January 11, 2013

Via electronic mail

Mr. David Gibson
Executive Officer and Members of the Board
California Regional Water Quality Control Board, San Diego Region
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Re: Comments on Tentative Order R9-2013-0001, San Diego Region MS4 Permit

Dear Mr. Gibson:

On behalf of the Natural Resources Defense Council ("NRDC"), we are writing with regard to the Draft National Pollutant Discharge Elimination System (NPDES) Permit and Waste Discharge Requirements for Discharges from the Municipal Separate Storm Sewer Systems (MS4s) Draining the Watersheds Within the San Diego Region, Draft permit R9-2013-0001, NPDES Permit No. CAS0109266 ("Draft Permit"). We appreciate the opportunity to submit these comments to the San Diego Regional Water Quality Control Board ("Regional Board") on the Draft Permit.[1]

I. Stormwater Runoff is a Leading Source of Water Pollution in the San Diego Region

The U.S. Environmental Protection Agency ("U.S. EPA") considers urban runoff to be "one of the most significant reasons that water quality standards are not being met nationwide."[2] As the U.S. EPA has stated:

> Most stormwater runoff is the result of the man-made hydrologic modifications that normally accompany development. The addition of impervious surfaces, soil compaction, and tree and vegetation removal

[1] NRDC previously submitted comments on the Draft Permit to the Regional Board on September 14, 2012. We incorporate those comments and documents submitted in support by reference here.
[2] U.S. General Accounting Office (June 2001) *Water Quality: Urban Runoff Programs*, Report No. GAO-01-679.

> result in alterations to the movement of water through the environment. As interception, evapotranspiration, and infiltration are reduced and precipitation is converted to overland flow, these modifications affect not only the characteristics of the developed site but also the watershed in which the development is located. Stormwater has been identified as one of the leading sources of pollution for all waterbody types in the United States. Furthermore, the impacts of stormwater pollution are not static; they usually increase with more development and urbanization.[3]

A recent study of the effects of urban development on stream ecosystems by the U.S. Geological Survey showed that urban development impacts stream chemistry, hydrology, habitat, and species composition, and that communities of invertebrate species "Begin to Degrade at the Earliest Stages of Urban Development."[4]

In the San Diego Region, the Regional Board has found that:

- "Land development has created and continues to create new sources of non-storm water discharges and pollutants in storm water discharges as human population density increases. This brings higher levels of car emissions, car maintenance wastes, municipal sewage, pesticides, household hazardous wastes, pet wastes, and trash. Pollutants from these sources are dumped or washed off the surface by non-storm water or storm water flows into and from the MS4s." (Draft Permit, at Finding 10);

- "[C]ommon pollutants in runoff discharged from the MS4s include total suspended solids, sediment, pathogens (e.g., bacteria, viruses, protozoa), heavy metals (e.g., cadmium, copper, lead, and zinc), petroleum products and polynuclear aromatic hydrocarbons, synthetic organics (e.g., pesticides, herbicides, and PCBs), nutrients (e.g., nitrogen and phosphorus), oxygen-demanding substances (e.g., decaying vegetation, animal waste), detergents, and trash." (Draft Permit, at Finding 12); and,

- "The Copermittees' water quality monitoring data . . . documents persistent exceedances of Basin Plan water quality objectives for runoff-related pollutants at various watershed monitoring stations. Persistent toxicity has also been observed at several watershed monitoring stations. In addition, bioassessment data indicate that the majority of the monitored receiving waters have Poor to Very Poor Index

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[3] U.S. Environmental Protection Agency (December 2007) *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*, at v.
[4] U.S. Geological Survey (2012) *Effects of Urban Development on Stream Ecosystems in Nine Metropolitan Study Areas Across the United States*, at 4; see generally, 1-5. Available at: http://pubs.usgs.gov/circ/1373/.

> of Biotic Integrity (IBI) ratings. These findings indicate that runoff discharges are causing or contributing to water quality impairments, and are a leading cause of such impairments in the San Diego Region." (Draft Permit, at Finding 14.)

The Draft Permit establishes requirements critical to addressing this pollution.

II. <u>Pollutants in Stormwater Must be Reduced to the Maximum Extent Practicable</u>

Consistent with the federal Clean Water Act, a fundamental goal of all municipal stormwater permits is to ensure that discharges from storm sewers do not cause or contribute to a violation of water quality standards. (33 U.S.C. § 1341.) In addition, for MS4s covered under the National Pollutant Discharge Elimination System program, permits for discharges from municipal storm sewers:

> shall require controls to 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)(iii).) The maximum extent practicable ("MEP") standard serves as a floor to performance for regulated parties. This standard does not grant unbridled leeway to Permittees in developing controls to reduce the discharge of pollution. "[W]hat the discharger will do to reduce discharges to the 'maximum extent practicable' . . . crosses the threshold from being an item of procedural correspondence to being a substantive requirement of a regulatory regime." (*Environmental Defense Center, Inc. v. U.S. E.P.A* (9th Cir. 2003) 344 F.3d 832, 853.) The MEP standard "imposes a clear duty on the agency to fulfill the statutory command to the extent that it is feasible or possible." (*Defenders of Wildlife v. Babbitt,* 130 F. Supp. 2d 121, 131 (D.D.C. 2001); *Friends of Boundary Waters Wilderness v. Thomas,* 53 F.3d 881, 885 (8th Cir. 1995) ("feasible" means "physically possible").

As one state hearing board held:

> [MEP] means to the fullest degree technologically feasible for the protection of water quality, except where costs are wholly disproportionate to the potential benefits…. This standard requires more of Permittees than mere compliance with water quality standards or numeric effluent limitations designed to meet such standards…. The term "maximum extent practicable" in the stormwater context implies that the mitigation measures in a stormwater permit must be more than simply adopting standard practices. This definition applies particularly in areas where standard practices are already failing to protect water quality….

(*North Carolina Wildlife Fed. Central Piedmont Group of the NC Sierra Club v. N.C. Division of Water Quality* (N.C.O.A.H. October 13, 2006) 2006 WL 3890348, Conclusions of Law 21-22 (internal citations omitted).) The North Carolina board further found that the permits in question violated the MEP standard both because commenters highlighted measures that would reduce pollution more effectively than the permits' requirements and because other controls, such as infiltration measures, "would [also] reduce discharges more than the measures contained in the permits." (*Id.* at Conclusions of Law 19.)

Nor is MEP a static requirement—the standard anticipates and in fact requires new and additional controls to be included with each successive permit. As U.S. EPA has explained, NPDES permits, including the MEP standard, will "evolve and mature over time" and must be flexible "to reflect changing conditions." (55 Fed. Reg. 47990, 48052.) "EPA envisions application of the MEP standard as an iterative process. MEP should continually adapt to current conditions and BMP effectiveness and should strive to attain water quality standards. Successive iterations of the mix of BMPs and measurable goals will be driven by the objective of assuring maintenance of water quality standards." (64 Fed. Reg. 68722, 68754.) In other words, successive iterations of permits for a given jurisdiction will necessarily evolve, and contain new and more stringent requirements for controlling the discharge of pollutants in runoff.

Although requiring compliance with MEP may be sufficient to achieve water quality standards and other common permit terms, the Clean Water Act independently requires that MS4 permits achieve water quality standard compliance.[5] EPA has stated "all permits for MS4s must include any requirements necessary to achieve compliance with [water quality standards]."[6] Notwithstanding this requirement, permits also require "such other provisions as the Administrator or the State determines appropriate for the control of such pollutants." This language in section 1342(p) has been held by California courts to grant "the EPA (and/or a state approved to issue the NPDES permit) . . . the discretion to impose 'appropriate' water pollution controls in addition to those that come within the definition of 'maximum extent practicable.'" (*Building Industry Ass'n of San*

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[5] See, 33 U.S.C. § 1311(a); 1313; 1341(a); 1342(p); 40 C.F.R. § 122.44(d)(1) (permits must contain, as applicable, any requirements necessary to "[a]chieve water quality standards established under section 303 of the CWA, including State narrative criteria for water quality"); Memorandum from E. Donald Elliott, Assistant Administrator and General Counsel, U.S. Environmental Protection Agency, to Nancy J. Marvel, Regional Counsel Region IX, re: Compliance with Water Quality Standards in NPDES Permits Issued to Municipal Separate Storm Sewer Systems, Jan. 9, 1991 ("EPA Elliott Memo"). But see, *Defenders of Wildlife v. Browner* (9th Cir. 1999) 191 F.3d 1159, 1166 (holding that permitting authority is not required to impose strict water quality-based effluent limitations, but has the authority to do so).

[6] EPA Elliott Memo, at 1; *In re: Government of the District of Columbia Municipal Separate Storm Sewer System* (EPA 2002) 10 E.A.D. 323, 2002 WL 257698.

Diego County v. State Water Resources Control Bd. (2004) 124 Cal.App.4th 866, 883 (citing *Defenders of Wildlife v. Browner* (1999) 191 F.3d 1159, at 1165–1167).)

As a result, while the MEP standard represents a statutory floor, rather than limit, for permit requirements, the Regional Board and EPA maintain the authority to impose additional restrictions over and above MEP as they determine appropriate. Both California and federal authority maintain that MS4 permits must include provisions to ensure that discharges do not cause or contribute to exceedances of water quality standards.

III. Permit Provisions

A. The Draft Permit's Receiving Water Limitations Appropriately Prohibit Discharges that Cause or Contribute to the Violation of Water Quality Standards.

Consistent with the 2007 San Diego County MS4 Permit, 2009 South Orange County MS4 Permit, and 2010 Riverside County MS4 Permit,[7] as well as federal authority and State Water Board WQ Order No. 99-05,[8] the Draft Permit requires that "Discharges from MS4s must not cause or contribute to the violation of water quality standards in any receiving waters." (Draft Permit, at II.A.2.a.)[9] Multiple California and federal courts have upheld such provisions, including in prior iterations of the San Diego MS4 Permit.[10]

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[7] See, San Diego Regional Water Quality Control Board (January 24, 2007) San Diego County MS4 Permit, Order No. R9-2007-0001, at A.3 ("2007 San Diego Permit"); San Diego Regional Water Quality Control Board (December 16, 2009) South Orange County MS4 Permit, Order No. R9-2009-0002, at A.3; San Diego Regional Water Quality Control Board (November 10, 2010) Riverside County MS4 Permit, Order No. R9-2010-0016, at A.3.

[8] Under Order No. 99-05, the State Board directed the Regional Boards to include receiving water limitations language devised by EPA, without incorporation of a safe harbor provision, into all future MS4 permits.

[9] See, 2007 San Diego Permit, at § A.3; see also, South Orange County MS4 Permit, Order No. R9-2009-0002, at § A.3.

