santa Monica Bay Watershed is likely to be suitable for Green Solution projects.



Example Concept Plan for a proposed Green Solution Project on Venice Blvd. (PSOMAS)

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The Imperial Highway Greenway is an example of how roadways and rights-of-way can be converted into Green Solutions that naturally capture, filter and treat polluted runoff. Design and construction by PSOMAS.

Green Solution Potential on Private Lands: Regional Shopping Centers, Large Office Buildings, & Large Apartment Complexes

Private lands make up 63% of the acreage and 98% of all parcels in the Santa Monica Bay Watershed, so implementing Green Solutions on private lands to treat the polluted runoff produced by those lands is very useful because it reduces the overall pollutant load from off-site runoff that Green Solutions on public lands would otherwise have to capture and clean. The CCS Team found that implementing Green Solutions on these land uses could treat runoff from nearly 3,000 private acres in the watershed.

Implementing Green Solutions on regional shopping centers, and on large office buildings and apartment complexes could treat runoff from nearly 3,000 private acres.

The CCS Team identified regional shopping centers, office buildings and multi-family residential with five or more units as private land uses with the highest suitability for treating the most amount of polluted runoff on-site. Our analysis focused on those land uses with high total acreage, high percentages of paved area, potential of high pollutant loading, and the greatest likelihood for having physical space to install Green Solutions. These private land Green Solutions would treat runoff from each site only, would not include treating off-site runoff, and would provide visual green open space benefits but not public space.

Safeguarding Public Health and Safety

Our analysis shows that Green Solution projects treating offsite runoff can be safely implemented on school, college and vacant lands. Public health and safety can be ensured through proper and thoughtful design specific to the land use, education, and regular and proper operations and maintenance. Designs using ponds, wetlands and other similar natural water treatment elements can be used on middle and high school, college and vacant sites, while elementary school sites should not include these elements.

The following design and maintenance "toolbox" includes examples of the types of public health and safety safeguard measures that should be used:

- Adhere to Health Department requirements; design stormwater facilities to drain within 72 hours
- Restrict access and prevent contact through fences, setbacks, signage and landscaping
- Minimize inlets and outlets to treatment facilities
- Perform regular maintenance to ensure proper function and prevent buildup of potential conditions of concern
- Monitor stormwater pollutants at upstream sampling points and remove sediment when necessary
- Monitor soil contaminant levels via regular soil sampling and remove sediment when necessary
- Use subdrains and impermeable liners preventing groundwater contamination and drawdown times

Table 4. Acres, total parcels, % suitable for site greening and Potential Acres Treatable by Private Land Uses

Private Land Use	Total Acres	Total Parcels	% Suitable for Site Greening	Potential Acres Treatable
Multifamily Residential, Five or More Units	2,018	1,622	5-15%	1,009
Office Building	1,337	517	10-20%	1,337
Shopping Center, Regional	272	62	10-20%	272
TOTAL	**3,627**	**2,201**		**2,616**

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CONCLUSION

This Green Solution approach provides a quantified, strategic road map to improving water quality, ensures wise investment of public funds, maximizes cleanup of polluted runoff and addresses conservation and community needs.

The Green Solution: A Smart & Effective Tool for Treating Polluted Runoff

Green Solution Projects are proving to be one of the most effective and cost-efficient ways to make lasting water quality improvements consistent with the requirements of the State Water Resources Control Board and the LA. Regional Water Quality Control Board. Green Solutions provide park and recreation opportunities in heavily urbanized and park-poor areas, provide important natural habitat, and can be effective "water recyclers", reducing the effects of drought caused by global warming by catching, storing and re-using stormwater for landscaping.

Many water quality experts and scientists believe that much of the toxins, bacteria and other contaminants carried by stormwater and daily dry weather runoff can be permanently addressed by directing these polluted waters to a network of well-designed Green Solutions: new and restored natural habitat, parks, and recreation lands that allow soil and plants to naturally filter and uptake water and pollutants, while providing a wide range of open space and other benefits.

These Green Solution projects provide one of the most viable and effective means of permanently cleaning up polluted runoff because they address wide-spread imperviousness due to decades of urban growth and development, and help restore the natural functions of soil and plants to capture, filter and clean contaminants from runoff before it reaches creeks, lakes, the harbor, beaches and Santa Monica Bay.

Community Conservation Solutions' Green Solution Project for the Santa Monica Bay Watershed, Phase II, quantifies and prioritizes the many opportunities on existing public school, college and vacant lands for naturally capturing, filtering and cleaning polluted runoff from up to 13,000 acres of the watershed – while creating a network of new, state-of-the-art "smart" green parks, habitat and open space in urban areas.

The CCS Team identified 212 high-priority potential project sites on existing public school, college and vacant lands that could treat up to 13,000 acres of the Santa Monica Bay Watershed - while creating over 1,000 acres of new parks, habitat and open space.

This analytical approach to improving water quality in rivers, bays and ocean waters breaks new ground by prioritizing projects for implementation, ensuring that public funds are spent wisely and that selected projects can maximize cleanup of polluted runoff, meet conservation priorities, and are located where community needs are greatest.

By integrating watershed hydrology, storm drain information, pollutant loading, community needs and conservation priorities and scoring suitable project sites, this prioritized Green Solution

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approach provides a strategic road map to help public agencies meet water quality improvement goals – while creating badly-needed networks of green open space in the heavily impervious Santa Monica Bay Watershed.

The CCS Team identified 212 high-priority potential water quality improvement project sites totaling 3,000 acres on existing public school, college and vacant lands. CCS determined that implementing smart Green Solution projects on these sites could treat up to 13,000 acres of the Santa Monica Bay Watershed – an area equal to four times the size of downtown Los Angeles - while creating over 1,000 acres of new parks, habitat and open space in park-poor areas. There are 127 of the very highest priority project sites, totaling 2,000 acres, and these could treat over 8,000 acres. CCS Team's analysis also showed how these Green Solution projects could be implemented to protect public health and safety by identifying guidelines for design, operations and maintenance.

This analytical, prioritized Green Solution approach presents a practical and strategic way to efficiently improve water quality in the creeks, rivers, beaches and ocean waters of the Santa Monica Bay Watershed – while creating a network of new habitat, parks and other green open space in communities where these amenities are most needed.

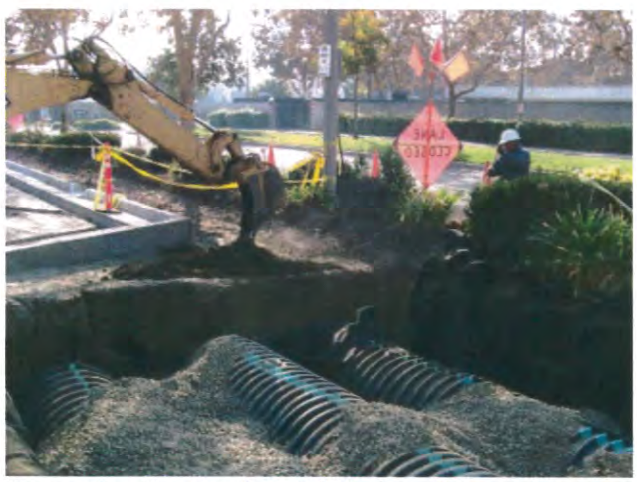
The CCS Team also found that roads and rights-of-way provide important Green Solution opportunities in the Santa Monica Bay Watershed, and that conversion of medians and parkways in an example, selection of some of the most suitable roads could treat up to 2,600 acres, cleaning some of the most heavily polluted runoff and providing overall urban greening benefits.

The analysis also showed that private land uses which generate high pollutant loads include regional shopping centers, office buildings and large apartment complexes, and that these land uses can treat much of their on-site runoff through Green Solutions. By implementing Green Solutions on these types of land uses, nearly 3,000 acres of runoff could be kept out of the public drainage system.

The CCS Team's Green Solution approach integrates hydrology, pollutant loading, conservation priorities and community needs to prioritize public opportunity parcels for future water quality improvement projects.

The CCS Team analysis shows that solving polluted runoff problems requires a comprehensive approach that combines Green Solutions projects on public lands, roads, and certain suitable private land uses. Strategic conversion of existing public lands is the most important because these sites can capture and treat the highest volumes of runoff from surrounding, impervious areas – and can provide other significant public benefits through creating parks, habitat and open space that can be used by the public.

This analytical, prioritized Green Solution approach presents a practical and strategic way to move forward efficiently and in



Community Conservation Solution's unique methodology provides a rational quantified approach to selecting public lands for conversion to engineered green spaces that naturally capture and clean polluted runoff.

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RB-AR35656

an informed way to improve water quality in Santa Monica Bay and in the creeks, rivers and beaches of the Santa Monica Bay Watershed – while creating a networks of new habitat, parks and other green open space throughout the watershed in communities where these amenities are most needed. By making smart use of existing public lands, this prioritized Green Solution approach to cleaning up polluted runoff can make most efficient use of public funds, and could significantly improve water quality in the Santa Monica Bay Watershed.

Community Conservation Solutions' prioritized, integrated and strategic Green Solution approach can be implemented in any area which needs to address pressing water quality problems due to runoff, and which wishes to make best use of existing land resources and limited funding while creating the important public benefits that can be achieved by Green Solution Projects through restoring and creating "smart" habitat, park and other green open space.

Recommendations and Next Steps

Next steps should focus on selecting specific high-priority sites identified in this Green Solution Project for potential project implementation, and conducting the site-specific technical review and preliminary site design necessary to define runoff treatment capacity, site hydrology and hydraulics, and site-specific park, habitat and open space opportunities. Next steps should include developing inter-agency partnerships with site owners, estimating costs and identifying funding for site construction.

To better quantify Green Solution Project opportunities on roadways and rights-of-way on a comprehensive, watershed-wide scale, GIS data on roads with medians and parkways in the Santa Monica Bay Watershed should be assembled or created, and analyzed. Roadway analysis should include integration of multiple factors and site prioritization, as the CCS team did with specific public lands in this Phase II study. This will allow identification and prioritization of roads in the watershed, so that specific Green Solution projects on roads can be selected based on highest capacity for treatment of polluted runoff and urban greening.

> The CCS Team prioritized Green Solution approach to cleaning up polluted runoff could significantly improve water quality in the Santa Monica Bay Watershed.

Funders

This project was funded by the Santa Monica Bay Restoration Commission and the California Coastal Conservancy.

1 Los Angeles County Department of Public Works, adjusted for Santa Monica Bay Watershed percent of total for LA County Flood Control District
2 Kenneth R. Weiss and Usha Lee McFarling, "Altered Oceans, A five-part series on the crisis in the seas," Los Angeles Times, July-August 2006
3 *Ibid*
4 Suzan Given et al, "Regional Public Health Cost Estimates of Contaminated Coastal Waters: A Case Study of Gastroenteritis at Southern California Beaches," Environmental Science & Technology, Vol. 40. No. 16 (2006): 1

COMMUNITY CONSERVATION SOLUTIONS

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ABOUT The Project Team

COMMUNITY CONSERVATION SOLUTIONS

Community Conservation Solution's mission is to tackle the most complex and challenging problems created when people and nature intersect. CCS does this by developing creative, practical and lasting solutions that unite diverse communities and interests and leverage investments of public funds. CCS has successfully crafted innovative solutions to serious environmental problems affecting California's natural and human communities, by integrating the protection and restoration of natural lands and waters with compatible community uses, economic benefits and permanent public benefits.

CCS' successful project solutions include: the two-square mile Baldwin Hills Park in the heart of urban Los Angeles; wetland restoration in Upper Newport Bay; acquisition of the Spring Street Center for the Los Angeles Conservation Corps; the Los Angeles River Natural Park to naturally treat urban runoff while creating a regional river public access gateway; and developing new, quantified approaches to improving water quality through the Green Solution Project.

Community Conservation Solution works on diverse projects in urban and rural areas that help both natural habitats and people. Our projects range from parks and beaches to wilderness and watersheds, and from recreational sites to mixed-use developments. CCS is a non-profit, 501(c)(3) organization.

PSOMAS

Psomas is a leading consulting engineering firm serving clients in the water/wastewater; transportation; and public, institutional and private land development markets. Ranked as one of Engineering News Record (ENR) magazine's Top 100 Pure Design Firms in the United States, Psomas offers civil engineering, land surveying, planning and entitlements, program/construction management, natural resources, GIS consulting, and Special District Financing services to the public and private sector. Founded over 60 years ago, Psomas provides services from offices throughout California, Arizona, and Utah.

Psomas specializes in delivery of sustainable storm water management consulting and design solutions to municipalities, public and quasi-public organizations, and private sector clients. Psomas' projects range from studies to constructed solutions; challenging infill development to city and county-wide initiatives; and from integrated low impact development measures to purpose-built treatment wetland systems.

GREENINFO NETWORK

Over the past 15 years, GreenInfo Network (www.greeninfo.org) has provided Geographic Information System (GIS) and related technology support to a wide range of water, land conservation and many other types of projects throughout California and the U.S. A non-profit, GreenInfo Network assists other public interest groups and agencies working at local, regional and national scales, providing them with services including data creation and acquisition, geospatial analyses, geographic modeling, conservation and land use planning, watershed-based planning and modeling, database development, and high quality communications design and cartography. GreenInfo Network's staff is highly skilled in effective, efficient and creative use of information technology to help clients more effectively understand and communicate the relationships between issues, people and places.