[10] *See, e.g.*, *Building Industry Ass'n of San Diego County*, 124 Cal.App.4th at 883; *In re L.A. County Mun. Storm Water Permit Litigation.*, No. BS 080548 at 4-7 (L.A. Super. Ct. Mar. 24, 2005) ("*L.A. County Mun. Stormwater*"); *County of Los Angeles v. Cal. State Water Res. Control Bd.* (2006) 143 Cal.App.4th 985, 989; *Natural Resources Defense Council v. County of Los Angeles* (2011) 673 F.3d 880, 897. The court in *In re L.A. County Mun. Stormwater* noted that, "the Regional Board acted within its authority when it included Parts 2.1 and 2.2 in the Permit without a 'safe harbor,' whether or not compliance therewith requires efforts that exceed the 'MEP' standard." (*In re L.A. County Mun. Stormwater*, at 7.) But regardless of this authority, the Court found that "the terms of the Permit taken, as a whole [including the Permit's receiving water limitations], constitute the Regional Board's definition of MEP." (*Id*. at 7-8.)

As such, the prohibition against discharges that cause or contribute to violations of water quality standards is appropriately incorporated into the Draft Permit's receiving water limitations here.

Moreover, any weakening of the receiving water limitations language would constitute a violation of the Clean Water Act's anti-backsliding provisions, which require that "a permit may not be renewed, reissued, or modified to contain effluent limitations which are less stringent than the comparable effluent limitations in the previous permit," except in circumstances not presented by the Draft Permit. (33 U.S.C. § 1342(o)(1).) Similarly, federal regulations require that "when a permit is renewed or reissued, interim effluent limitations, standards or conditions must be at least as stringent as the final effluent limitations, standards, or conditions in the previous permit. . . ." (40 C.F.R. § 122.44(l)(1).) Because the prohibition against exceedances of water quality standards was required by the prior San Diego, South Orange County, and Riverside permits, this provision cannot be less stringent in the Draft Permit. A weakening of the receiving water limitations would further violate state and federal antidegradation requirements, which mandate that existing water quality in navigable waters be maintained unless degradation is justified by specific findings.[11] As a result, the adopted permit must require compliance with water quality standards, without restriction.

B. The Draft Permit's Development Planning Requirements Must Require On-Site Retention of at least the 85th Percentile Storm

We strongly support that the Draft Permit establishes requirements for new development and redevelopment projects to retain stormwater runoff on-site. A principal reason to adopt such an approach is the superior pollutant load reduction capacity of LID practices that retain runoff on-site, for a variety of climatic scenarios, including for the San Diego region.[12] However, we are concerned that, as currently drafted, the Draft Permit's Development Planning requirements in many circumstances will allow projects to retain less runoff than has been demonstrated to be practicable. This in turn will result in increased discharge of pollutants to receiving waters over what could practicably be reduced, in violation of Clean Water Act's MEP standard. In particular, the Draft Permit's provision allowing for required runoff retention to be calculated as the "volume

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[11] See, 40 C.F.R. § 131.12; State Board Resolution 68-16; *Associacion de Gente Unida for El Agua v. Central Valley Regional Board* (2012) (210 Cal.App.4th 1255) [149 Cal.Rptr.3d 132, 142; 144] (citing "St. Water Res. Control Bd., Guidance Memorandum (Feb. 16, 1995)).

[12] Dr. Richard Horner and Jocelyn Gretz (December 2011) Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices Applied to Meet Various Potential Stormwater Runoff Regulatory Standards ("Horner and Gretz Runoff Study"); see also, Horner, Richard. Report for Ventura County; Horner, Richard. Initial Investigation for San Francisco Bay Area; Horner, Richard. Supplementary Investigation for San Francisco Bay Area; Horner, Richard. Report for San Diego Region.

of storm water that would be retained on-site if the site was fully undeveloped and naturally vegetated" should be deleted. (See Draft Permit, at E.3.c(1)(a)(ii).)

The Draft Permit requires, under one provision, that the runoff from the 85th percentile, 24-hour rain event must be retained on-site. (Draft Permit, at E.3.c(1)(a)(i).) This requirement, resulting in retention of stormwater runoff with no off-site discharge in the vast majority of storms, is consistent with on-site retention requirements of other permits throughout California, as in permits and ordinances found in all corners of the United States. Similar or more stringent requirements are included in the following permits:

Ventura County: MS4 permit requires on-site retention of ninety-five percent of rainfall from the 85th percentile storm; off-site mitigation allowed if on-site retention is technically infeasible;[13]

South Orange County: MS4 permit requires on-site retention of the 85th percentile storm, off-site mitigation allowed if on-site retention is technically infeasible;[14]

However, the 85th percentile standard is actually less stringent than required by permits in many other parts of the county. For example, permits in the following locations require retention that generally exceeds the 85th percentile storm volume in San Diego:

Washington D.C.: MS4 permit requires retention of the first 1.2 inches of stormwater (which represents the 90th percentile storm) for all new development and redevelopment over 5,000 square feet.[15]

West Virginia: Statewide Phase II MS4 permit requires on-site retention of "the first one inch of rainfall from a 24-hour storm" event unless infeasible;[16] and,

Philadelphia, PA: Infiltrate the first one inch of rainfall from all impervious surfaces; if on-site infiltration is infeasible, the same performance must be achieved off-site.[17]

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[13] Los Angeles Regional Water Quality Control Board (July 8, 2010) Ventura County Municipal Separate Stormwater National Pollutant Discharge Elimination System (NPDES) Permit; Order No. R4-2009-0057; NPDES Permit No. CAS004002.
[14] San Diego Regional Water Quality Control Board (December 16, 2009) South Orange County MS4 Permit, Order No. R9-2009-0002, NPDES Permit No. CAS0108740.
[15] U. S. EPA (2011) Fact Sheet, National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) Permit No. DC0000221 (Government of the District of Columbia).
[16] State of West Virginia Department of Environmental Protection, Division of Water and Waste Management, General National Pollution Discharge Elimination System Water Pollution Control Permit, NPDES Permit No. WV0116025 at 13-14 (June 22, 2009).
[17] City of Philadelphia (Jan. 29, 2008) Stormwater Management Guidance Manual 2.0, at 1.1, available at.

Further, research conducted by Dr. Richard Horner, a member of the National Academy of Sciences Panel on Reducing Stormwater Discharge Contributions to Water Pollution demonstrates that, for five different types of land use development or redevelopment projects in Southern California, the full 85th percentile, or even the full 95th percentile, 24-hour precipitation event could be retained on-site using *only* infiltration practices on sites overlying soils classified as Group C (typically containing 20 to 40 percent clay) under the Natural Resources Conservation Service (NRCS) major soil orders classification scheme.[18] Critically, even for sites overlying Group D soils (typically 40 percent or more clay with substantially restricted water transmissivity) and assuming *no* infiltration was feasible, greater than 50 percent of the 85th percentile storm (or between 37 and 62 percent of annual runoff) could be retained at each development type using only rooftop runoff dispersion or rooftop harvest and reuse techniques.[19] Additional retention under these scenarios could be achieved through use of evaporation practices, green roofs, or, in cases where some infiltration is feasible, use of infiltration BMPs.

The Permit also allows for required stormwater runoff retention to be calculated as the "volume of storm water that would be retained onsite if the site was fully undeveloped and naturally vegetated" based on site specific soil conditions and natural vegetative cover. (Draft Permit, at E.3.c(1)(a)(ii).) This approach requires only that a development retain the change in runoff between pre-development (or undeveloped) conditions and post-development, or the "delta volume." Yet, as described below, the delta volume approach alone does not achieve control of pollutants to the MEP, and represents a significant departure from both state and national precedents. For this reason, it has been rejected in other California Permits as insufficient to meet statutory requirements.[20]

While the delta volume approach may be appropriate in assessing effects of hydromodification, because preservation of hydrologic profile from pre-development to post-development[21] will not cause modification in the hydrology of the receiving water,

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[18] Horner and Gretz Runoff Study, at Table 16 p. 35; Natural Resources Conservation Service, Distribution Maps of Dominant Soil Orders (http://soils.usda.gov/technical/classification/orders/, last accessed December 16, 2011).
[19] Horner and Gretz Runoff Study, at Table 16 p. 35; 27-34. We note as well that even in areas characterized regionally as underlain by D soils, site specific investigation may establish substantial potential for infiltration of runoff.
[20] See, e.g., Santa Ana Regional Water Quality Control Board, OC MS4 Tentative Order No. R8-2008-0030 (R8-2009-0030) Comments/Responses, at comment 103.
[21] We distinguish delta volume's application to water quality considerations from the otherwise appropriate application of comparisons of pre-development to post development hydrology as a means of establishing hydromodification controls. Irrespective of this approach, however, we note that the Draft Permit should require projects to implement hydromodification controls to meet "predevelopment (naturally occurring)" runoff flow rate (see Draft Permit, at E.3.c.(2)(a)), rather than "pre-project" conditions, or the conditions of a previously developed site immediately prior to

this approach is inappropriate for management of water quality. Under the delta volume approach, the unretained volume of runoff resulting from development (i.e., any amount of runoff greater than would have been retained under undeveloped conditions), will carry pollutants to receiving waters that would not have been present in runoff from undeveloped land.

This is particularly a concern in the San Diego region, which contains significant land area underlain by clay rich soils that may reduce infiltrative capacity.[22] For example, for development sites underlain by C soils, Dr. Horner's research demonstrates that the delta volume approach may actually require the site to retain more runoff than would be retained under the 85th percentile storm standard.[23] However, for development sites underlain by D soils, which may include large portions of the San Diego region, the delta volume approach will result in requiring development to substantially *less* runoff than would be required, or feasibly retained, under the 85th percentile storm standard. Under case studies for the 85th percentile storm standard, development sites would be required to retain between 37 and 62 percent of average annual runoff, with even greater retention possible given use of soil amendments or other practices to augment recharge. For the same sites, the delta volume approach would only require retention of between 27 and 44 percent of annual runoff.[24] Because the delta volume standard allows runoff that could be feasibly retained on-site to be discharged and carry pollutants to receiving waters, the standard violates the Clean Water Act's MEP requirement. The Draft Permit should either delete reference to this standard from section E.3.c(1)(a)(ii), or require that a project site retain the runoff from the 85th percentile, 24-hour storm event, or the delta volume approach, *whichever is greater*.

1. <u>The Draft Permit Must Require a Determination that it is Technically Infeasible to Retain the Design Storm On-Site Before Biofiltration or Off-site Mitigation/Retrofitting is Authorized.</u>

While we support the inclusion of strong retention standards for stormwater runoff, and the Draft Permit's requirement to incorporate on-site treatment in addition to performance of off-site mitigation in the event of technical infeasibility for on-site retention, we are concerned by statements of Regional Board staff that they "would like to make a shift away from determining what is infeasible onsite to determining what is

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construction. This issue is of concern for both natural, non-hardened channels, and for concrete lined or hardened channels, where allowing use of a "pre-project" standard for hydromodification may serve to prevent stream rehabilitation.

[22] See, e.g., Horner and Gretz Runoff Study, at 15-16.

[23] *Id*., at Table 16 p 35. In the San Marcos case studies, the delta volume approach would require retention of 72 to 80 percent of average annual runoff, while retention of the 85th percentile storm event would result in retention of 62 percent of average annual runoff.

[24] *Id*.

feasible onsite"[25] and Draft Permit provisions allowing for use of biofiltration and off-site mitigation even where on-site retention is feasible. Because retention of the 85th Percentile Storm event has been established as MEP in California Permits,[26] the project proponent must meet this standard or demonstrate that it cannot be met.

The jurisdictions identified in sections above have recognized the paramount importance of mandating on-site retention of a certain quantity of stormwater since, in contrast to retention practices, which ensure that 100 percent of the pollutant load in the retained volume of runoff does not reach receiving waters, biofiltration practices (or tree-box filters and other similar practices) that treat and then discharge runoff through an underdrain result in the release of pollutants to receiving waters. Indeed, in order to achieve equivalent pollutant load reduction benefits to the use of on-site retention, biofiltration practices would have to be 100 percent effective at filtering pollutants from the same volume of runoff, which they are invariably not. As a result, while biofiltration practices (or conventional flow-through practices) may be appropriate for on-site treatment when coupled with an off-site mitigation requirement in cases of technical infeasibility (discussed further below), they are not a proper substitute for low impact development ("LID") practices that retain water on-site.

This conclusion is borne out by data presented in the Draft Ventura County Technical Guidance Manual, which estimates pollutant removal efficiency for total suspended solids to be 54-89 percent, and for total zinc to be 48-96 percent.[27] Biofiltration has additionally been shown to be a particularly ineffective method of pollutant removal for addressing nitrogen or phosphorous, two common contaminants found in stormwater.[28] The Draft Ventura Technical Guidance, for example, indicates that biofiltration achieves

[25] Regional MS4 Permit RWQCB Workshop Notes, September 5, 2012, at 4.
[26] See, e.g., Ventura County MS4 Permit, Order No. R4-2009-0057; San Francisco Bay Area MS4 Permit, Order No. R2-2009-0074; North Orange County MS4 Permit, Order No. R8-2009-0030; South Orange County MS4 Permit, Order No. R9-2009-0002.
[27] Ventura County Low Impact Development Technical Guidance Manual, July 13, 2011, at D-7.
[28] Lawn irrigation has been identified as a "hot spot" for nutrient contamination in urban watersheds—lawns "contribute greater concentrations of Total N, Total P and dissolved phosphorus than other urban source areas . . . source research suggests that nutrient concentrations in lawn runoff can be as much as four times greater than other urban sources such as streets, rooftops or driveways." Center for Watershed Protection (March 2003) *Impacts of Impervious Cover on Aquatic Systems* at 69; see also H.S. Garn (2002) *Effects of lawn fertilizer on nutrient concentration in runoff from lakeshore lawns, Lauderdale Lakes, Wisconsin*. U.S. Geological Survey Water- Resources Investigations Report 02-4130 (In an investigation of runoff from lawns in Wisconsin, runoff from fertilized lawns contained elevated concentrations of phosphorous and dissolved phosphorous).

pollutant removal efficiency for total nitrogen at between only 21-54 percent,[29] as compared with 100 percent for runoff retained on-site. As a result, even where a multiplier is applied requiring 1.5 times as much runoff be treated using biofiltration as would otherwise be retained, biofiltration may achieve substantially less pollution reduction as would retention.

Likewise, the Draft Permit's provisions allowing for a project to perform off-site mitigation through off-site regional BMPs or retrofits may violate the Clean Water Act's MEP requirement because it does not provide any actual mechanism to ensure that an alternative "off-site" location will provide "greater overall water quality benefit" to on-site retention. (Draft Permit, at E.3.c(3)(b).) NRDC supports use of regional projects that may provide multiple benefits, including increased local water supply, where runoff is *conveyed* from a project site to a regional facility that will retain that runoff, albeit at a different location, with no discharge to receiving waters, as this process typically does not implicate significant water quality concerns. Where the same, specific quantum of runoff from the project is ultimately retained, 100 percent of the pollution contained in that particular volume of water will be prevented from reaching receiving waters.

In contrast, where a project, performs off-site mitigation or retrofit at some other location within the same watershed or sub-watershed that is not hydrologically connected to the original project site, it raises substantial concerns as to whether the alternate location will provide equal water quality benefits to the receiving surface water. Among the issues presented by this form of off-site mitigation are whether the off-site mitigation will be performed at a similar land use type; whether the mitigation project will achieve equivalent pollutant load reduction; and if so, what pollutants it will be monitored for. In practice it may prove exceedingly difficult to assess the equivalency of benefits to surface water quality from retention at one site to the next. Further, while we note that the Regional Board has included a multiplier for retention 1.1 times the design volume not retained on-site in cases of off-site mitigation, (Draft Permit, at E.3.c(3)(b)(iv)) the Board has not provided any analysis or evidence to demonstrate that this volume will be sufficient to offset the release of pollution from on-site sources. As a result, off-site mitigation should be allowed only where on-site retention or regional projects where runoff is conveyed directly to the retention site are infeasible.

Finally, while we support development under the USGCB LEED program, the Board has not provided any analysis to demonstrate that meeting the criteria set forth in section E.3.c(3)(b)(ii) will result in a reduction of pollution equivalent to the Permit's otherwise

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[29] Ventura County Low Impact Development Technical Guidance Manual, July 13, 2011, at D-7. See also, BASMAA (December 1, 2010) *Draft Model Bioretention Soil Media Specifications-MRP Provision C.3.c.iii*, at Annotated Bibliography section 3.0 (noting nutrient removal from synthetic stormwater runoff demonstrated only 55 to 65 percent of total Kjeldahl nitrogen removal and that only 20 percent of nitrate is removed from the runoff).

applicable retention standard, or to the MEP. This section should therefore be revised accordingly or deleted.

2. LID Is Cost-Effective and Provides Significant Economic Benefits

LID "provides ecosystem services and associated economic benefits that conventional stormwater controls do not."[30] Because traditional stormwater management approaches involve the construction of complex systems of infrastructure, they can entail substantial costs. Since LID emphasizes 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."[31] A 2007 U.S. EPA study found that "in the vast majority of cases . . . implementing well-chosen LID practices saves money for developers, property owners, and communities while protecting and restoring water quality."[32] With only "a few exceptions," the EPA study found that "[t]otal capital cost savings ranged from 15 to 80 percent when LID methods were used" instead of conventional stormwater management techniques.[33] The savings identified in documented studies are noteworthy considering they do not reflect the additional economically beneficial attributes LID provides, including reduced costs of municipal infrastructure, reduced costs of municipal stormwater management, and increased value of real estate.[34]

Nor is the EPA study alone in reaching this conclusion. A survey released by the American Society of Landscape Architects in 2011 found that green infrastructure reduced or did not influence project costs 75 percent of the time.[35] A joint project by the University of New Hampshire Stormwater Center and Virginia Commonwealth University found that use of LID provided stormwater management cost savings of 6 percent for residential development and 26 percent for commercial developments as compared with conventional stormwater management.[36] And while the economics of

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[30] ECONorthwest, The Economics of Low-Impact Development: A Literature Review, at iii. (2007) ("ECONorthwest") (Exh. 61).
[31] U.S. EPA Cost Study, at 2; U.S. Department of Housing and Urban Development, The Practice of Low Impact Development, at 33 (2003) (Exh. 62).
[32] U.S. EPA Cost Study, at iii.
[33] *Id.* at iv.
[34] See ECONorthwest, at 5; *Id*. at 15 (disconnecting downspouts to allow for natural infiltration in the Beecher Water District near Flint, Michigan cost the district about $15,000, but decreased the mean volume of sewer flows by 26 percent, and saved the district more than $8,000 per month in stormwater fees); U.S. EPA Cost Study, at 7.
[35] American Society of Landscape Architects (2011) Advocacy: Stormwater Case Studies.
[36] Roseen, R., T. Janeski, J. Houle, M. Simpson, and J. Gunderson (2011) *Forging the Link: Linking the Economic Benefits of Low Impact Development and Community*

integrating LID into redevelopment projects vary slightly from new development, there is little evidence it typically raises project costs. An analysis of three communities by ECONorthwest found that while complying with stormwater standards, including strict runoff volume reduction requirements, is a cost consideration, it is rarely, if ever, a driving factor in decisions to undertake redevelopment projects.[37]

Further, LID can provide substantial benefits for the San Diego region in terms of increased local supply of water and reduced energy usage, in addition to the stormwater runoff and pollution benefits it can provide.[38]

C. The Requirements for Water Quality Improvement Plans Lack Sufficient Detail, Represent an Illicit Self Regulatory Scheme, and Violate Clean Water Act Prohibitions Against the Discharge of Non-stormwater

1. <u>The Draft Permit Must Provide for Adequate Public and Agency Review of Any Substantive Permit Requirements Designed by the Permittees</u>

While we support watershed based efforts to address stormwater pollution in the San Diego region, the Draft Permit's requirements for Water Quality Improvement Plans are in many parts vague, essentially directing Permittees to develop their own priorities and requirements, which are subject only to minimal, inadequate public review or Regional Board oversight. In this way, the provisions represent a "plan to develop a plan," rather than any form of plan in itself. In *Environmental Defense Center, Inc. v. U.S. E.P.A* ((9th Cir. 2003) 344 F.3d 832, 854-56), the court explained: "[S]tormwater management programs that are designed by regulated parties must, in every instance, be subject to meaningful review by an appropriate regulating entity. . . . Congress identified public participation rights as a critical means of advancing the goals of the Clean Water Act in

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Decisions. University of New Hampshire Stormwater Center, the Virginia Commonwealth University, and Antioch University New England. Available at: http://www.unh.edu/unhsc/resource-manual-and-fact-sheets; see generally, NRDC (2011) Rooftops to Rivers II: Green Strategies for Controlling Stormwater and Combined Sewer Overflows, at 19-30.

[37] ECONorthwest (2011) "Managing Stormwater in Redevelopment and Greenfield Development Projects Using Green Infrastructure: Economic Factors that Influence Developers Decisions,"prepared by S. Reich et al, at 2.

[38] See, NRDC and University of California at Santa Barbara (2009) A Clear Blue Future: How Greening California Cities Can Address Water Resources and Climate Challenges in the 21st Century; See also, NRDC (2011) Capturing Rainwater from Rooftops: An Efficient Water Resource Management Strategy that Increases Supply and Reduces Pollution; NRDC and University of California at Los Angeles (2012) Looking Up: How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California.

its primary statement of the Act's approach and philosophy." Provisions or substantive permit terms such as these which get at the core of permit requirements, and are designed or developed by the Permittees must be subject to proper opportunity for public comment to the Regional Board, and should be properly reviewed by the Regional Board at public hearing prior to approval and implementation.