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www.conservationsolutions.org/greensolution.html

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MAPS

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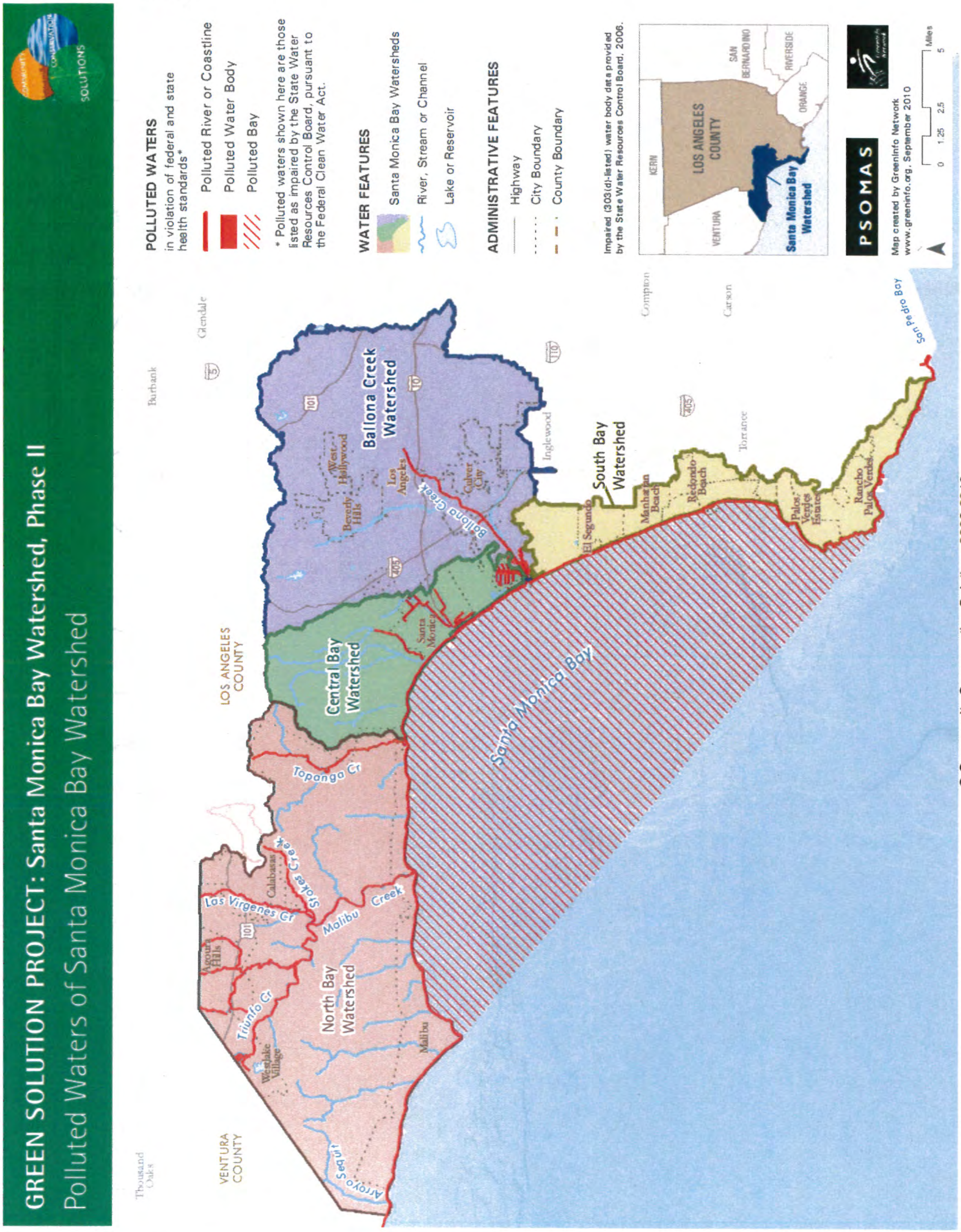

Polluted Waters of Santa Monica Bay Watershed

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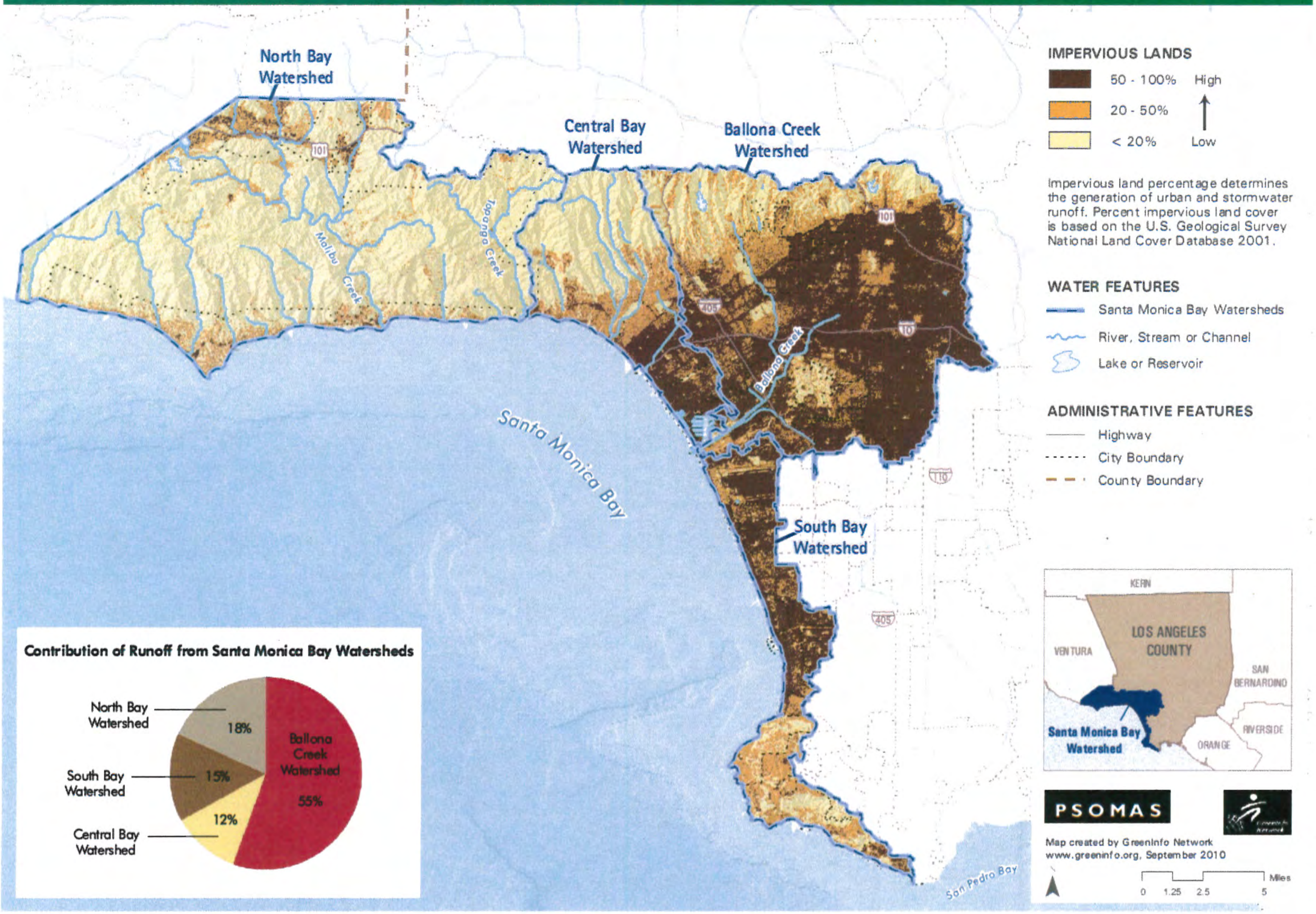
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Impervious Lands and Pollutant Loading



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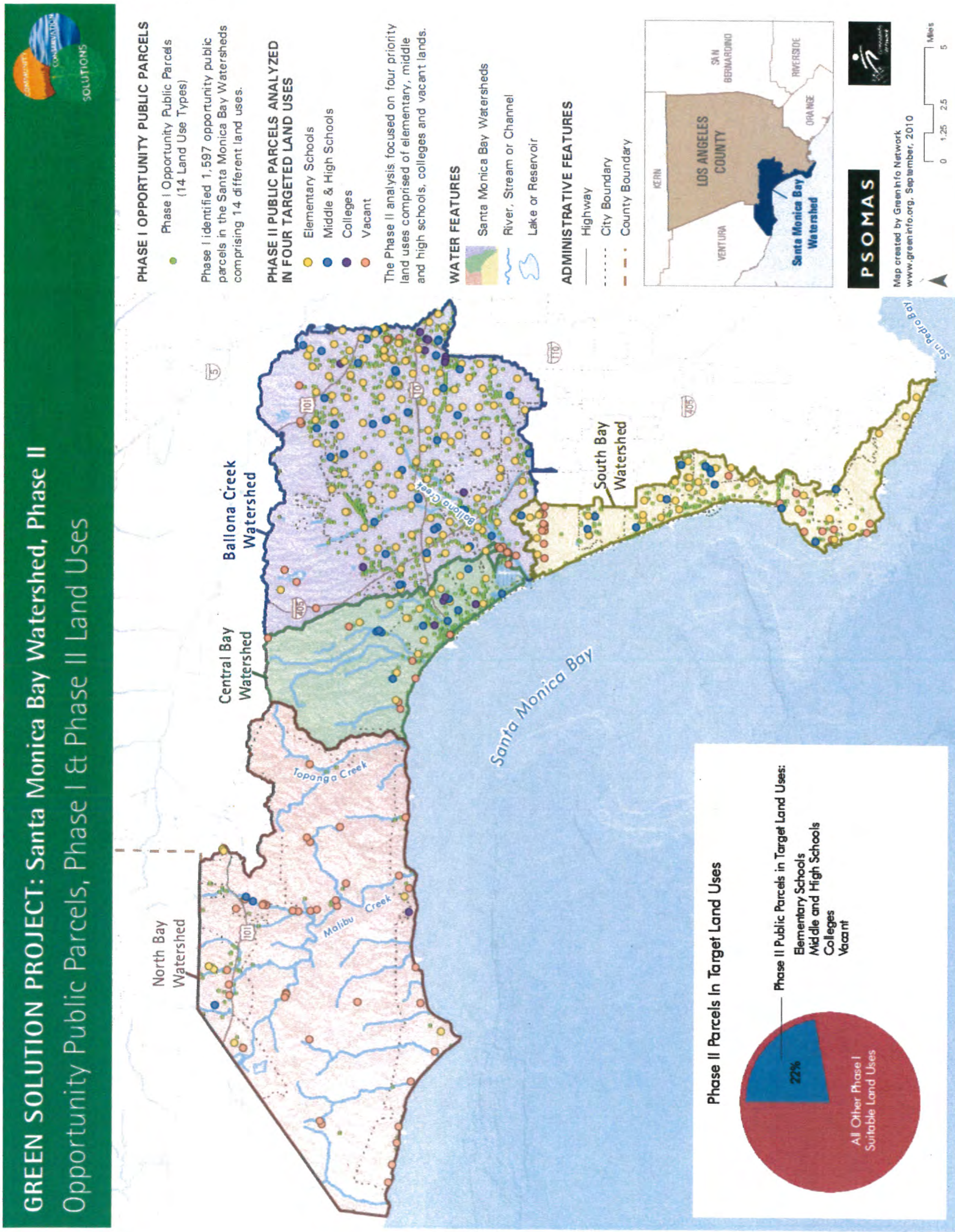
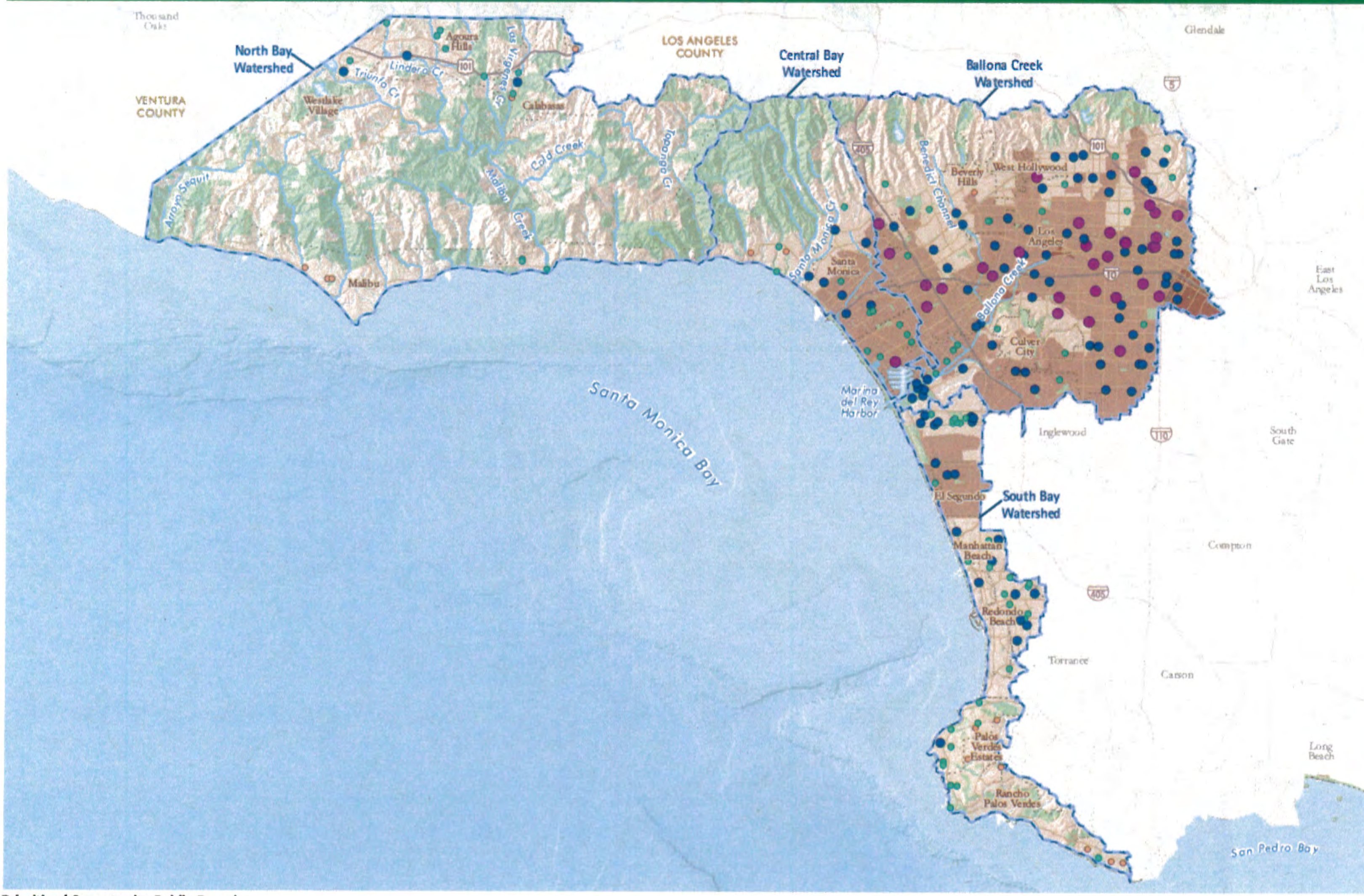
Impervious Lands and Pollutant Loading



Opportunity Public Parcels, Phase I & Phase II Land Uses – Santa Monica Bay Watersheds

GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels



PRIORITIZED OPPORTUNITY PUBLIC PARCELS INTEGRATING WATER QUALITY, COMMUNITY & CONSERVATION NEEDS

Runoff quantity and pollutant load, community needs and open space/habitat proximity were integrated to evaluate, rank and prioritize opportunity public parcels for Green Solution project implementation. Parcels shown are elementary, middle and high schools, colleges and vacant lands that meet size, slope and storm drain proximity criteria.