2. The Permit's use of Numeric Action Limits Violates Clean Water Act Prohibitions Against the Discharge of Non-Stormwater

While we support the Regional Board's attempt to provide increased focus on dry weather, non-storm water discharges, we are concerned that the provisions for use of "numeric action limits" ("NALs") as drafted in the Water Quality Improvement Plans (Draft Permit, at II.C.1), do not fully support the Clean Water Act's absolute prohibition against the discharge of non-storm water to the MS4 system. The federal Clean Water Act mandates that MS4 permits "include a requirement to effectively prohibit non-stormwater discharges into the storm sewers." (33 U.S.C. § 1342(p)(3)(B)(ii); see 40 C.F.R. § 122.26(d)(2)(iv)(B)(1).) The Permit incorporates this requirement under section II.A.1.b. To support the development and prioritization of water quality improvement strategies for addressing non-storm water discharges to and from the MS4s and identify sources of non-stormwater pollution or potential violations of Permit provisions, the Draft Permit establishes (or requires Permittees to establish) quantifiable discharge goals for specific pollutants in the form of NALs.

We presume that the NAL provisions are intended to support the goal of compliance with the Clean Water Act's prohibition. However, the Draft Permit, which states that "NALs are not considered by the San Diego Water Board to be enforceable limitations," could be confusingly taken to suggest that the Permit allows for non-storm water discharges to occur or to contribute pollutants to the MS4 system so long as the pollution occurs at levels below the NALs.[39] This would violate both the Clean Water Act's absolute prohibition against non-storm water discharges to the MS4 under 33 U.S.C. § 1342(p)(3)(B)(ii), and the Act's implementing regulations, which require that "where such discharges are identified by the municipality as sources of pollutants to waters of the United States," in any amount, they must be addressed by the Permittee. (40 C.F.R. § 122.26(d)(2)(iv)(B)(1).)[40] The Draft Permit must require action by the Permittees to address non-stormwater discharges for pollution observed at levels both above *and* below

[39] We note a similar concern with respect to "SALs" for stormwater discharges, as this provision could be interpreted as authorizing the discharge of pollutants below the SAL, but which may contribute to an exceedance of water quality standards. (Draft Permit, at II.C.2.)
[40] Critically in this regard, any amount of pollution from an exempt source is prohibited, regardless of whether it occurs at levels below the NALs. As a result, action should be required of the Copermittees even for pollution occurring at levels below the NALs

the specified NALs in order to meet obligations fixed by the Clean Water Act, as the Act requires action to prohibit all discharges, regardless of the discharge's pollutant load.

IV. Conclusion

We appreciate this opportunity to comment on the Draft Permit. Please feel free to contact us with any questions or concerns you may have.

Sincerely,

Noah Garrison
Project Attorney
Natural Resources Defense Council

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January 11, 2013

Mr. David Gibson, Executive Officer, and Members of the Board
California Regional Water Quality Control Board, San Diego Region
9174 Sky Park Court, Suite 100
San Diego, CA 92123

Dear Mr. Gibson and Board Members:

I am writing with respect to a provision with which I disagree among the Storm Water Pollutant Control BMP Requirements of Tentative Order No. R9-2013-0001, NPDES No. CAS0109266 ("the Tentative Order"). I base my comments on my extensive experience in the stormwater management field, summarized in the attachment to this letter. My full *curriculum vitae* are available on request.

I refer specifically to Tentative Order section E.3.c(1)(a)(ii), which gives as one of two options for a standard of runoff retention (i.e., interception, storage, infiltration, and/or evapotranspiration):

> The volume of storm water that would be retained onsite if the site was fully undeveloped and naturally vegetated, as determined using continuous simulation modeling techniques based on site-specific soil conditions and typical native vegetative cover.

The implication of this passage is that the retention requirement is equal to the difference between the post- and pre-development stormwater runoff volumes. In this letter I refer to this requirement as the "differential volume standard".

I disagree with the Tentative Order's allowing application of the differential volume standard, in any case and without restriction, as an alternative to a retention requirement based on the full volume of storm water produced by the 85th percentile, 24-hour storm event [i.e., provision E.3.c(1)(a)(i)]. Broadly exercising the differential volume option instead of the alternative would result in considerably greater volumes of urban stormwater discharge over the San Diego region as a whole, with concomitant, substantial increases in the mass loading to receiving waters of a range of pollutants.[1] It also departs from standard and well-accepted practice around the nation. This letter provides supporting documentation for my opinion.

[1] For purposes of my analysis and comments I assume that the difference implied by the provision is between the post- and pre-development <u>average annual</u> runoff volumes. If, on the other hand, the intent is to apply it up to a certain rainfall event cap (e.g., the 85th percentile, 24-hour storm), I object even more strenuously to allowance of this option. I do so because that capped standard would result in the release of even more stormwater pollutant mass, as shown later in this letter.

Basis of Full-Volume Standard

Using the differential volume between pre- and post-development conditions breaks the long-standing precedent, in California and elsewhere, of using the full volume of stormwater discharged from the developed site in a designated event as the basis for stormwater best management practices ("BMPs") that store runoff for longer than a few minutes.[1] The widespread adoption (see examples below) of the full water quality volume instead of the differential volume occurred for good reasons. The total runoff volume from the 85th percentile, 24-hour event—the prevailing design standard in southern California—was determined through objective analysis to represent the point above which substantially diminishing returns in water quality improvement would accompany considerable BMP size enlargement and, therefore, cost (Guo and Urbonas 1996).[2] The analysis identified the full volume generated by the 85th percentile, 24-hour event— not some lesser quantity like the differential volume—as the appropriate threshold at which the decrease in benefits accelerates.

The use of a differential hydrologic measure that compares pre- and post-development states is common in the management of storm runoff quantity (i.e., hydromodification). The pre- vs. post-development measure is appropriate in that situation because successfully matching pre- and post-development hydrologic characteristics causes no modification in the hydrologic status of the receiving water and, hence, no negative physical effects.

When managing water quality, in contrast, any untreated volume (in the differential volume scenario, this would be the amount that originally flowed from the undeveloped land) would deliver to the receiving water the many pollutants characteristic of urban runoff. There, these pollutants would create negative physical, chemical, and biological effects. On the other hand, if the appropriate water quality volume is used (i.e., no less than the full volume of the 85th percentile, 24-hour event), the retentive stormwater management BMPs would deliver no pollutants to the receiving water in any rainfall up to and including the design event. Undeveloped land generates runoff discharged to surface waters as a function of factors such as its soils, hydrogeology, topography, and vegetative cover. Sites having conditions such as soils of relatively fine texture, high groundwater table, steep slopes, and/or scanty vegetation can produce substantial surface runoff flows in the undeveloped state compared to locations not having such characteristics.

Comparative Quantitative Assessment of Alternative Standards for the San Diego Area

A fairly common condition in the San Diego area is soil relatively restrictive to infiltration of water (Hydrologic Soil Group D soils). Lands with these soils, even in the undeveloped

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[1] There is a different basis for BMPs through which water flows rapidly (e.g., biofiltration swales), as given by Tentative Order provision E.3.c(1)(c)(ii).

[2] Guo, J.C.Y. and B. Urbonas. 1996. Maximized Detention Volume Determined by Runoff Capture Ratio. *Journal of Water Resources Planning and Management*, January/February.

condition, produce substantially more runoff than other soils, the least restrictive of which yield very little runoff at all when undeveloped. However, that D soil runoff is uncontaminated with the numerous pollutants characteristic of urban runoff. Developing on these soils and allowing retention only of the differential runoff volume still releases the relatively high pre-development quantity of runoff, now contaminated with the urban pollutants.

I performed an analysis and prepared a report on the relative benefits of five potential runoff retention standards, including: Standard 1—the 85th percentile, 24-hour event standard; Standard 4—a differential standard based on the average annual runoff volume; and Standard 5—a differential standard capped at the 85th percentile, 24-hour event (standard numerical designation are from the original report, Horner and Gretz 2011).[1] I applied "low impact development" (LID) runoff retention strategies to attempt to meet each standard for a range of land uses from single-family residential, to "big-box" commercial, to high-density infill redevelopment. I divided the strategies into Basic ARCD and Full ARCD (ARCD is aquatic resources conservation design, essentially a synonym for LID). When infiltration alone (Basic ARCD) could not accomplish full retention according to the standard, roof runoff management strategies were selected as appropriate for the land use case (Full ARCD). For the retail commercial development, roof runoff management would be accomplished by harvesting, temporarily storing, and applying water to use in the building. In residential cases roof runoff would be dispersed on the landscape for evapotranspiration and some infiltration. I performed the analysis for four locations around the nation, including the San Diego area (a specific location based on San Marcos). I used the two most common soil types around San Marcos, Hydrologic Soil Groups C (somewhat restrictive to infiltration) and D.

My calculations showed that it is possible to retain <u>all</u> of the average annual runoff volume on the C soil using only Basic ARCD.[2] No urban stormwater pollutants would enter receiving waters in an average year in that situation. Any retention standard that might be set by a permit could be met with that soil condition, and also in any less restrictive Hydrologic Soil Group (e.g, A and B soils) present. With D soils I estimated that Full ARCD would retain 37-66 percent of the average annual runoff volume, depending on the land use and its land cover characteristics. The pollutant mass (the multiplication product of pollutant concentration and runoff volume) prevented from entering receiving waters would be somewhat greater as a percentage of the total produced in an average year, because the BMPs would reduce concentrations as well as volume.

I also analyzed the water quality benefits that would be realized if each standard was <u>just</u> met; i.e., the BMPs do not necessarily accomplish all that they could but just enough to meet the respective standard. With the San Diego area D soil I determined that the 85th percentile, 24-

[1] Horner, R.R. and J. Gretz. 2011. Investigation of the Feasibility and Benefits of Low-Impact Site Design Practices Applied to Meet Various Potential Stormwater Runoff Regulatory Standards. Report to U.S. Environmental Protection Agency by Natural Resources Defense Council.

[2] As a result, a more stringent standard, such as retention of runoff from the 90th or 95th percentile, 24-hour storm event or, alternatively, 90 or 95 percent of the average annual runoff volume would be appropriately applied in the permit. Retention Standards 2 and 3 assessed by Horner and Gretz (2011) were based , respectively, on the 95th percentile, 24-hour event and 90 percent of the average annual volume

hour event standard (Standard 1) would not actually be met with Full ARCD strategies for most land use cases. However, in attempting to meet that standard those strategies would retain 37-62 percent of the average annual runoff volume, again depending on the land use. The capped differential volume standard (Standard 5) would be met with Full ARCD for all land use cases, but the average annual volume retention would be only 16-28 percent. The differential standard based on the average annual runoff volume (Standard 4) would be achieved with all but one land use, retaining 27-44 percent of the average annual volume, still less than with Standard 1. This analysis demonstrates the clear superiority of Standard 1, especially over the capped differential volume standard, on the relatively restrictive soils. Priority projects should be required to comply with this standard on-site to the extent possible and to compensate for any shortfall by creating or contributing to off-site retention opportunities in the same watershed.

As I noted above, all standards can be achieved for any land use considered on the C soils. If those standards are just met, Standard 1 would result in retention of 62 percent of the average annual runoff volume in all land use cases. Standard 4 would actually out-perform Standard 1with these soils, retaining an estimated 72-80 percent. However, Standard 5 would again yield lesser benefits, retaining only 44-49 percent. Accordingly, here should be no consideration of a capped differential volume standard in my opinion; and there should be no consideration of a differential volume standard on D soils or where this standard under-performs the standard based on retention of the 85th percentile, 24-hour storm event.

My Recommendations

For optimum water quality benefits, I recommend and encourage that the Tentative Order be revised to require the larger of the two retention volumes determined according to both provisions E.3.c(1)(a)(i) and E.3.c(1)(a)(ii). The latter standard should be clarified to constitute the difference between the post- and pre-development average annual runoff volumes, with the pre-development state taken as the typical land cover existing before European settlement of an area. Furthermore, I urge that the permit require compensation for any shortfall in meeting the retention requirement by creating or contributing to off-site retention opportunities in the same watershed.

Example Standards from Elsewhere in the United States

As pointed out above, adopting a volumetric basis for stormwater treatment design and then subjecting that full volume to onsite retention or treatment has been the rule in the United States. Jurisdictions take differing approaches to defining that volume; but, once it is set, they utilize the entire quantity as the basis for BMP design. Common approaches include the storm percentile method: a storm event of selected frequency and duration is chosen, which correlates to a certain depth of precipitation spread over a watershed area. In addition to southern California, Georgia provides an example of this approach (http://www.georgiastormwater.com/vol2/1-3.pdf at 1.3-1):

> Treat the runoff from 85% of the storms that occur in an average year. For Georgia, this equates to providing water quality treatment for the runoff resulting from a rainfall depth

of 1.2 inches.

The state of Washington employs a second approach, originally developed according to a storm percentile analysis (http://www.ecy.wa.gov/pubs/0510029.pdf at 2-28):

> Water Quality Design Storm Volume: The volume of runoff predicted from a 24-hour storm with a 6-month return frequency (a.k.a., 6-month, 24-hour storm). Wetpool facilities are sized based upon the volume of runoff predicted through use of the Natural Resource Conservation Service curve number equations … for the 6-month, 24-hour storm. Alternatively, the 91st percentile, 24-hour runoff volume indicated by an approved continuous runoff model may be used.

Numerous jurisdictions, such as Maine, use the precipitation depth approach (http://www.maine.gov/dep/blwq/docstand/stormwater/stormwaterbmps/vol3/chapter2.pdf at 2-12):

> Stormwater management facilities must be designed to treat the first 1 inch of runoff ...

Similarly, Maryland's standard is (http://www.mde.state.md.us/assets/document/chapter2.pdf at 2.1):

> P= rainfall depth in inches and is equal to 1.0" in the Eastern Rainfall Zone and 0.9" in the Western Rainfall Zone ...

Pennsylvania specifies (http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=| at 3.3.4):

- Stormwater facilities shall be sized to capture at least the first two inches (2") of runoff from all contributing impervious surfaces.
- At least the first one inch (1.0") of runoff from new impervious surfaces shall be permanently removed from the runoff flow – i.e., it shall not be released into the surface Waters of this Commonwealth. Removal options include reuse, evaporation, transpiration, and infiltration.

North Carolina's approach is (http://h2o.enr.state.nc.us/su/documents/BMPManual_WholeDocument_CoverRevisedDec2007.pdf at 2-2):

> Non-coastal counties: Control and treat the first 1.0" of rain. (Note: a more complex basis applies to coastal counties.)

In none of these cases does the stormwater treatment design basis involve a differential volume computation, and certainly not one capped at a certain event. I encourage the San Diego Regional Board to take notice.

I would be glad to discuss my comments and invite you to contact me if you wish to do so.

Sincerely,

Richard R. Horner

Richard R. Horner

Attachment: Richard R. Horner, Ph.D., Background and Experience

RICHARD R. HORNER, PH.D.

BACKGROUND AND EXPERIENCE

I have 36 years of experience in the urban stormwater management field and 11 additional years of engineering practice. During this period I have performed research, taught, and offered consulting services on all aspects of the subject, including investigating the sources of pollutants and other causes of aquatic ecological damage, impacts on organisms in waters receiving urban stormwater drainage, and the full range of methods of avoiding or reducing these impacts.

I received a Ph.D. in Civil and Environmental Engineering from the University of Washington in 1978, following two Mechanical Engineering degrees from the University of Pennsylvania. Although my degrees are all in engineering, I have had substantial course work and practical experience in aquatic biology and chemistry. For 12 years beginning in 1981, I was a full-time research professor in the University of Washington's Department of Civil and Environmental Engineering. From 1993 until 2011, I served half time in that position and had adjunct appointments in two additional departments (Landscape Architecture and the College of the Environment's Center for Urban Horticulture). I spent the remainder of my time in private consulting through a sole proprietorship. My appointment became emeritus in late 2011, but I continue university research and teaching at a reduced level while maintaining my consulting practice.

I have conducted numerous research investigations and consulting projects involving all aspects of stormwater management. Serving as a principal or co-principal investigator on more than 40 research studies, my work has produced three books, approximately 30 papers in the peer-reviewed literature, and over 20 reviewed papers in conference proceedings. I have also authored or co-authored more than 80 scientific or technical reports. In addition to graduate and undergraduate teaching, I have taught many continuing education short courses to professionals in practice. My consulting clients include federal, state, and local government agencies; citizens' environmental groups; and private firms that work for these entities, primarily on the West Coast of the United States and Canada but in some instances elsewhere in the nation.

Over an 18-year period I spent a major share of my time as the principal investigator on two extended research projects concerning the ecological responses of freshwater resources to urban conditions and the urbanization process. I led an interdisciplinary team for 11 years in studying the effects of human activities on freshwater wetlands of the Puget Sound lowlands. This work led to a comprehensive set of management guidelines to reduce negative effects and a published book detailing the study and its results. The second effort, extending 10 years, involved an analogous investigation of human effects on Puget Sound's salmon spawning and rearing streams. These two research programs had broad sponsorship, including the U.S. Environmental Protection Agency, the Washington Department of Ecology, and a number of local governments.

I have helped to develop stormwater management programs in Washington State, California, and British Columbia and studied such programs around the nation. I was one of four principal participants in a U.S. Environmental Protection Agency-sponsored assessment of 32 state, regional, and local programs spread among 14 states in arid, semi-arid, and humid areas of the West and Southwest, as well as the Midwest, Northeast, and Southeast. This evaluation led to the 1997 publication of "Institutional Aspects of Urban Runoff Management: A Guide for Program Development and Implementation" (subtitled "A Comprehensive Review of the Institutional Framework of Successful Urban Runoff Management Programs").

My background includes 19 years of work in California, where I have been a federal court-appointed overseer of stormwater program development and implementation at the city and county level and for two Caltrans districts. I was directly involved in the process of developing the 13 volumes of Los Angeles County's Stormwater Program Implementation Manual, working under the terms of a settlement agreement in federal court as the plaintiffs' technical representative. My role was to provide quality-control review of multiple drafts of each volume and contribute to bringing the program and all of its elements to an adequate level. I have also evaluated the stormwater programs in San Diego, Orange, Riverside, San Bernardino, Ventura, Santa Barbara, San Luis Obispo, and Monterey Counties, as well as a regional program for the San Francisco Bay Area. My clients in these cases include Natural Resources Defense Council, Santa Monica Baykeeper, Orange County Coastkeeper, Ventura Coastkeeper, Santa Barbara Channelkeeper, Russian Riverkeeper, and San Diego Coastkeeper. At the recommendation of the latter organization, I have been a consultant on stormwater issues to the City of San Diego, the San Diego Unified Port District, and the San Diego County Regional Airport Authority.

For the last six years I have been a member of Salmon-Safe's assessment team. Salmon-Safe is an organization based in Portland, Oregon that certifies academic and professional campuses and other developed lands for maintaining practices supportive of salmon protection and recovery. We have assessed numerous parcels in Oregon and Washington and extended certification to those whose practices met our criteria or conditions imposed to achieve certification.

I was a member of the National Academy of Sciences-National Research Council (NAS-NRC) committee on Reducing Stormwater Discharge Contributions to Water Pollution. NAS-NRC committees bring together experts to address broad national issues and give unbiased advice to the federal government. The present panel was the first ever to be appointed on the subject of stormwater. Its broad goals were to understand better the links between stormwater discharges and impacts on water resources, to assess the state of the science of stormwater management, and to apply the findings to make policy recommendations to the U.S. Environmental Protection Agency relative to municipal, industrial, and construction stormwater permitting. The committee issued its final report in October 2008.

INVESTIGATION OF THE FEASIBILITY AND BENEFITS OF LOW-IMPACT SITE DESIGN PRACTICES APPLIED TO MEET VARIOUS POTENTIAL STORMWATER RUNOFF REGULATORY STANDARDS

By

Richard R. Horner[1] and Jocelyn Gretz[2]

Report to

U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, N.W.
Washington, DC 20460

From

Natural Resources Defense Council
1314 Second Street
Santa Monica, CA 90401

December, 2011

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EXECUTIVE SUMMARY

STUDY DESIGN

A study was performed to investigate the degree to which stormwater management practices, commonly referred to as “low-impact development” methods or “green infrastructure,” can retain urban runoff and meet five possible regulatory standards that could be applied nationally. Retention is defined as preventing the conversion of precipitation to runoff discharging from a development site on the surface, from where it can enter a receiving water. Retaining runoff from impervious and pollutant generating pervious surfaces prevents the introduction of urban runoff pollutants to receiving waters as well as reduces runoff volume to prevent stream channel and habitat damage, flooding, and loss of groundwater recharge. ARCD methods were assessed for their ability to: (1-2) meet standards pertaining to retention of the runoff generated by the 85th and 95th percentile, 24-hour precipitation events; (3) retain 90 percent of the post-development runoff; and (4-5) retain the difference between the post- and pre-development runoff, both with and without a cap at the 85th percentile, 24-hour event. The study assessed five urban land use types (three residential, one retail commercial, and one infill redevelopment), each placed in four climate regions in the continental United States on two regionally common soil types.