Parcel Score		# Parcels
High	5	32
	4	95
	3	70
Low	1-2	15

WATER FEATURES

- Watershed Boundary
- River, Stream or Channel
- Lake or Reservoir

POLLUTED RUNOFF CLEANUP PRIORITY
Score, Catchment Prioritization Index (CPI)

Very High	5
High	4
Low to Moderate	1-3

CPI is an indicator of polluted runoff treatment need. CPI scores are based on land use, estimated runoff pollutant concentrations and average precipitation.

ADMINISTRATIVE FEATURES

- Highway
- Major Road
- City Boundary
- Park / Open Space

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Map created by GreenInfo Network
www.greeninfo.org, September 2010

0 1.25 2.5 5 Miles

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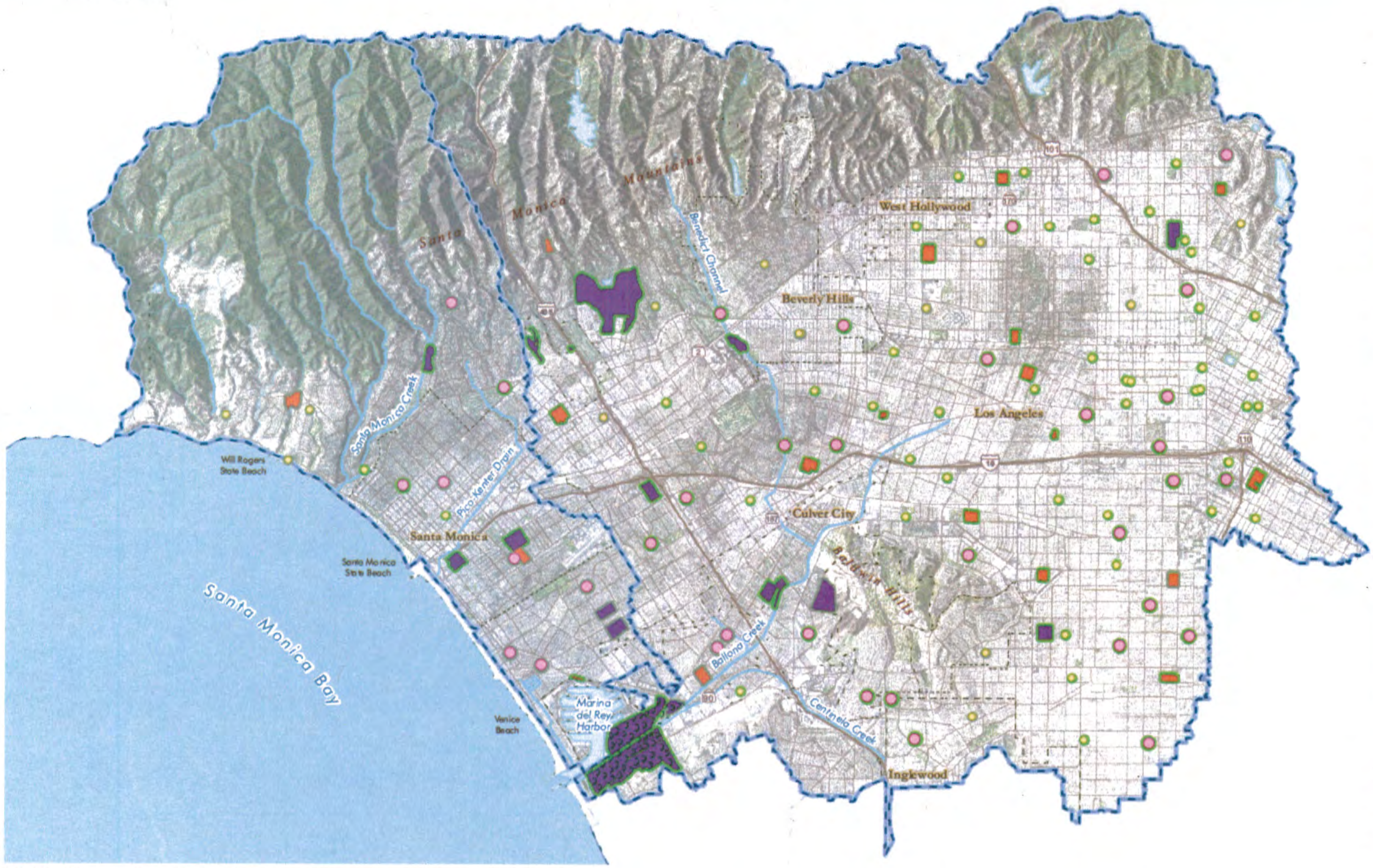
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Size, Ballona Creek & Central Bay Watersheds



PRIORITIZED OPPORTUNITY PUBLIC PARCELS INTEGRATING WATER QUALITY, COMMUNITY & CONSERVATION NEEDS

Runoff quantity and pollutant load, community needs and open space/habitat proximity were integrated to evaluate, rank and prioritize opportunity public parcels for Green Solution project implementation. Parcels shown are elementary, middle/ high schools, colleges and vacant lands that meet size, slope and storm drain proximity criteria.

OPPORTUNITY PUBLIC PARCELS BY SIZE

- Less than 5 acres
- 5 to 10 acres
- 10 to 25 acres
- 25 acres or larger

OPPORTUNITY PUBLIC PARCELS BY SCORE

	Parcel Score		# Parcels
	High	4-6	104
	Low-Med	1-3	33

WATER FEATURES

- Watershed Boundary
- River, Stream or Channel
- Lake or Reservoir

ADMINISTRATIVE FEATURES

- Highway
- City Boundary
- California Dept. of Fish and Game Ecological Reserve

KERN
VENTURA
LOS ANGELES COUNTY
SAN BERNARDINO
Santa Monica Bay Watershed
ORANGE
RIVERSIDE

PSOMAS

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0 0.5 1 2 Miles

Prioritized Opportunity Public Parcels by Size, Ballona Creek & Central Bay Watersheds

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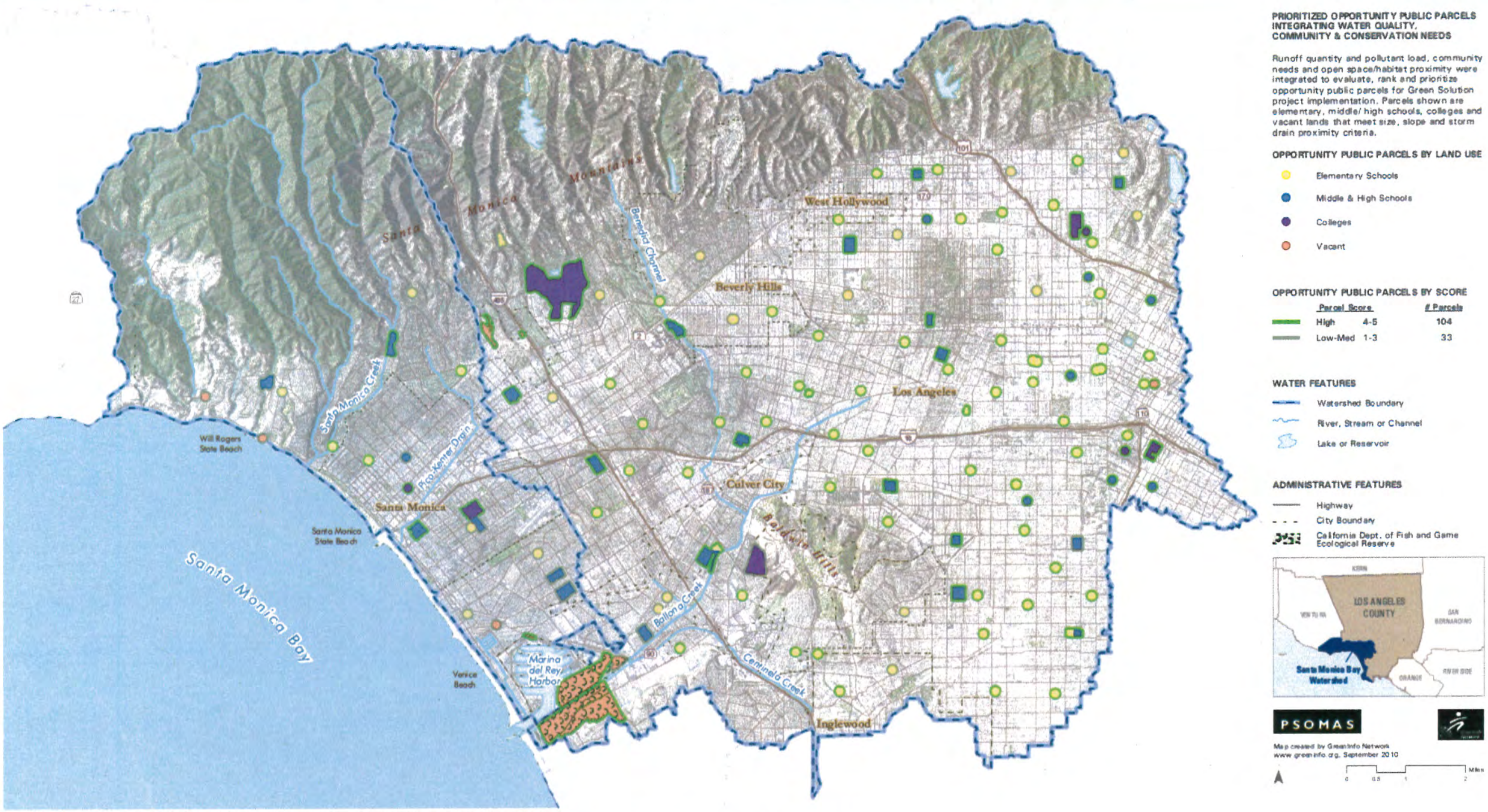
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Land Use, Ballona Creek & Central Bay Watersheds



Prioritized Opportunity Public Parcels by Land Use, Ballona Creek & Central Bay Watersheds

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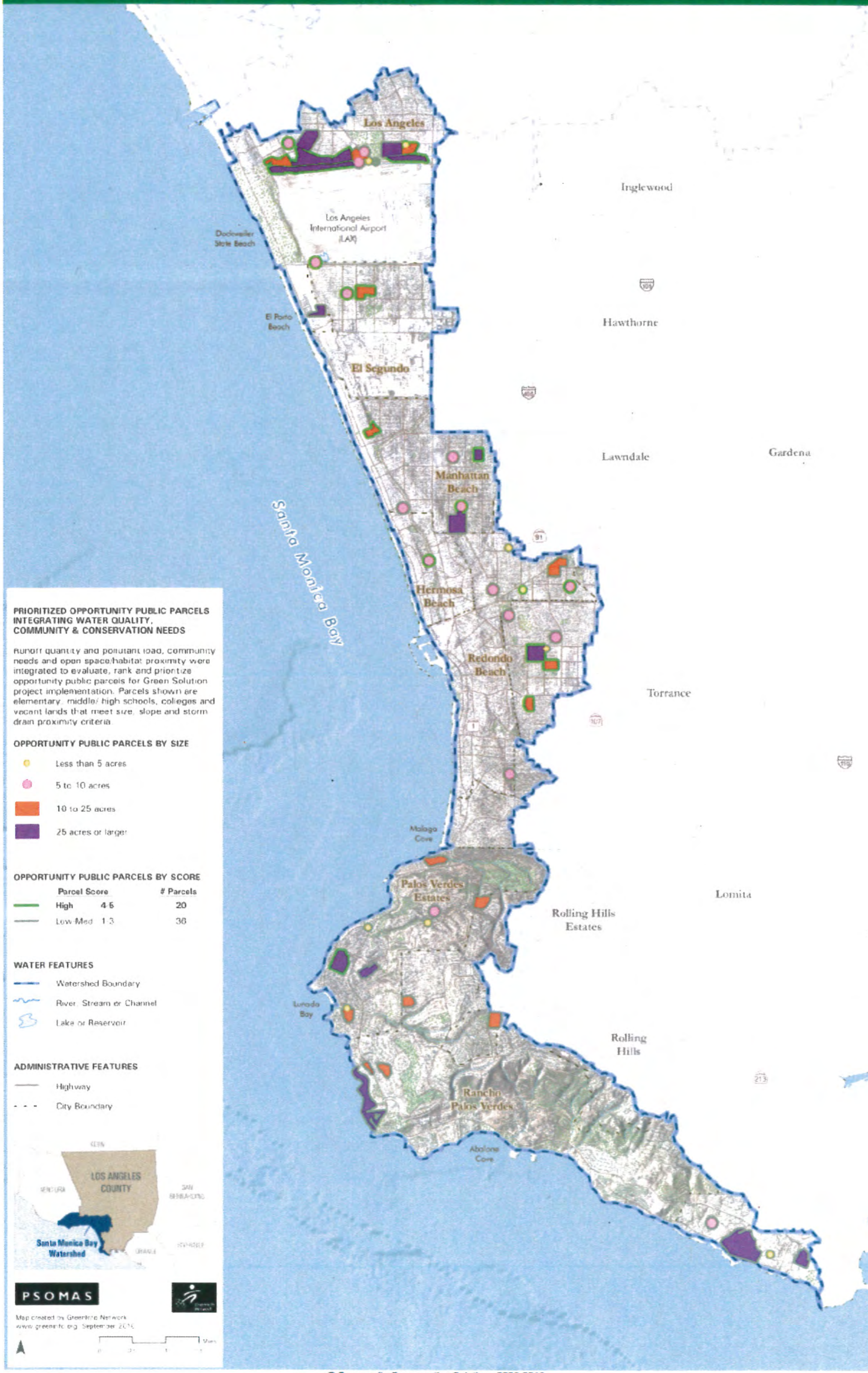
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Size, South Bay Watershed