Infiltrating bioretention was applied as an initial strategy in the analysis of each case. When the initial strategy could not fully retain post-development runoff, additional methods were applied, involving roof runoff harvesting in the most impervious development cases and roof water dispersion in those with substantial pervious area. Benefits were assessed with respect to reduction of the annual average surface runoff volume from the quantity estimated without any stormwater management practices, the associated maintenance of pre-development groundwater recharge, and water quality improvement achieved through preventing discharge to receiving waters of pollutants generated with developed land uses.

RETENTION AND POLLUTANT REDUCTION CAPABILITIES

The initial strategy of infiltrating bioretention could retain all post-development runoff and pre-existing groundwater recharge, as well as attenuate all pollutant transport, in the three residential land use development types on hydrologic soil group (HSG) B soils, in all cases, in all regions, taking a fraction of the available pervious area to do so. For the more highly impervious commercial retail and redevelopment cases, bioretention would retain about 45 percent of the runoff and pollutants generated and save about 40 percent of the pre-development recharge. Adding roof runoff management measures in these cases would approximately double retention and pollutant reduction for the retail commercial land use and raise it to 100 percent for the redevelopment. Results were generally similar with HSG C soils, although more of the pervious portion of sites was required to equal the retention seen on B soils.

For development on the D soils in all climate regions, use of roof runoff management techniques was estimated to increase runoff retention and pollutant reduction from zero to between about one-third to two-thirds of the post-development runoff generated, depending on the land use case. These strategies would offer little groundwater recharge benefit with this soil condition, but would still have the potential to significantly reduce runoff volume and pollutant loading.

ABILITY TO MEET STANDARDS

The projected ability to meet the five standards identified above was found to vary mostly in relation to soil type (B or C versus D) and the relative imperviousness of development. The ability to meet the five standards varied much less across climate regions. With B and C soils, the methods considered were projected to meet all five standards in all but 12 of 125 evaluations. With D soils, however, only three standards could be met at all and those only occasionally. However, even on D soils, all cases for Standard 1 (retention of the 85th percentile, 24-hour precipitation event) were able to retain greater than 50 percent of the required runoff volume. Moreover, opportunities to use ARCD practices or site design principles not modeled in this analysis have the potential to further increase runoff retention volume.

Standard 3 (retain 90 percent of the average annual post-development runoff volume) would be the most environmentally protective standard. Meeting or coming as close as possible to meeting, but not exceeding, this standard was estimated to lead to 66-90 percent of total runoff retention and pollutant loading reduction on B and C soils and 37-66 percent runoff retention on D soils. Standard 2 (retain the runoff produced by the 95th percentile, 24-hour precipitation event) would yield equivalent protection on D soils and only slightly less protection with B and C soils. The outcome with this standard would also be more consistent region to region than with the alternative standard 1, based on the 85th instead of the 95th percentile precipitation event. Sites located on B or C soils were able retain the runoff produced by the 85th percentile storm in 24 of 25 cases modeled (in 18 of the 25 cases by using infiltrating bioretention alone), and were able to retain the runoff produced by the 95th percentile storm in 22 of 25 cases modeled.

Standards 4 and 5, based on the differential between pre- and post-development runoff volume, are inconsistent in retaining runoff and reducing pollutants, in that they are relatively protective where pre-development runoff is estimated to be low relative to post-development flow, but result in progressively lower retention and pollutant loading reduction as pre- and post-development volumes converge, such as in several cases on D soils. Standard 5 is especially weak in this regard. The potentially low level of retention and pollutant loading reduction renders these standards based on the change in pre- versus post-development runoff volume poor candidates for national application, at least as formulated in these terms.

In summary, standards 2 and 3 are clearly superior to the other three options from both a volume and pollutant load reduction standpoint. Standard 3 is entirely consistent from place to place in degree of environmental protection, and standard 2 does not deviate much. Analysis of the five development cases on two soil groups in each of four regions demonstrated the two standards are virtually identical in the runoff retention and pollutant loading reduction they would bring about. Of the remaining standards, standard 1 (retantion of the runoff produced by the 85th percentile storm event) remains more consistent across regions and more protective of water quality for development on D soils than either standard 4 or 5, and is preferable to those standards in this regard.

INTRODUCTION

GENERAL STUDY DESCRIPTION

Study Design

This purpose of this study was to investigate the degree to which low-impact development (LID) [1] practices can meet or exceed the requirements of various potential stormwater management facility design standards and to determine the environmental benefits that can be realized by applying these techniques. The investigation was performed by estimating the stormwater retention possible with full application of low-impact options under a range of conditions broadly representative of different regions within the United States and then determining the implications of the findings for achieving various standards and for providing benefits. Retention is defined as preventing the conversion of precipitation to surface runoff from urbanized land uses through infiltration, evapotranspiration, and/or harvesting for some water supply purpose. Retaining runoff from impervious and pollutant generating pervious surfaces prevents the introduction of urban runoff pollutants to receiving waters as well as reduces runoff volume to prevent stream channel and habitat damage, flooding, and loss of groundwater recharge. Benefits were assessed with respect to reduction of the potential developed land surface runoff volume, the associated maintenance of pre-development groundwater recharge, and water quality improvement achieved through preventing discharge to receiving waters of pollutants generated with developed land uses.

The potential regulatory standards investigated were capture and retention of, at minimum:

- Standard 1—The runoff produced by the 85th percentile, 24-hour precipitation event,[2] a standard commonly used in California;
- Standard 2—The runoff produced by the 95th percentile, 24-hour precipitation event, the standard adopted under Section 438 of the Energy Independence and Security Act;
- Standard 3—90 percent of the average annual post-development runoff volume;
- Standard 4—The difference between the post- and pre-development[3] average annual runoff volumes; and
- Standard 5—The difference between the post- and pre-development runoff volumes for all events up to and including the 85th percentile, 24-hour precipitation event.

Conditions broadly representative of the nation were selected by, first, considering the climate regions defined in USEPA's (1983) Nationwide Urban Runoff Project (NURP) report. For full analysis, climate regions 1 (Northeast-Upper Midwest), 3 (Southeast), 5 (South Central), and 6 (Southwest) were chosen as providing a wide range of climatological conditions and geographic distribution. Once the four regions were picked, a metropolitan area and a specific city in each were chosen to serve as typical models of development circumstances in the general area, as

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[1] The National Research Council (NRC, 2009) renamed LID, also known as green infrastructure, as aquatic resources conservation design (ARCD), the term used henceforth in this report.

[2] The 85th percentile, 24-hour event represents the precipitation quantity in a 24-hour period not exceeded in 85 percent of all events in an extended record.

[3] In this study the pre-development state is taken as the typical land cover existing before European settlement of an area.

detailed in the Case Studies discussion below. In addition, region 7 (Pacific Northwest) was identified as an additional location to be discussed. This region is the site of a considerable amount of ARCD application in an area somewhat different climatologically than other selected regions, in having persistent winter rainfall totaling annually, in the major urban areas, intermediately among the other regions. Results of research on ARCD conducted in this region are discussed at several points in this report.

Soils and topography were the next considerations in developing broadly representative conditions. U.S. Department of Agriculture websites were the source of general soil characterizations for the study regions and specific soil survey data in and around the representative metropolitan areas. Soils generally represented some range in textural classes and associated hydraulic conductivities. For each region, a soil type predominating among those representing hydraulic conductivities relatively high and low for the region were selected to serve as a basis for the analyses. The effect of slope was also investigated but ultimately found not to affect results substantially.

Five types of urban development were selected to represent breadth in land use: (1) multi-family residential, (2) small-scale single-family residential, (3) large-scale single-family residential, (4) large-scale commercial, and (5) infill redevelopment. Building permit data from each region were consulted to determine typical distributions of site features for each (e.g., land cover by buildings, parking areas, roadways, walkways, driveways, landscaping).

Case studies thus comprised four climate regions, each with two soil conditions and five land use types, for a total of 40 permutations. For each, the ability of the site to accommodate soil- and vegetation-based ARCD practices was investigated. Runoff quantities were estimated and compared to the five potential regulatory standards. Annual mass loading discharges were estimated for four pollutants: total suspended solids (TSS), total recoverable copper (TCu) and zinc (TZn), and total phosphorus (TP). In any case where soil- and vegetation-based ARCD infiltration techniques appeared not to be able to attenuate all runoff, specific roof runoff management strategies were investigated as possible measures to achieve additional retention. Runoff quantities and pollutant discharges were recalculated based on use of these additional practices in place.

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 to meet the respective potential regulatory standards.

AQUATIC RESOURCES CONSERVATION DESIGN PRACTICES

General Description

As the stormwater management field developed, it passed through several stages. First, it was thought that the key to success was to match post-development with pre-development peak flow rates, while also reducing a few common pollutants (usually, TSS) by a set percentage. Finding that these efforts generally required large ponds, but that they did not forestall impacts, stormwater managers next deduced that runoff volumes and high discharge durations would also have to decrease. Almost simultaneously, although not necessarily in concert, the idea of low-impact development arose to offer a way to achieve actual avoidance, or at least minimization, of discharge quantity and pollutant increases reaching far above pre-development levels. These methods reduce storm runoff and its contaminants by decreasing their generation at sources, infiltrating into the soil or evaporating or transpiring[4] 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.

The National Research Council ("NRC") (2009) renamed LID as Aquatic Resources Conservation Design (ARCD) for several reasons. First, this term signifies that the principles and many of the methods apply not only to building on previously undeveloped sites, but also to redeveloping and retrofitting existing development. Second, incorporating aquatic resources conservation in the title is a direct reminder of the central reason for improving stormwater regulation and management. ARCD encompasses the complete range of practices to counteract all negative urban runoff impacts; i.e., the full suite of practices that emphasize and accomplish retention as defined above. These practices aim at decreasing surface runoff peak flow rates, volumes, and elevated flow durations, as well as avoiding or at least minimizing the introduction of pollutants to any surface runoff produced. Reducing the concentration of pollutants, together with runoff volume decrease, cuts the cumulative mass loadings (mass per unit time) of pollutants entering receiving waters over time.

The menu of ARCD practices begins with conserving, as much as possible, existing trees, other vegetation, and soils, as well as natural drainage features (e.g., depressions, dispersed sheet flows, swales). Clustering development to affect less land is a fundamental practice advancing this goal. Conserving natural features would further entail performing construction in such a way that vegetation and soils are not needlessly disturbed and soils are not compacted by heavy equipment. Using less of polluting materials, isolating contaminating materials and activities from contact with rainfall or runoff, and reducing the introduction of irrigation and other non-stormwater flows into storm drain systems are essential. Many ARCD practices fall into the category of minimizing impervious areas through decreasing building footprints and restricting the widths of streets and other pavements to the minimums necessary. Another important category of ARCD practices involves directing runoff from roofs and pavements onto pervious areas as sheet flow, where all or much of the runoff can infiltrate or evaporate in many situations.

Water can be harvested from impervious surfaces, especially roofs, and put to use for irrigation, non-potable indoor water supply. Harvesting is a standard technique for Leadership in Energy and Environmental Design (LEED) buildings (U.S. Green Building Council, 2008). Many successful systems of this type are in operation, with examples 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). Harvesting is feasible at the small scale using rain barrels and at larger scales using larger collection cisterns and piping systems. These small-scale applications have been used throughout the world for centuries and are rapidly spreading in the United States today (See, e.g., Texas Water Development Board, 2005; Georgia Department of Community Affairs, 2009).

If these practices are used but runoff is still produced, ARCD offers an array of techniques to retain it on-site through infiltration and evapotranspiration (ET). The bioretention cell (rain garden) is the workhorse practice in this category, but swales conveying flow slowly, filter strips set up for sheet flows, and other modes are also important. Relatively low traffic areas can be constructed with permeable surfaces such as porous asphalt, open-graded Portland cement concrete, coarse granular materials, concrete or plastic unit pavers, or plastic grid systems to allow for infiltration.

[4] Transpiration refers to vaporization of water from plant tissue, while evaporation applies to vaporization from a liquid (e.g., pool) or solid (e.g., leaf) surface. The terms are often combined to form the compound evapotranspiration (ET).

ARCD practices should be selected and applied as close to sources as possible to stem runoff and pollutant production near the point of potential generation. However, these practices must also work well together and, in many cases, must be supplemented with strategies operating farther downstream. For example, the City of Seattle, in its "natural drainage system" retrofit initiative, built serial bioretention cells flanking relatively flat streets. "Cascades" of vegetated stepped pools created by weirs were installed along more sloping streets. In some cases the cells drain to downstream cascades. The upstream components are highly effective in attenuating most or even all runoff. Flowing at higher velocities on sloped surfaces, the cascades do not perform at such a high level, although under favorable conditions they can still infiltrate or evapotranspire the majority of the incoming runoff (Chapman 2006, Chapman and Horner 2010). Even if not as impressive statistically, cascades can actually decrease storm discharge to streams more than the cells do, because of their generally greater size. Also, the cascades extract pollutants from remnant runoff through mechanisms mediated by vegetation and soils. The success of Seattle's natural drainage systems demonstrates that well designed ARCD practices can mimic natural landscapes hydrologically, and thereby avoid raising discharge quantities.

A watershed-based program emphasizing ARCD practices would convey significant benefits beyond greatly improved stormwater management. ARCD techniques overall would advance water conservation, and infiltrative practices would increase recharge of groundwater resources. ARCD practices can be made attractive and thereby improve neighborhood aesthetics and property values. Retention of more natural vegetation can both save wildlife habitat and provide recreational opportunities. Municipalities could use the program in their general urban improvement initiatives, giving incentives to property owners to contribute to goals in that area while also protecting water resources.

A Catalogue of ARCD Practices

ARCD practices are numerous and expanding as existing configurations are applied in new ways. Table 1 presents a catalogue adapted from USEPA (2007) and NRC (2009). This catalogue contains practices that are not equally applicable in all settings; e.g., nevertheless, each category offers practices applicable in a broad variety of circumstances.

The best strategy for choosing among and implementing these practices is a decentralized, integrated one; i.e., selecting practices that fit together as a system, starting at or near sources and working through the landscape until management objectives are met. This strategy makes maximum possible use of practices in the first three categories, which prevent stormwater quantity and quality problems, and then selects among the remaining classifications in relation to the localized and overall site conditions. Source control and preservation of existing vegetation and soils obviously avoid post-development runoff quantity and pollutant increases from any portion of the site that can be so treated. Among all strategies, these best maintain natural infiltration and ET patterns and yield of materials flowing from the site. This preventive strategy is supplemented by strategies to create as little impervious cover as possible. The remaining practices then contend with the excess runoff and pollutants over pre-development levels generated by the development.

For the practices that infiltrate water, a site's soil characteristics and depth to groundwater can and should be determined through infiltration rate testing and excavation to determine the infiltration capability. Because of the often substantial variability of conditions around a site, these determinations should be made at multiple points. If the natural infiltration rate is low, generally < 0.5 inch/hour (< 1.25 cm/h, Geosyntec 2008), in many situations the soil can be amended, usually with organic compost, to apply an infiltrative practice.

In addition to soil characteristics, the position of the groundwater table is a crucial determinant of whether or not stormwater infiltration should be promoted by applying ground-based ARCD practices. A seasonal high water table too close to the surface results in rapid saturation of a thin soil column and retarded infiltration. Ponding water longer than 72 hours can permit mosquito growth, damage vegetation, and promote clogging of the facility by microorganism growths and polysaccharide organic materials that form in the reduced-oxygen environment accompanying excessive ponding time (Mitchell and Nevo 1964, Ronner and Wong 1996). Also, storm runoff flow through a short soil column or very rapidly through a coarse-textured soil can convey contaminants to groundwater.

Evidence gathering from available performance data is that evapotranspiration (ET) can be a substantial factor in water retention (discussed below) but may be difficult to quantify at a given site without more research. A conservative approach is to design on the basis of infiltration rate, calculated to include consideration of soil amendments, if any. Together with careful investigation of soils and hydrogeologic conditions, this means of proceeding is very likely to produce facilities that retain at least as much runoff as predicted, and almost certainly more as a result of unquantified ET.

Table 1. A Catalogue of Aquatic Resources Conservation Design Practices (USEPA [2007] and NRC [2009])

Category	Definition	Examples
Source control	Minimizing pollutants or isolating them from contact with rainfall or runoff	• Substituting less for more polluting products • Segregating, covering, containing, and/or enclosing pollutant-generating materials, wastes, and activities • Avoiding or minimizing fertilizer and pesticide applications • Removing animal wastes deposited outdoors • Conserving water to reduce non-stormwater discharges
Conservation site design	Minimizing the generation of runoff by preserving open space and reducing the amount of land disturbance and impervious surface	• Clustering development • Preserving wetlands, riparian areas, forested tracts, and porous soils • Reducing pavement widths (streets, sidewalks, driveways, parking lot aisles) • Reducing building footprints
Conservation construction	Retaining vegetation and avoiding removing topsoil or compacting soil	• Minimizing site clearing • Minimizing site grading • Prohibiting heavy vehicles from driving anywhere unnecessary
Runoff harvesting	Capturing rainwater, generally from roofs, for a beneficial use	• Using storage and distribution systems (rain barrels or cisterns) for irrigation and/or indoor supply for public and private buildings
Natural runoff conveyance practices	Maintaining natural drainage patterns (e.g., depressions, natural swales) as much as possible, and designing drainage paths to increase the time before runoff leaves the site	• Emphasizing sheet instead of concentrated flow • Eliminating curb-and-gutter systems in favor of natural drainage systems • Roughening land surfaces • Creating long flow paths over landscaped areas • When flow must be concentrated, using vegetated channels with flow controls (e.g., check dams)
Practices for temporary runoff storage followed by infiltration and/or evapotranspiration[a]	Use of soil pore space and vegetative tissue to increase the opportunity for runoff to percolate to groundwater or vaporize to the atmosphere	• Bioretention cells (rain garden) • Vegetated swales (channel flow) • Vegetated filter strips (sheet flow) • Planter boxes • Tree pits • Infiltration basins • Infiltration trenches • Roof downspout surface or subsurface dispersal • Permeable pavement • Vegetated (green) roofs
ARCD landscaping[b]	Soil amendment and/or plant selection to increase storage, infiltration, and evapotranspiration	• Organic compost soil amendments • Native, drought-tolerant plantings • Reforestation • Turf conversion to meadow, shrubs, and/or trees

[a] Some of these practices are also conventional stormwater BMPs but are ARCD practices when ARCD landscaping methods are employed as necessary to maximize storage, infiltration, and evapotranspiration. The first five examples can be constructed with an impermeable liner and an underdrain connection to a storm sewer, if full retention is technically infeasible (see further discussion later). Vegetated roofs store and evapotranspire water but offer no infiltration opportunity, unless their discharge is directed to a secondary, ground-based facility.
[b] Selection of landscaping methods depends on the ARCD practice to which it applies and the stormwater management objectives, but amending soils unless they are highly infiltrative and planting several vegetation canopy layers (e.g., herbaceous growth, shrubs, and trees) are generally conducive to increasing storage, infiltration, and evapotranspiration.

Application of ARCD Practices in This Study

The investigation performed for this study first assessed the capacity of each case study site to infiltrate the full average annual post-development storm runoff volume and thereby reduce pollutant releases to zero. The report terms this initial evaluation as the “Basic ARCD Analysis”. The means of infiltration was not distinguished at this level of analysis. For example, it was not specified if runoff would be distributed in sheet flow across a pervious area or channeled into a rain garden. As detailed later in the Methods of Analysis section, this analysis was limited to the estimated infiltration capacity of the case study soil type, possibly compost-amended, and the available pervious area.

Critically, there was no attempt to estimate the loss of surface runoff through ET in the Basic ARCD analysis (ET is considered, to address rooftop runoff only, as part of our “Full ARCD analysis,” discussed below). In general, the estimated mean annual evapotranspiration in the Southeast is about 70 percent of the precipitation, or roughly 35 inches per year. For large areas of the Southwest, evapotranspiration is virtually equal to 100 percent of the precipitation, which is only about 10 inches per year. The ratio of estimated mean annual evapotranspiration to precipitation is least in the mountains of the Pacific Northwest and New England where evapotranspiration is about 40 percent of the precipitation (Hanson, 1991). By leaving out these substantial losses, generally 40 percent of precipitation or more, the retention estimates in this study can be considered quite conservative.

Additionally, there was no consideration of many ARCD practices in the Table 1 catalogue that could be applied in site-specific design. For example, there were no refinements of the prevailing building standards to reduce street widths or cluster buildings and reduce their footprints. Further, green roofs were not considered in this study, although they are already making a contribution to runoff reduction around the nation and reflect a significant additional opportunity to retain runoff on-site. The U.S. EPA has stated that “a 3.5-4 in. (8 -10 cm) deep green roof can retain 50% or more of the annual precipitation.” (U.S. EPA, 2009a). For water quality, we did not assume any source control implementation. Thus, actual site design could take advantage of substantial additional capabilities not considered in this study.

In cases where the practices incorporated in the initial level of analysis (infiltration through bioretention) did not, according to the estimates, fully attenuate post-development pollutant discharges, specific attention was directed at ways of extracting additional water from surface discharge by managing roof runoff. This assessment is called the “Full ARCD Analysis” in the report. The options broadly divide into harvesting water for a purpose such as irrigation and/or non-potable indoor supply, or making special provisions to infiltrate or evapotranspire roof runoff even if soil conditions are limiting. Harvesting applies best to relatively large developments having sufficient demand for the collected water. While single-family residences can harvest water into rain barrels or cisterns for lawn and garden watering, these containers may be small in volume relative to runoff production; and though opportunity exists, no credit was taken for them in this study. However, even in poorly infiltrating soils, options exist to disperse house roof runoff as sheet flow for storage in vegetation and soil until evapotranspiration and some infiltration occurs.