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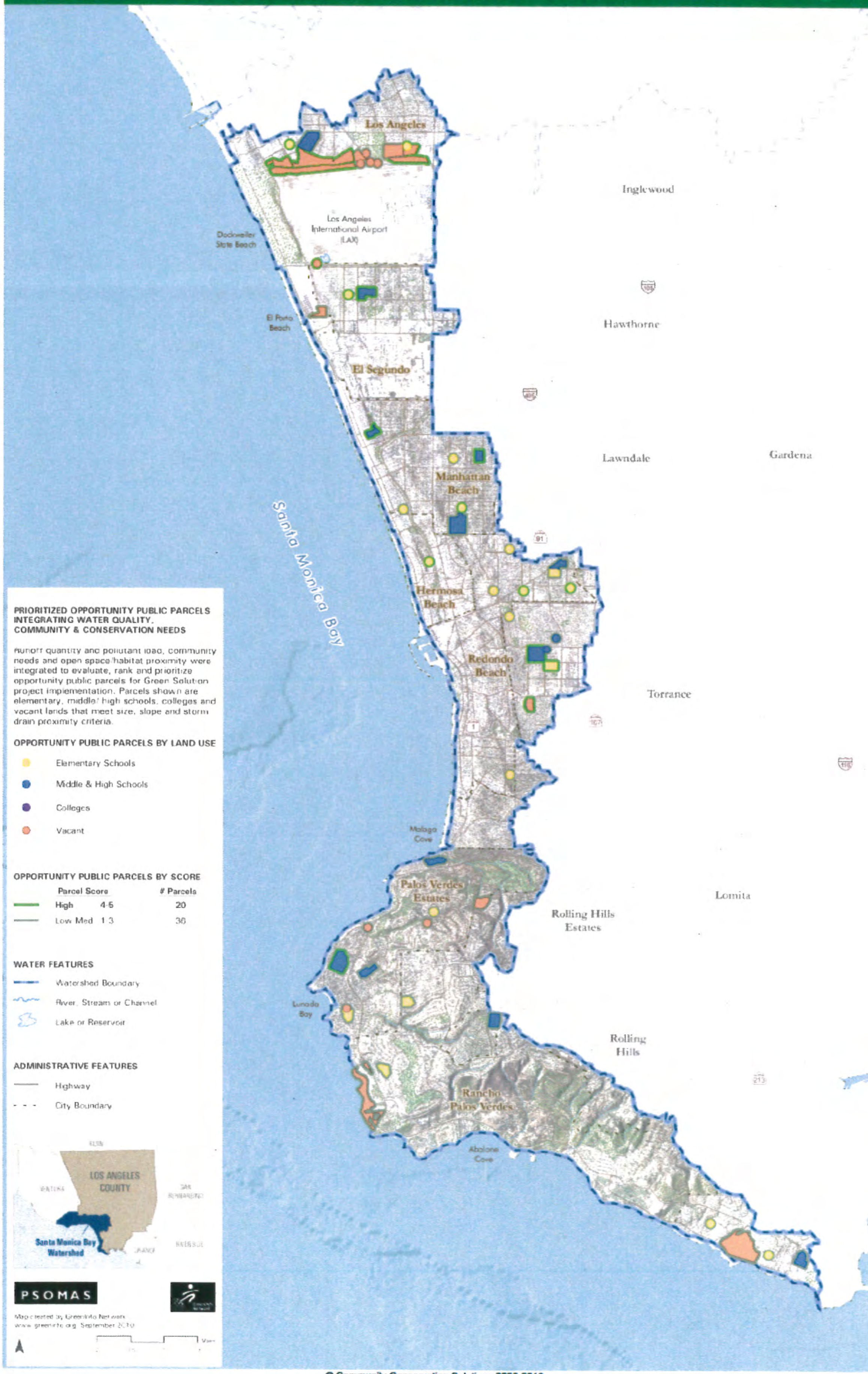
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Land Use, South Bay Watershed



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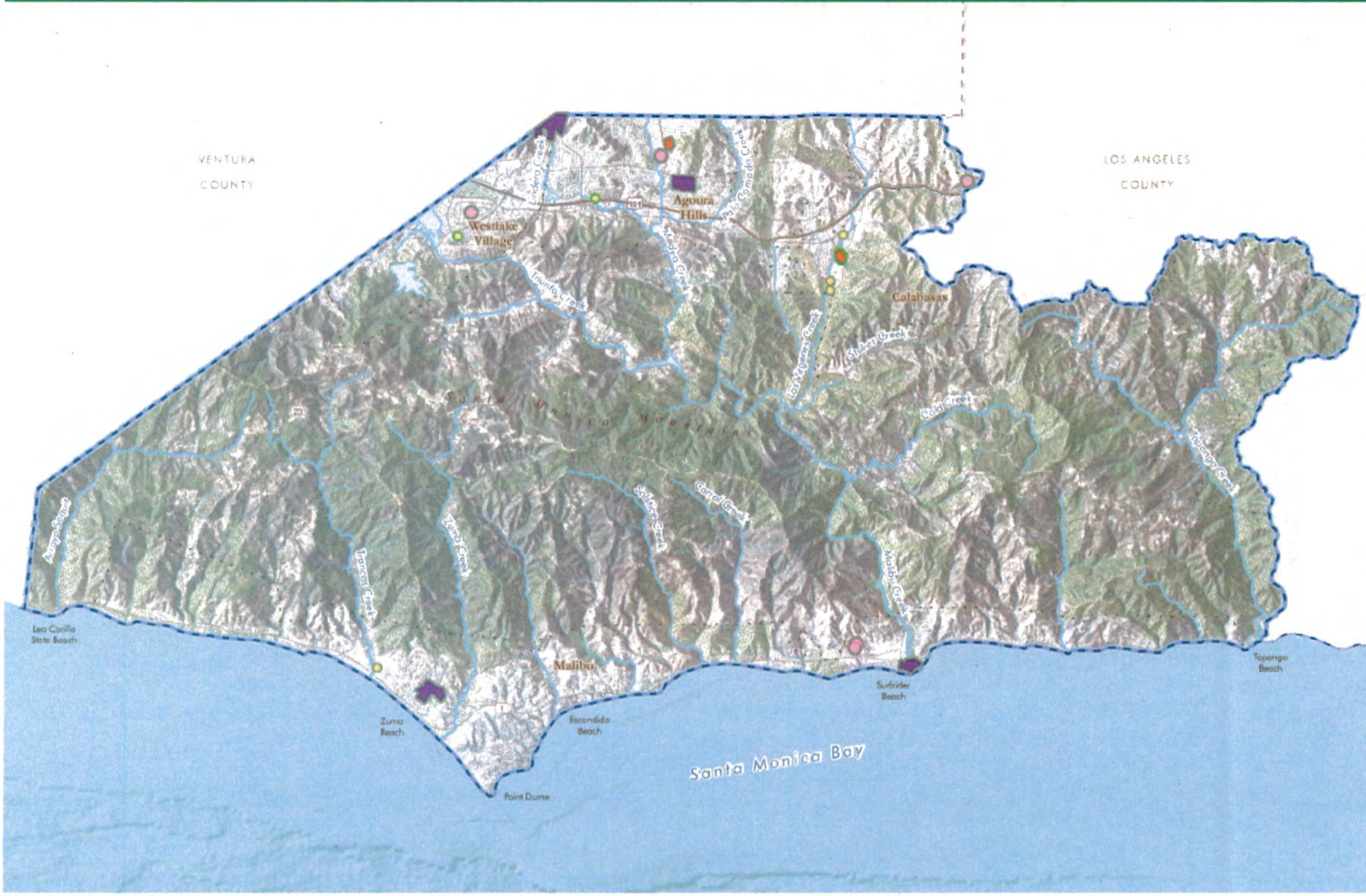
GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Size, North Bay Watershed



PRIORITIZED OPPORTUNITY PUBLIC PARCELS INTEGRATING WATER QUALITY, COMMUNITY & CONSERVATION NEEDS

Runoff quantity and pollutant load, community needs and open space/habitat proximity were integrated to evaluate, rank and prioritize opportunity public parcels for Green Solution project implementation. Parcels shown are elementary, middle/ high schools, colleges and vacant lands that meet size, slope and storm drain proximity criteria.

OPPORTUNITY PUBLIC PARCELS BY SIZE

- Less than 5 acres
- 5 to 10 acres
- 10 to 25 acres
- 25 acres or larger

OPPORTUNITY PUBLIC PARCELS BY SCORE

Parcel Score		# Parcels
High	4-5	3
Low-Med	1-3	16

WATER FEATURES

- Watershed Boundary
- River, Stream or Channel
- Lake or Reservoir

ADMINISTRATIVE FEATURES

- Highway
- City Boundary

PSOMAS

Map created by GreenInfo Network www.greeninfo.org, September 2010

Prioritized Opportunity Public Parcels by Size, North Bay Watershed

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GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Prioritized Opportunity Public Parcels by Land Use, North Bay Watershed

Prioritized Opportunity Public Parcels by Land Use, North Bay Watershed

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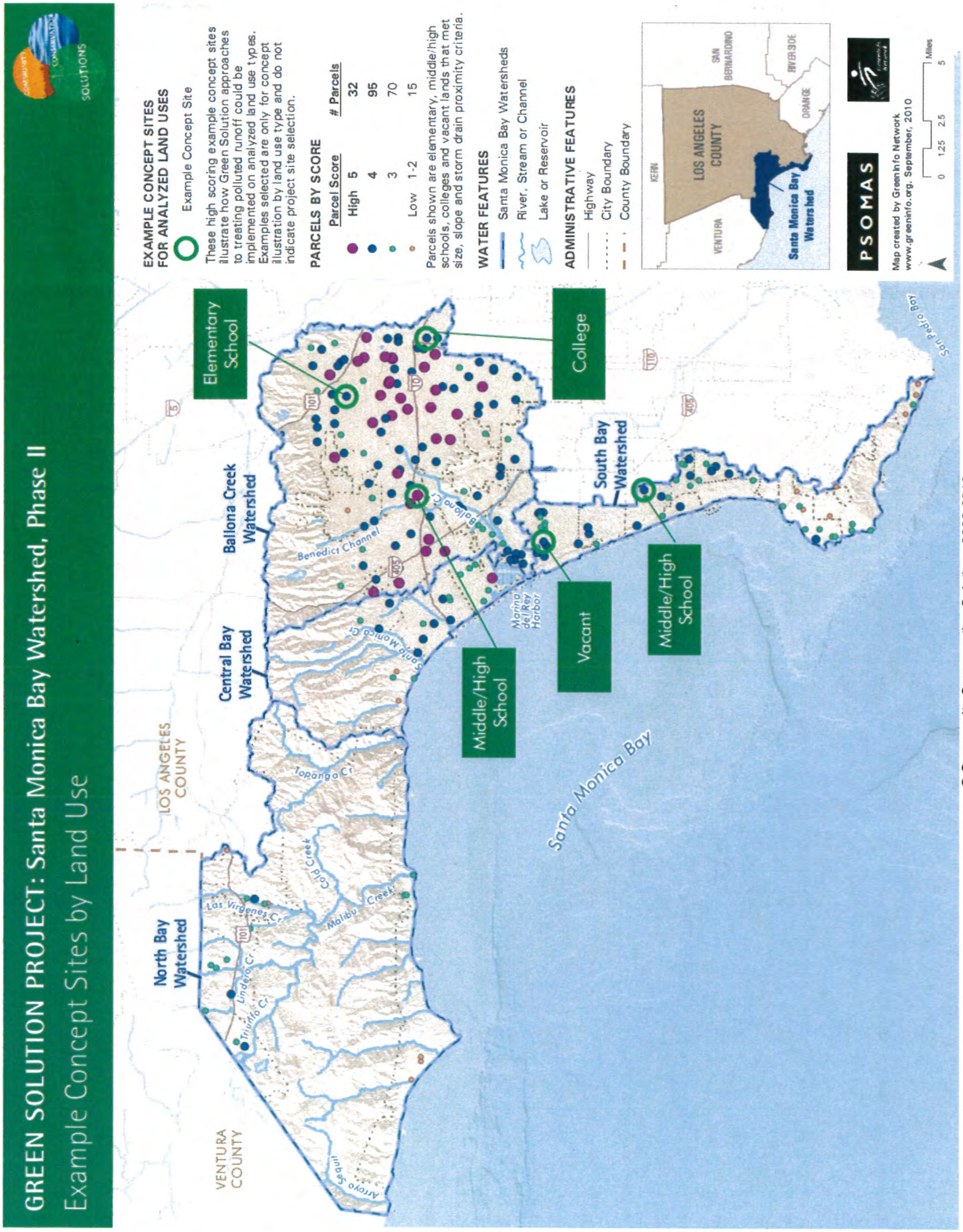
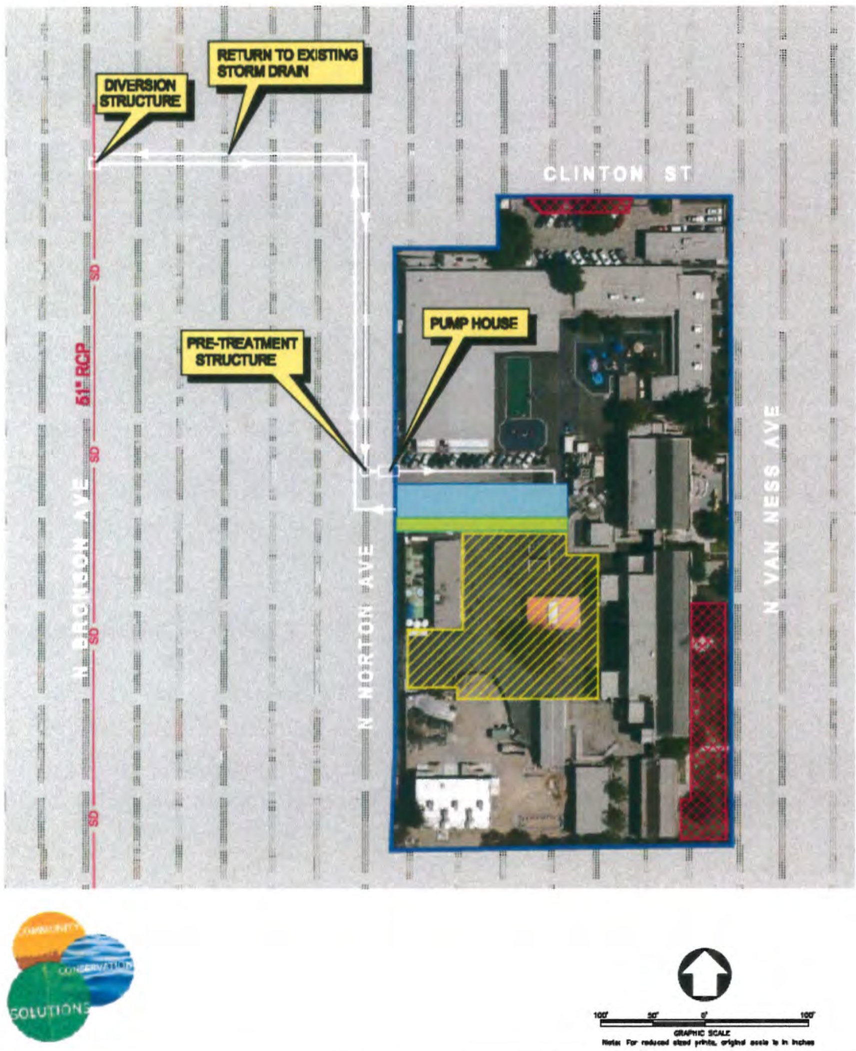


Example Concept Sites by Land Use



Site Characteristics

Site Area (Ac):	4.56 Ac
Percent of Site Used for GSP:	16%
Existing Impervious:	4.1 Ac
Proposed Impervious:	3.5 Ac

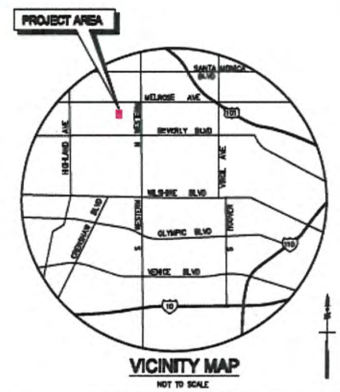
Runoff Treatment Potential

Proposed Treatment Volume:	14,000 ft³
Associated Treatment Area*:	7.0 Ac

*Treatment area could be on-site or off-site area and is defined by the first flush storm event of 0.75" across the effective tributary area.

LEGEND

- SD 51" RCP — EXISTING STORM DRAIN, MATERIAL & SIZE
- PROPOSED STORM DRAIN
- PARCEL BOUNDARY
- DIVERSION STRUCTURE
- STRUCTURAL PRE-TREATMENT
- PUMP HOUSE
- SUBSURFACE DETENTION/ RETENTION. RE-SURFACE WITH TURF PERMEABLE/ POROUS PAVEMENT
- GRASS BUFFER STRIP
- CONVERSION AREA
- RETRO FIT AREA



Project Setting and Characteristics

- On the ground distance to storm drain: 560'
- Approximate storm drain size: 51"
- The parcel is located in the Oakwood Community of the City of Los Angeles and is representative of most elementary schools in the watershed.
- Elementary school sites typically have fewer opportunities for surface types of BMPs such as swales and basins. Because they do not typically have large athletic fields the sites are generally smaller and have higher building densities. Furthermore, since students do not drive to these schools parking lots are generally small in size.
- The surrounding potential contributing area is primarily residential with some commercial parcels. (Assumed 70% Impervious)
- The primary purpose of this concept plan is to identify BMPs which could treat off-site urban runoff. Additional site BMPs such as directing roof runoff to landscape areas, upgrading irrigation facilities, etc. would be utilized with detailed site analysis.

Design Description

A sub-surface diversion structure will divert flows from the existing storm drain pipe and send flows through a pre-treatment structure. Then, flows will be pumped into a subsurface detention/retention basin. Existing asphalt on top of the detention/retention basin and surrounding areas will be replaced with porous paving. Once adequate detention time has been achieved the flows are returned back to the existing storm drain system. The sub-surface basin is the primary BMP for off-site and a portion of on-site flows. On-site flows will be primarily treated by the grass buffer strip, and proposed conversion and retrofit areas, which may include vegetated swales, rain gardens, and conversion from asphalt to porous paving/landscape areas.

Concept Site Design for a Elementary School Ballona Creek Parcel 01 Exhibit M.2

PSOMAS

DATE: 4-29-2010 REVISED ON:
JOB No:1CCI010100
SHEET 1 OF #
CCI-100-01

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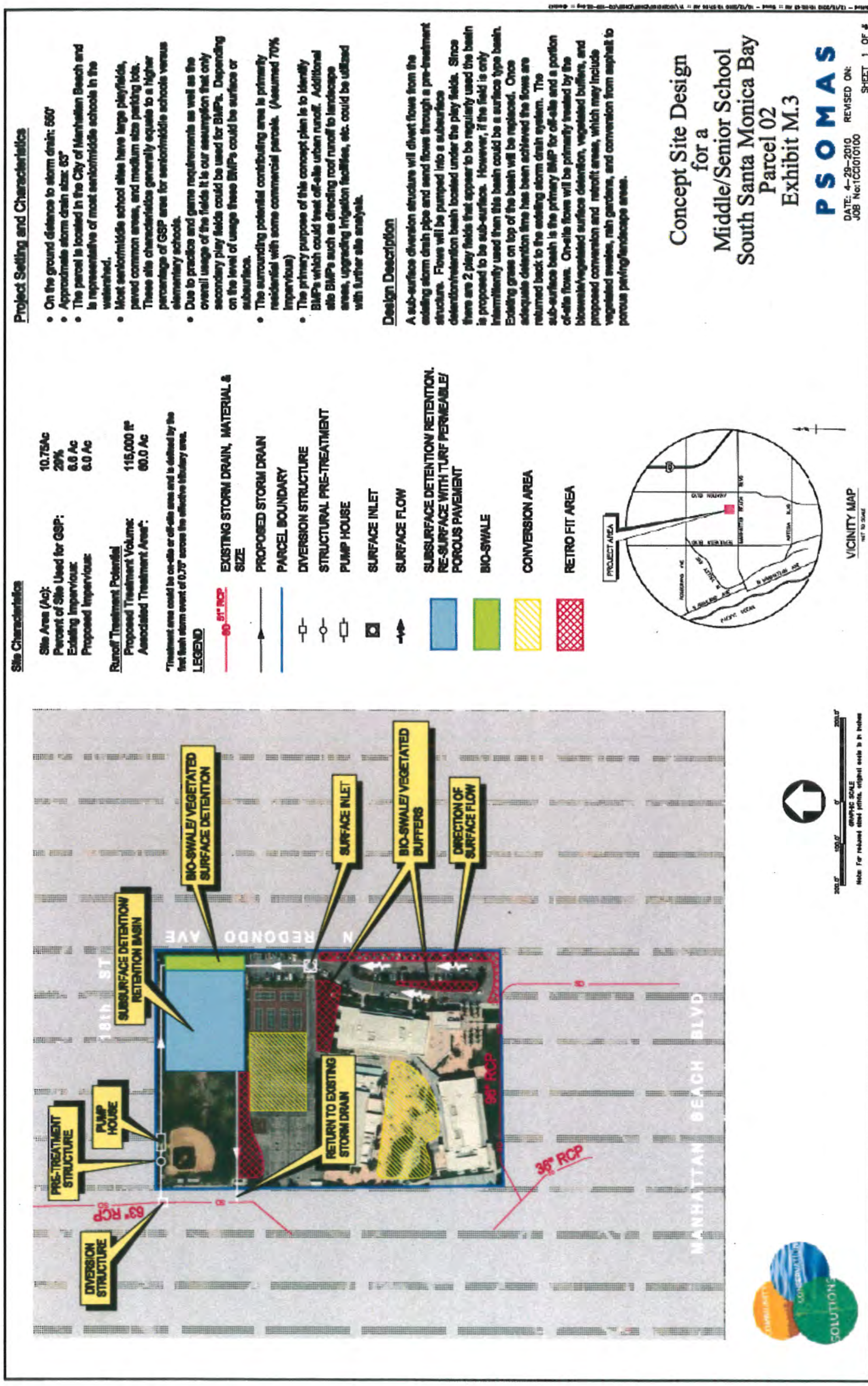
Concept Site Design for a Elementary School, Ballona Creek



Concept Site Design for a Middle/Senior School, South Santa Monica Bay

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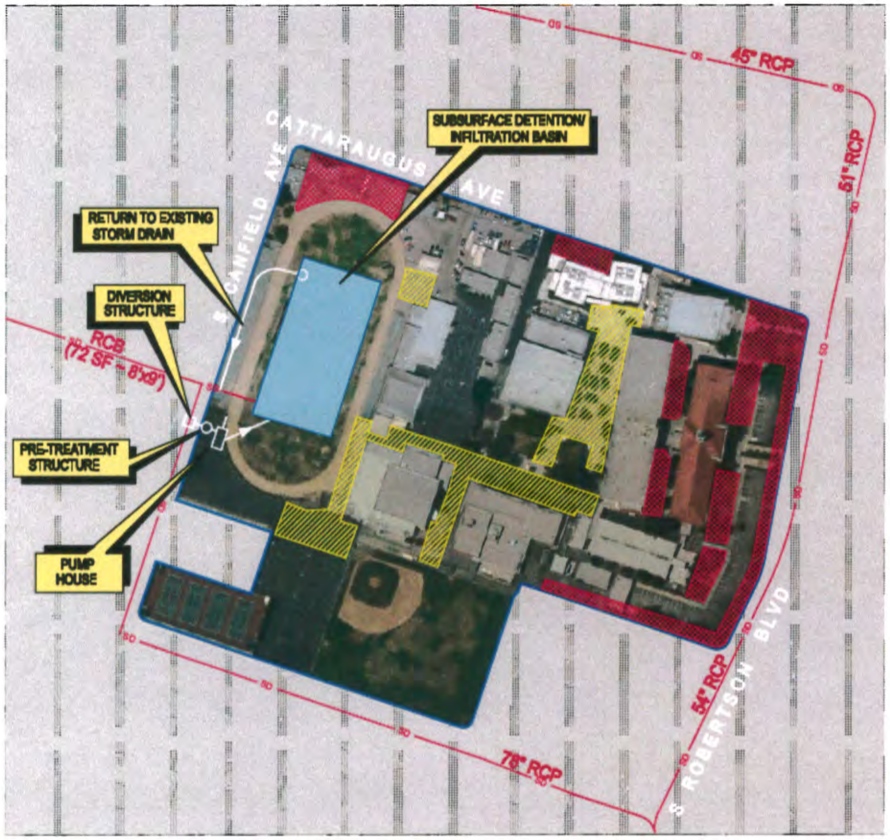
RB-AR35673



Site Characteristics

Site Area (Ac):	20.74 Ac
Percent of Site Used for GSP:	22%
Existing Impervious:	11.95 Ac
Proposed Impervious:	11.05 Ac

Runoff Treatment Potential

Proposed Treatment Volume:	113,000 ft³
Associated Treatment Area*:	60.0 Ac

*Treatment area could be on-site or off-site area and is defined by the first flush storm event of 0.75" across the effective tributary area.

LEGEND

- SD 51" RCP — EXISTING STORM DRAIN, MATERIAL & SIZE
- PROPOSED STORM DRAIN
- PARCEL BOUNDARY
- DIVERSION STRUCTURE
- STRUCTURAL PRE-TREATMENT
- PUMP HOUSE
- SUBSURFACE DETENTION/ INFILTRATION BASIN
- CONVERSION AREA
- RETRO FIT AREA

Project Setting and Characteristics

- On the ground distance to storm drain: 20'
- Approximate storm drain size: 78"
- The parcel is located near the Cheviot Hills Community of the City of Los Angeles and is representative of most senior/middle schools in the watershed.
- It is our assumption that only secondary play fields could be used for BMPs. Depending on the level of usage these BMPs could be surface or subsurface.
- The surrounding potential contributing area is mixed residential and commercial parcels. (Assumed 70% Impervious)
- The primary purpose of this concept plan is to identify BMPs which could treat off-site urban runoff. Additional site BMPs such as directing roof runoff to landscape areas, upgrading irrigation facilities, etc. could be utilized with further site analysis.

Design Description

A sub-surface diversion structure will divert flows from the existing storm drain pipe and send flows through a pre-treatment structure. Flows will be pumped into a subsurface detention/infiltration basin located under the football field. Since it appears to be regularly used the basin is proposed to be sub-surface. However, if the field is only intermittently used then this basin could be a surface type basin. Existing grass on top of the basin will be replaced. Once adequate detention time has been achieved the flows will be returned back to the existing storm drain system. The sub-surface basin is the primary BMP for off-site flows. Some on-site flows will be treated via conversion and retrofit areas including vegetated swales and conversion from asphalt to porous paving/landscape areas.

Concept Site Design
for a
Middle / Senior School
Ballona Creek
Parcel 03
Exhibit M.4

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SHEET 1 OF #

GRAPHIC SCALE

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Concept Site Design for a Middle/Senior School, Ballona Creek

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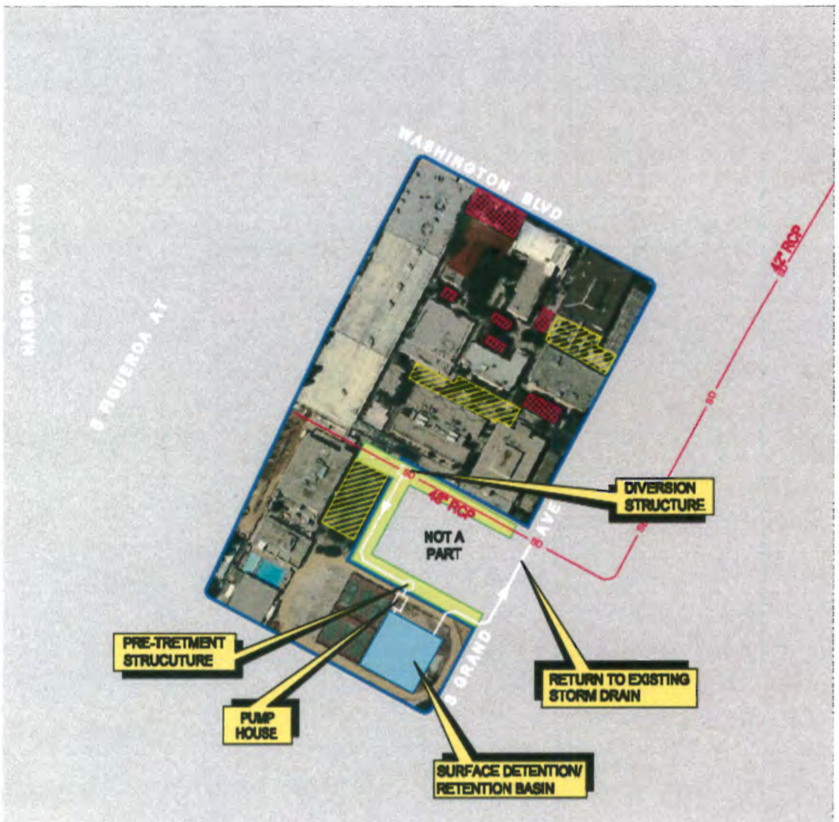


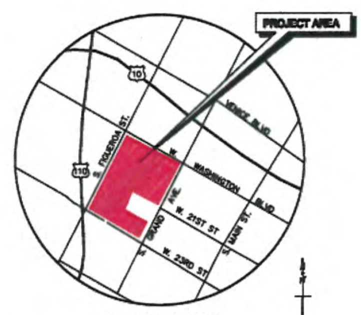
Site Characteristics

Site Area (Ac):	21.66 Ac
Percent of Site Used for GSP:	16%
Existing Impervious:	18.7 Ac
Proposed Impervious:	18.2 Ac
Runoff Treatment Potential	
Proposed Treatment Volume:	74,000 ft³
Associated Treatment Area*:	36.0 Ac

*Treatment area could be on-site or off-site area and is defined by the first flush storm event of 0.75" across the effective tributary area.

LEGEND

- SD 51" RCP — EXISTING STORM DRAIN, MATERIAL & SIZE
- PROPOSED STORM DRAIN
- PARCEL BOUNDARY
- DIVERSION STRUCTURE
- STRUCTURAL PRE-TREATMENT
- PUMP HOUSE
- SUBSURFACE DETENTION/ INFILTRATION BASIN
- CONVERSION AREA
- RETRO FIT AREA
- GREEN STREET CONVERSION



VICINITY MAP
NOT TO SCALE

Project Setting and Characteristics

- On the ground distance to storm drain: 450'
- Approximate storm drain size: 48"
- The parcel is located near Downtown Los Angeles and is representative of an urban college in the watershed.
- Due to the dense urban nature of this site only one play field was identified for use as a BMP. Depending on the level of usage of the field the BMP could be surface or subsurface.
- The surrounding potential contributing area is highly urban with industrial and commercial parcels. (Assumed 80% impervious)
- The primary purpose of this concept plan is to identify BMPs which could treat off-site urban runoff. Additional site BMPs such as directing roof runoff to landscape areas, upgrading irrigation facilities, etc. could be utilized with further site analysis.
- Conversion of 21st Street, 22nd Street, and Hope Street within the campus to Green Streets could also be completed as part of a Green Solution Project.

Design Description

A sub-surface diversion structure will divert flows from the existing storm drain pipe and send flows through a pre-treatment structure. Flows will be pumped into a surface detention/infiltration basin located within the limits of the practice field. Since it appears that the field area is too small for regulation games the basin is proposed to be surface. However, if the field has a high usage then this basin could be a sub-surface type basin. Existing grass on top of the basin will be replaced. Once adequate detention time has been achieved the flows will be returned back to the existing storm drain system. The sub-surface basin is the primary BMP for off-site flows. Some on-site flows will be treated via conversion and retrofit areas including vegetated swales and conversion from asphalt to porous paving/landscape areas. The portions of the existing public streets that pass through the campus could be converted to Green Streets which could incorporate tree well basins, curb extensions, etc. for onsite treatment.

Concept Site Design
for a
College
Ballona Creek
Parcel 04
Exhibit M.5

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CCI–100–04

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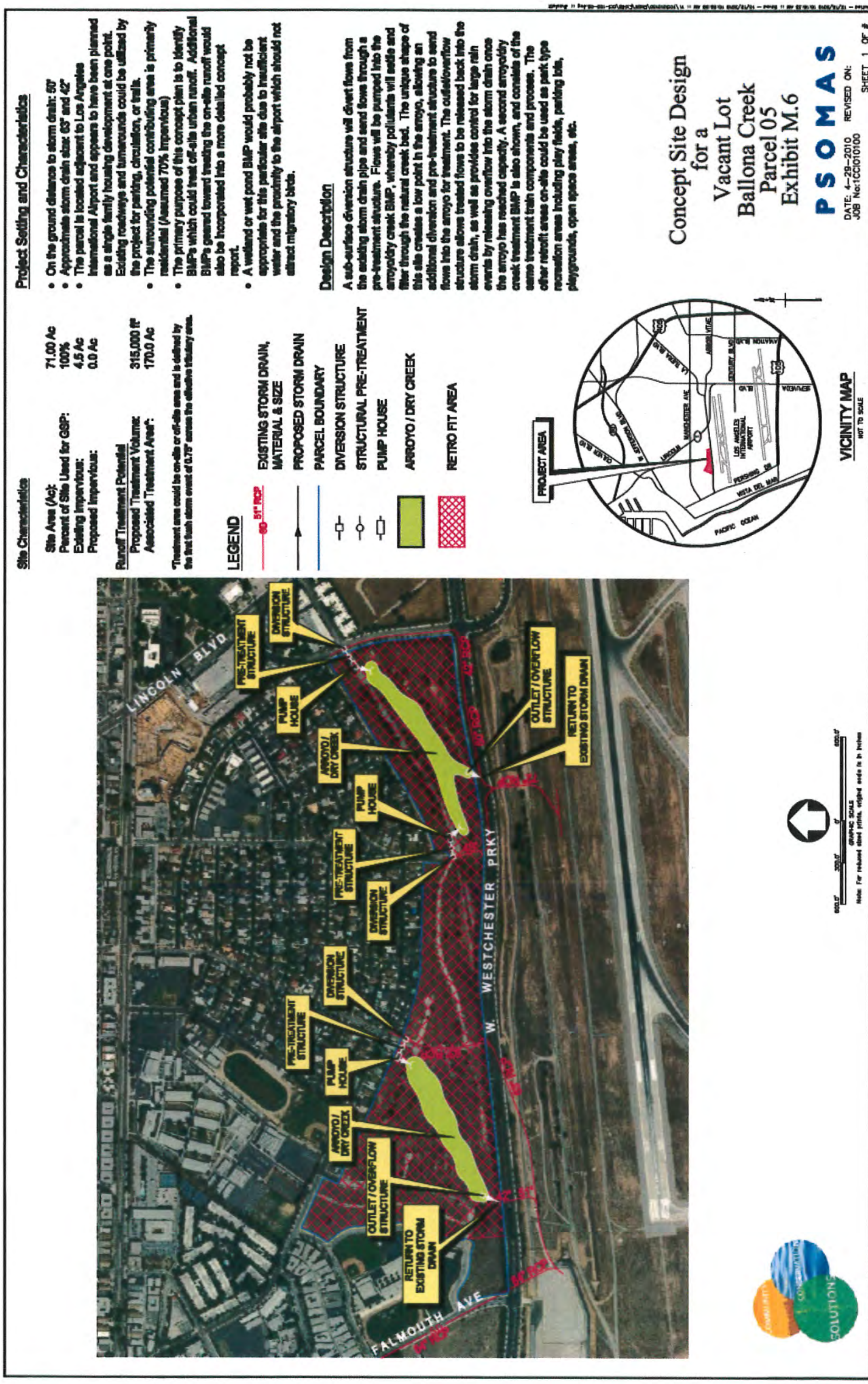
Concept Site Design for a College, Ballona Creek

RB-AR35675



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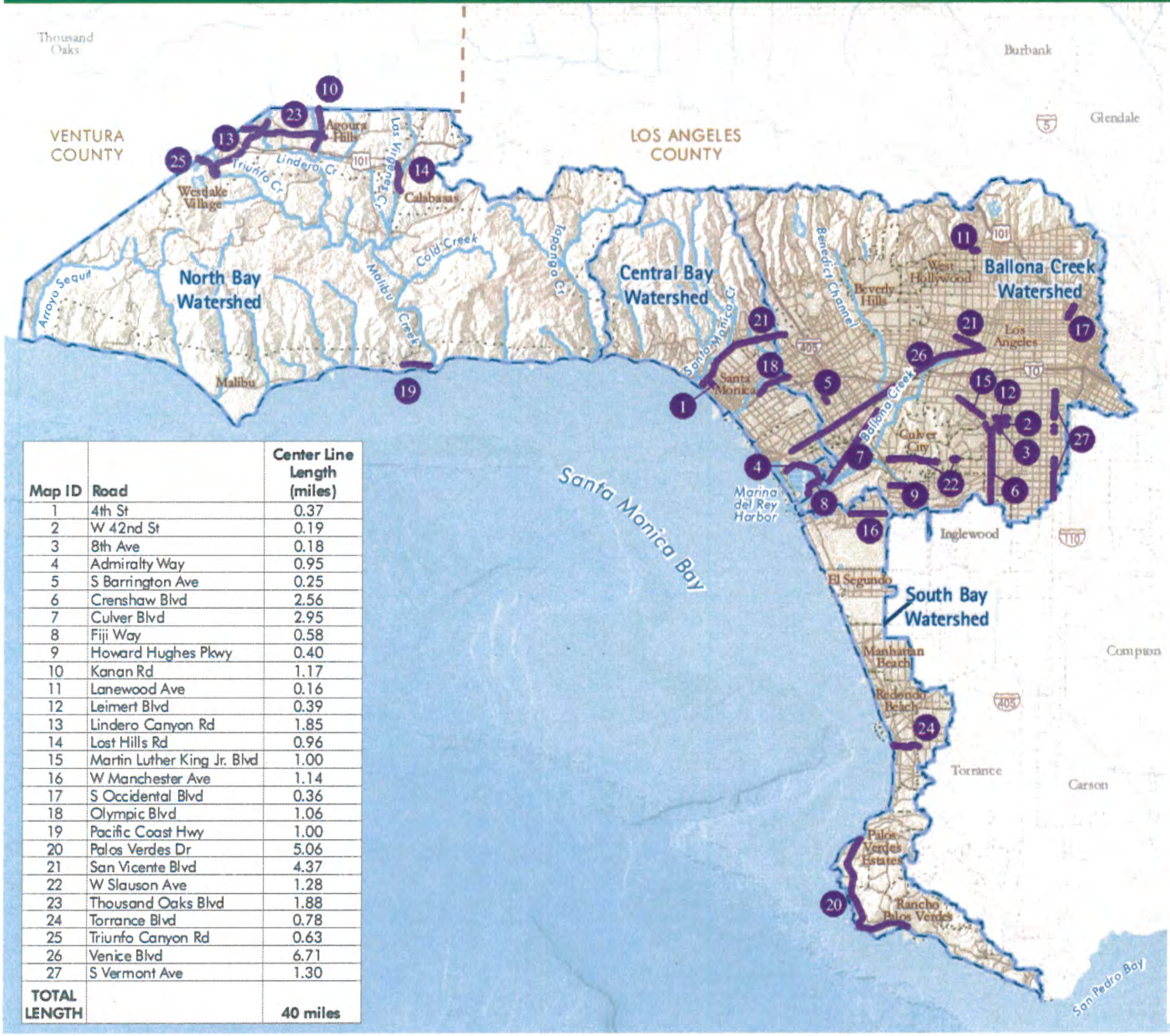
Concept Site Design for a Vacant Lot, Ballona Creek

RB-AR35676

GREEN SOLUTION PROJECT: Santa Monica Bay Watershed, Phase II

Example Opportunity Roads and Rights-of-Way



Map ID	Road	Center Line Length (miles)
1	4th St	0.37
2	W 42nd St	0.19
3	8th Ave	0.18
4	Admiralty Way	0.95
5	S Barrington Ave	0.25
6	Crenshaw Blvd	2.56
7	Culver Blvd	2.95
8	Fiji Way	0.58
9	Howard Hughes Pkwy	0.40
10	Kanan Rd	1.17
11	Lanewood Ave	0.16
12	Leimert Blvd	0.39
13	Lindero Canyon Rd	1.85
14	Lost Hills Rd	0.96
15	Martin Luther King Jr. Blvd	1.00
16	W Manchester Ave	1.14
17	S Occidental Blvd	0.36
18	Olympic Blvd	1.06
19	Pacific Coast Hwy	1.00
20	Palos Verdes Dr	5.06
21	San Vicente Blvd	4.37
22	W Slauson Ave	1.28
23	Thousand Oaks Blvd	1.88
24	Torrance Blvd	0.78
25	Triunfo Canyon Rd	0.63
26	Venice Blvd	6.71
27	S Vermont Ave	1.30
TOTAL LENGTH		40 miles

ROADS AND RIGHTS-OF-WAY: Example Opportunities for Green Solution Projects

Roadway

Roads highlighted are examples of streets and rights-of-way that could potentially incorporate Green Solution approaches to capture and treat runoff. Selections are based on visual inspection of aerial data and are not a comprehensive list.

For Example Roads Shown

Treatment capacity	up to 2600 acres
Average width	129 feet
Average median & parkway width	30 feet

Treatment capacity varies with road type; roads with medians and parkways provide highest treatment capacity.

WATER FEATURES

Santa Monica Bay Watersheds
River, Stream or Channel
Lake or Reservoir

ADMINISTRATIVE FEATURES

Highway
Main Road
City Boundary
County Boundary

PSOMAS

Map created by GreenInfo Network
www.greeninfo.org, September, 2010

0 1.25 2.5 5 Miles

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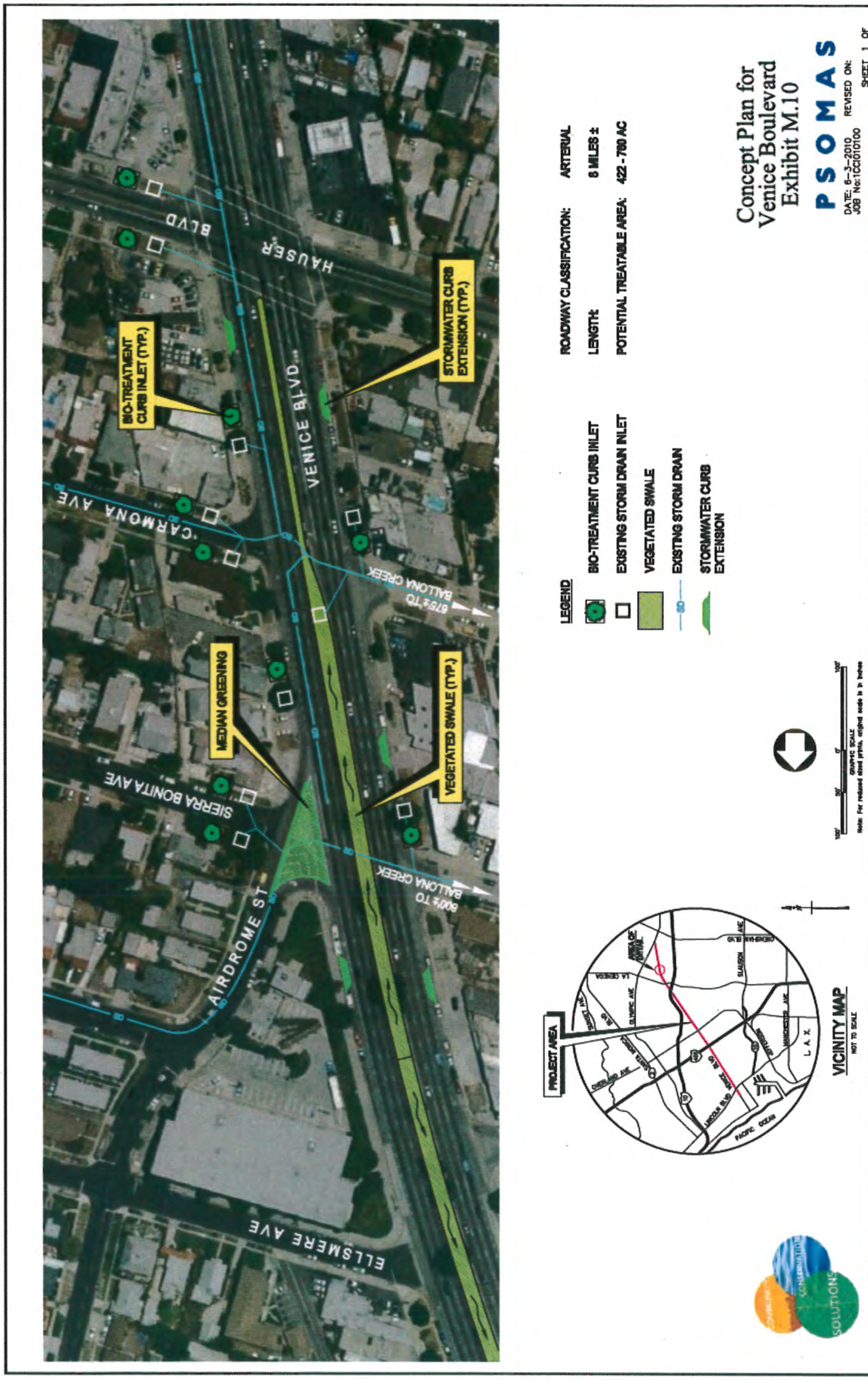
RB-AR35677



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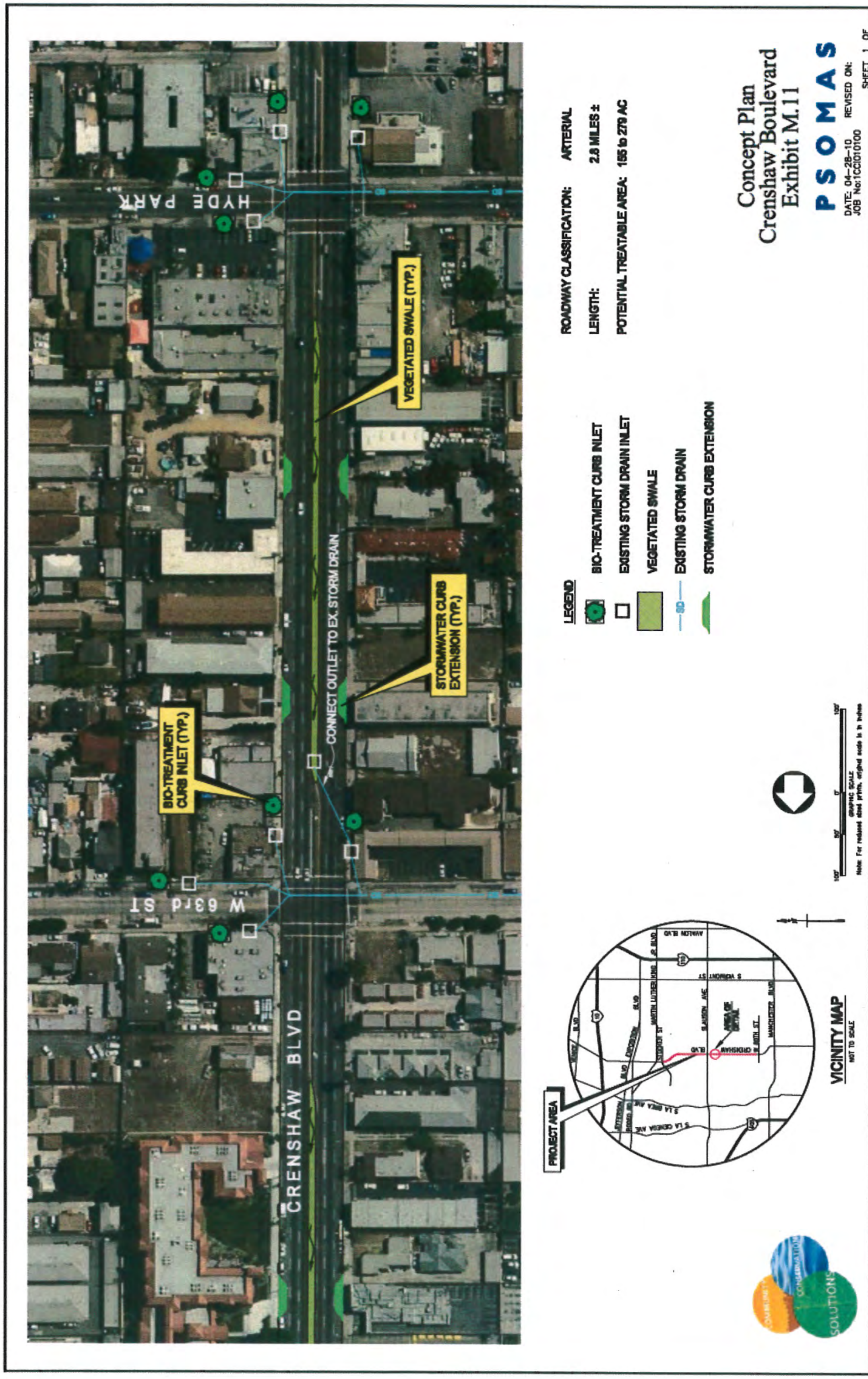
Concept Plan for Venice Boulevard

RB-AR35678



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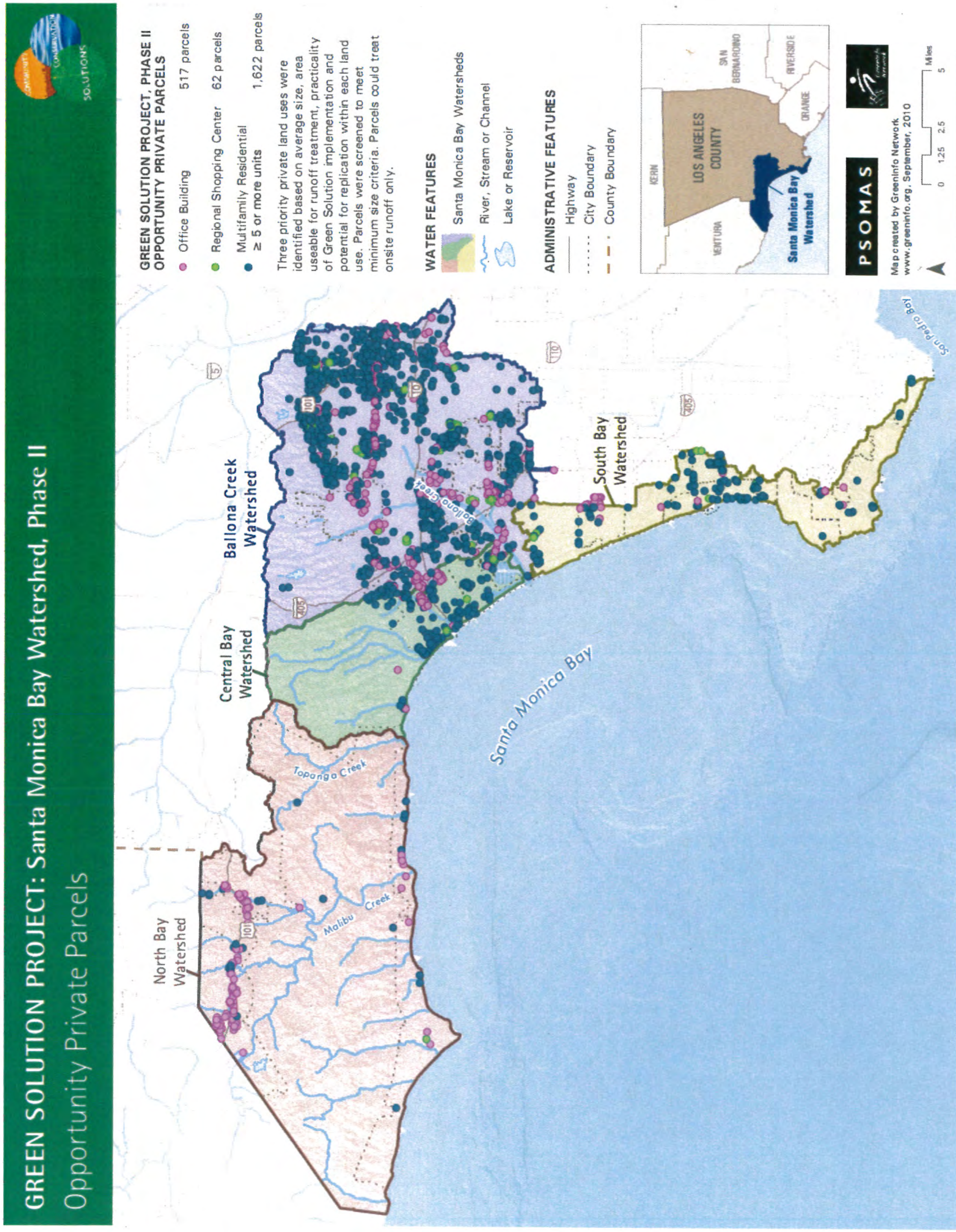
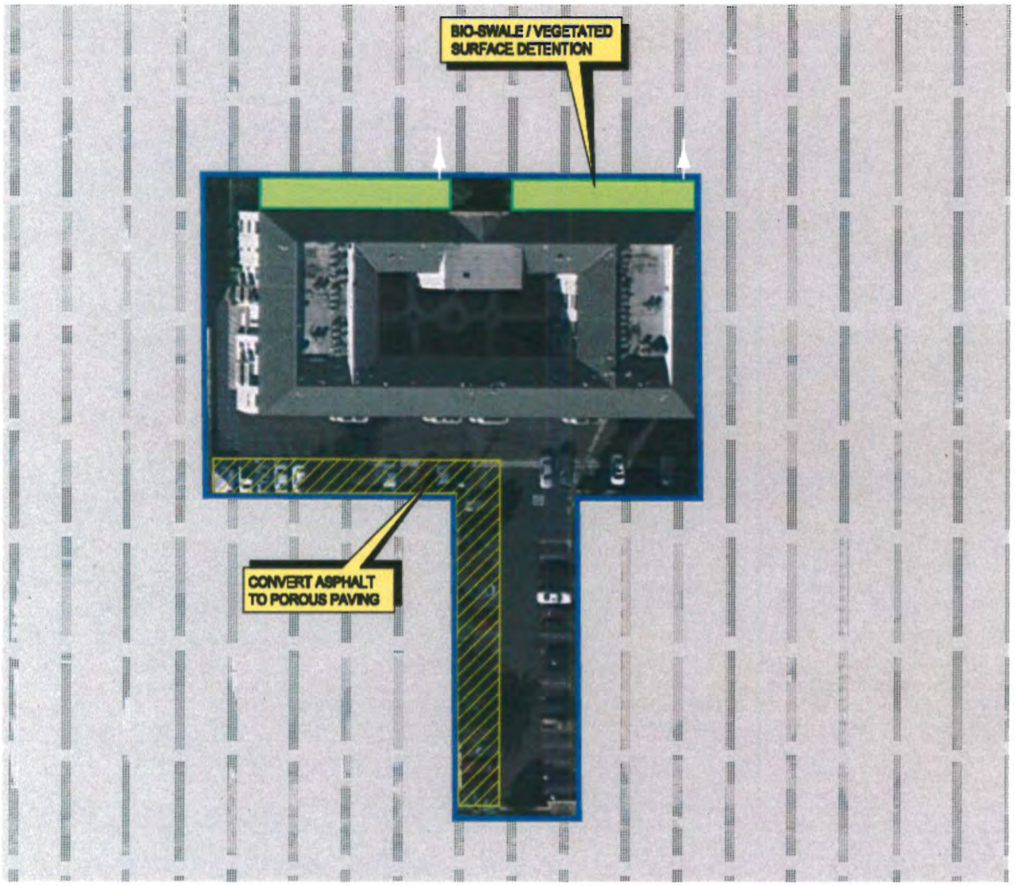
Concept Plan for Crenshaw Boulevard

RB-AR35679



Opportunity Private Parcels – Santa Monica Bay Watershed

RB-AR35680



Site Characteristics

Site Area (Ac):	1.07 Ac

On-Site Treatment

Storage Volume Available	0.02 Ac-Ft
Approx. Treatable Area:	0.5 Ac
Existing Impervious:	1.07 Ac
Proposed Impervious:	0.84 Ac

LEGEND

- PROPOSED STORM DRAIN
- PARCEL BOUNDARY
- CONVERSION AREA
- BIO-SWALE / VEGETATED SURFACE DETENTION

NOTES:

- THIS SITE CONCEPT REPRESENTS A TYPICAL PARCEL IN THIS LAND USE CATEGORY AND IS NOT INTENDED TO INCLUDE ALL POTENTIAL BMPS.
- IT IS ASSUMED THAT A STORM DRAIN CONNECTION CURRENTLY EXISTS ON-SITE, OR PUBLIC STORM DRAIN IS AVAILABLE ADJACENT TO THE SITE.
- THIS CONCEPT IS PROPOSED TO TREAT ON-SITE RUNOFF ONLY.

Design Description

Bio-swale/Vegetated surface detention is proposed to treat on-site runoff along the building frontage. It was assumed that half of the existing asphalt parking areas could be converted to porous paving. Depending on the site's needs the entire parking area could be converted to porous paving; however, since converting the entire parking area would be cost prohibitive in most scenarios and continued use of the lot would be needed during construction, it was reasonably proposed that only half of the existing parking lot would be converted.

GRAPHIC SCALE
Note: For reduced sized prints, original scale is in inches

Concept Plan: Parcel 01
Land Use Group:
Multi-Family Residential
Exhibit M.7

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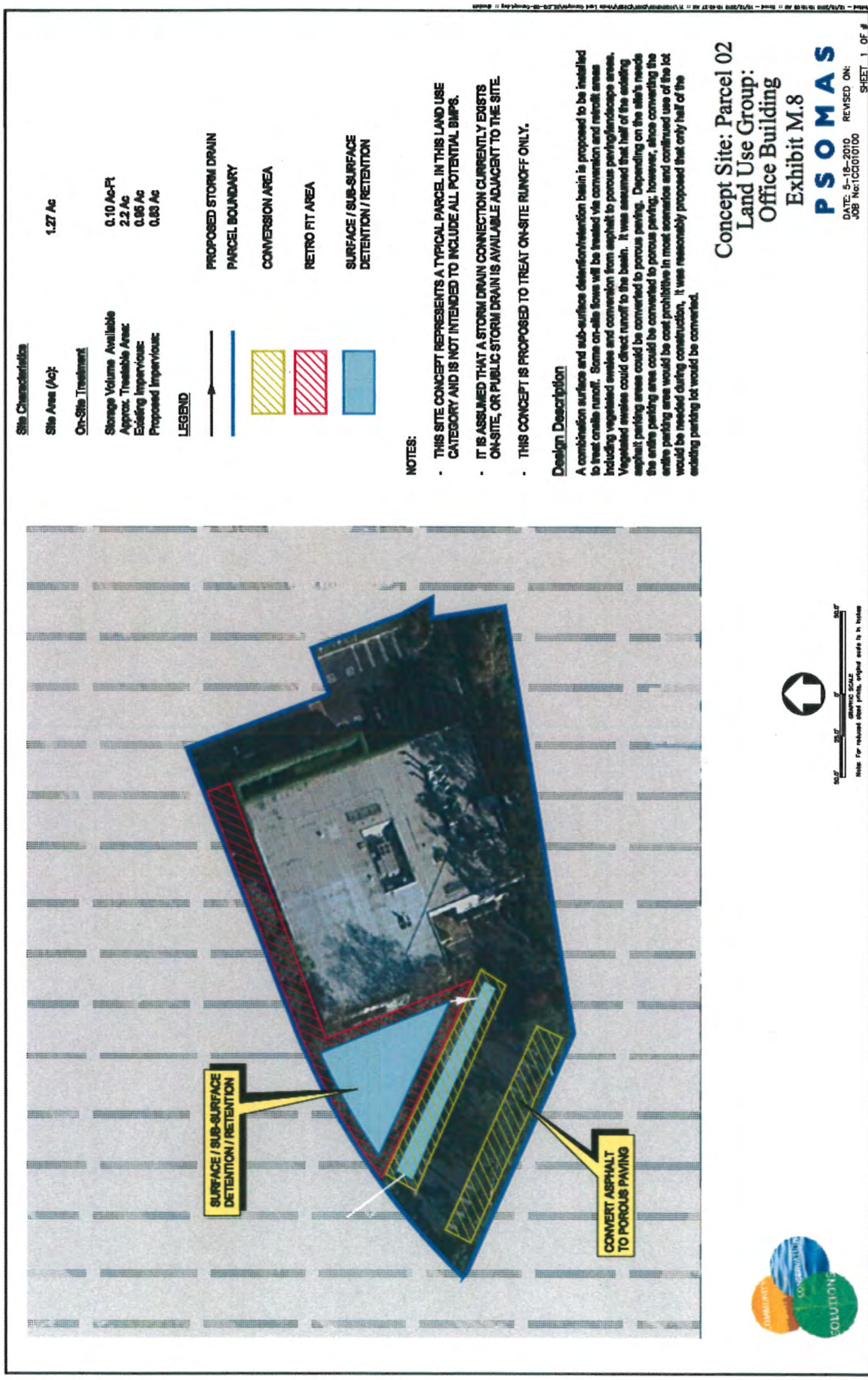
Concept Plan: Parcel 01 Land Use Group: Multi-Family Residential

RB-AR35681



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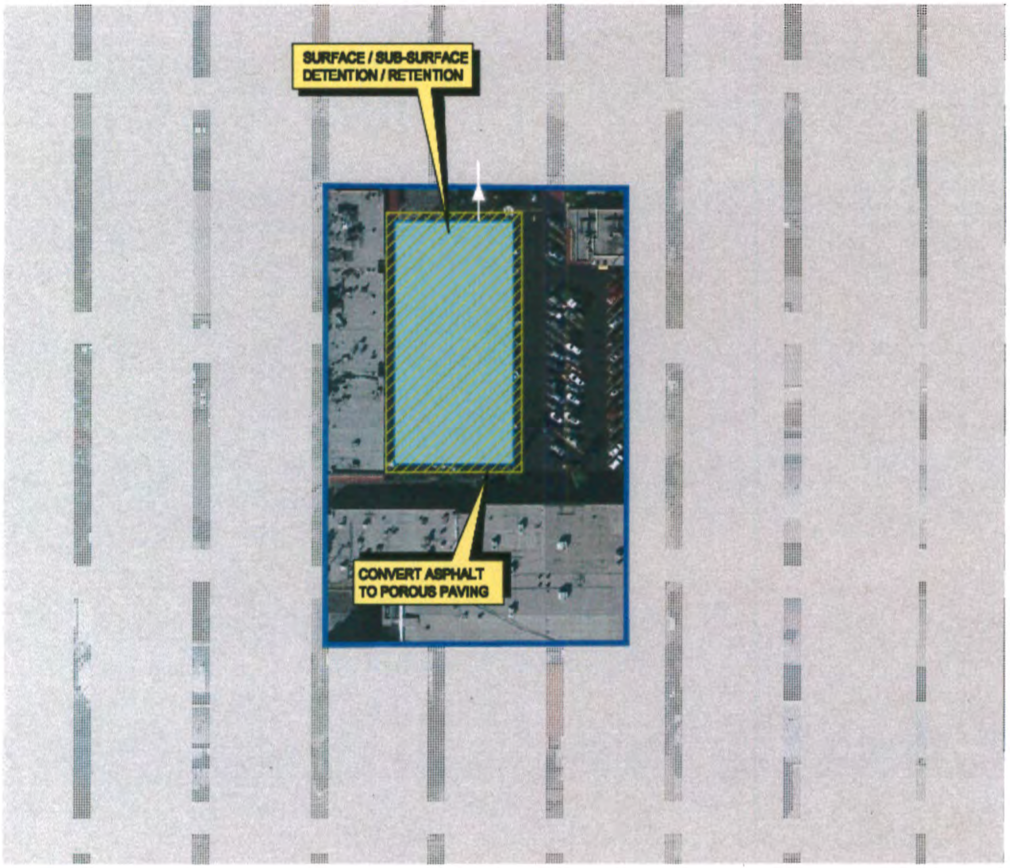
Concept Site: Parcel 02 Land Use Group: Office Building



Site Characteristics

Site Area (Ac):	2.98 Ac

On-Site Treatment

Storage Volume Available	0.35 Ac-Ft
Approx. Treatable Area:	7.0 Ac
Existing Impervious:	2.95 Ac
Proposed Impervious:	2.20 Ac

LEGEND

- PROPOSED STORM DRAIN
- PARCEL BOUNDARY
- CONVERSION AREA
- SUB-SURFACE DETENTION / RETENTION

NOTES:

- THIS SITE CONCEPT REPRESENTS A TYPICAL PARCEL IN THIS LAND USE CATEGORY AND IS NOT INTENDED TO INCLUDE ALL POTENTIAL BMPS.
- IT IS ASSUMED THAT A STORM DRAIN CONNECTION CURRENTLY EXISTS ON-SITE, OR PUBLIC STORM DRAIN IS AVAILABLE ADJACENT TO THE SITE.
- THIS CONCEPT IS PROPOSED TO TREAT ON-SITE RUNOFF ONLY.

Design Description

Almost the entire site is comprised of impervious areas, including roofs and parking areas. A subsurface detention/retention basin could be installed under the existing parking lot to treat on-site runoff. On-site flows would be directed to inlets which connect to the subsurface basin. The existing asphalt parking on top of the basin would be replaced with porous paving. For the conversion area, it was assumed that half of the existing asphalt parking areas could be converted to porous paving. Depending on the site's needs the entire parking area could be converted to porous paving; however, since converting the entire parking area would be cost prohibitive in most scenarios and continued use of the lot would be needed during construction, it was reasonably proposed that only half of the existing parking lot would be converted.

GRAPHIC SCALE 100' 50' 0' 100'

Note: For reduced sized prints, original scale is in inches

Concept Site: Parcel 03
Land Use Group:
Shopping Center
Exhibit M.9

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SHEET 1 OF #
CCI-SC-01

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Concept Site: Parcel 03 Land Use Group: Shopping Center

RB-AR35683

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