CASE STUDIES

CLIMATE REGIONS

Basis of Selection

The Nationwide Urban Runoff Project divided the nation into nine regions based on differences in volume, intensity, and duration of precipitation and interval between precipitation events (USEPA 1983). For broad representation of the U.S. generally this study chose regions 1 (Northeast-Upper Midwest), 3 (Southeast), 5 (South Central), and 6 (Southwest) for analysis. Table 2 provides the annual precipitation statistics from the NURP compilation.

Table 2. Precipitation Statistics (Means) for Four NURP Regions Selected for Study (USEPA 1983)

Region	Volume (inch)	Intensity (inch/hour)	Duration (hours)	Interval (hours)
1—Northeast-Upper Midwest	0.26	0.051	5.8	73
3—Southeast	0.49	0.102	5.2	89
5—South Central	0.33	0.080	4.0	108
6—Southwest	0.17	0.045	3.6	277

The selected regions represent a volume differential of about a factor of three, intensity variation of approximately two times, and inter-storm interval varying by almost four times. The NURP report shows coefficients of variation (mean/standard deviation) of greater than 1.0 for all of these means, indicating an overall high degree of dispersion.

Figure 1 visually depicts variation in mean annual precipitation across the continental United States. It shows that the selected regions are overall representative of the broadly prevailing range across the nation, particularly its major urban and still urbanizing areas.

Region 7 (Pacific Northwest) was also identified for discussion of research results on ARCD, although not full analysis. It has less intense (mean 0.024 inch/hour) but much more extended (mean 20.0 hours) precipitation compared to any other region in the nation. Mean storm volume ranks with region 3 (mean 0.48 inch); but fewer storms, especially in the summer, yield overall less total annual precipitation in lowland areas holding all urban development in region 7. It was of interest because of the already occurring use of ARCD techniques in a relatively rainy part of the country.

Representative Metropolitan Areas and Cities

Once the regions were identified, a metropolitan area within each area was chosen as a basis for assigning specific precipitation and development characteristics. The areas considered were USEPA-designated Urban Areas: “An urbanized area is a land area comprising one or more places – central place(s) – and the adjacent densely settled surrounding area – urban fringe – that together have a residential population of at least 50,000 and an overall population density of at least 1,000 people per square mile” (USEPA 2007). Stormwater regulations would have the most impact in areas that are being quickly developed, redeveloped, or both. Five of the twenty fastest growing counties in the nation from 2000 to 2009 were near Atlanta, GA and five were in the state of Texas (U.S. Census Bureau 2010). These statistics factored into the decision to focus on records from these regions.

Each selected metropolitan area is generally representative of its region in precipitation and development characteristics. Each is also undergoing relatively active new development and redevelopment, offering candidate locations where a prospective stormwater standard would frequently be applied. These metropolitan areas are: region 1—Boston, MA, region 3—Atlanta, GA, region 5—Austin, TX, and region 6—San Diego, CA

Figure 1. Precipitation of the Conterminous States of the United States, National Atlas of the United States, 2011.

Finally, a city with a high rate of development (and often redevelopment) was picked in each metropolitan area for investigation of building patterns and standards. The intent was to match regional patterns of climate, soils (see discussion on physiographic data, below), and land use and land cover realistically. After substantial investigation, the conclusion was that building standards, how land is used, and the relative allocation of impervious and pervious lands do not vary in any systematic way across the nation and cannot be regionally distinguished. Therefore, the variables of interest came down to precipitation and soils.

Alpharetta, about 30 miles north of Atlanta, represents that metropolitan area. In 1981 it was a small town of approximately 3,000 residents but grew to 51,243 by 2007. During the workday, the city swells to more than 120,000 residents, workers, and visitors. Alpharetta is home to large corporations such as AT&T (3500 employees), Verizon Wireless (3000 employees), and ADP, Inc./National Account Services (2100 employees). Infill redevelopment projects are anticipated in the downtown area (City of Alpharetta, 2011).

Round Rock is a typical developing city located 15 miles to the north of Austin, TX. In 1970 there were only 2,700 residents in this town, while today the population exceeds 100,000. Round Rock is the eighth-fastest growing city in the nation and the location of several large corporate campuses.

The Town of Framingham, 20 miles west of Boston, represents the northeastern climate zone. At nearly 67,000 inhabitants, Framingham is the largest entity designated as a “town” in the Commonwealth of Massachusetts. It is home to three large corporations and overall 2200 businesses providing 45,000 jobs. Differing greatly from the representative communities in other regions, Framingham was incorporated in 1700 and developed early in the nation's history. Today's activity includes redevelopment of brownfields and downtown revitalization, although some agricultural land still remains within the town limits (Town of Framingham, 2011).

San Marcos, representing the San Diego area and located about 35 miles north of the city, grew from a population of 17,479 in 1980 to 82,743 by 2008. Major institutions in the city include California State University San Marcos and Palomar Community College. At this stage the city is only approximately 72 percent built out, and thus new development continues (City of San Marcos, 2011).

Precipitation Data

Average monthly precipitation data were obtained from the NOAA Hourly Precipitation Data Rainfall Event Statistics[5] for one station with a long-term record in each region: Southeast—Atlanta/Hartsfield International Airport (Station #90451), South Central—Austin/Robert Mueller Municipal Airport (410428), Northeast—Boston/Logan International Airport (190770), and Southwest—San Diego/San Diego International Airport (Lindbergh Field) (47740). Atlanta receives the most precipitation, averaging about 49 inches per year, followed by Boston (47 inches/year), Austin (33 inches/year), and San Diego (10 inches/year). Figure 2 depicts precipitation variations over more than 50 years.

Values for either the 85th and 95th percentile, 24-hour storms were available in a number of state-specific resources, including the Georgia Stormwater Standards Supplement (Center for Watershed Protection 2009) and the Integrated Stormwater Management Program (North Central Texas Council of Governments 2010), as well as national publications such as an USEPA's technical guidance documents (USEPA 2009). However, few references had values for both 85th and 95th percentile storms. Therefore, these values were calculated following the methodology outlined in the USEPA's Technical Guidance on Implementing the Stormwater Runoff Requirements (USEPA 2009, page 30). Daily precipitation and temperature data from the National Climatic Data Center's TD Summary of the Day data set were collected and analyzed for the four stations lover a time period of 60 years, January 1, 1950 to January, 31 2010.

[5] National Climatic Data Center, Hourly Precipitation Data Rainfall Event Statistics (http://cdo.ncdc.noaa.gov/cgi-bin/HPD/HPDStats.pl, last accessed December 15, 2011).

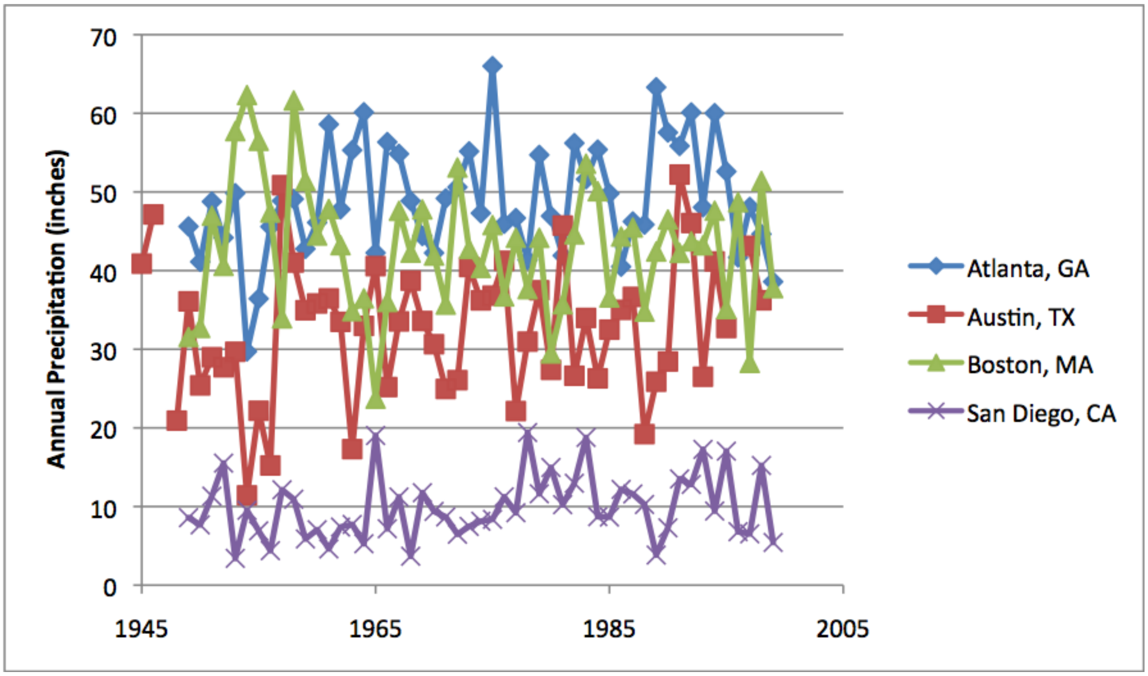

Figure 2. Average Annual Precipitation for Four Climate Regions over the Latter Part of the Twentieth Century (from NOAA Hourly Precipitation Data Rainfall Event Statistics, http://cdo.ncdc.noaa.gov/cgi-bin/HPD/HPDStats.pl)

For snowfall days, snow water equivalent (SWE) was calculated according to the guidelines provided by a National Climate Data Center's (NCDC) document, Estimating the Water Equivalent of Snow, utilizing the reported mean temperature for the day (National Climatic Data Center, accessed December 16, 2011). The NCDC tables calculate that the SWE is at most, about 10 percent of the total snowfall depth. In the methodology for determining the 85th and 95th percentile events, all days with < 0.1 inch precipitation are removed, lowering the impact of snow on the results. Snowfall had no effect in the Southwest region, a very minor effect in the Southeast and South Central, and still a relatively small effect in the Northeast, as follows: San Diego—0 snow days; Atlanta—74 of 4600 total days having ≥ 0.1 inch (1.6 percent), with a contribution ranging 0.01-0.79 inch precipitation; Austin—32 of 2418 days (1.3 percent), contributing 0.01-0.50 inch; and Boston—993 of 4783 days (20.8 percent), contributing 0.01-2.24 inch. Since snow does add to runoff that must be managed in a location like the Northeast, these snow water equivalents were left in the records. Table 3 summarizes precipitation data used in the analyses for the four regions.

Table 3. Precipitation Summary for Study Regions

Region	Average Annual Precipitation (inches)	85th Percentile, 24-Hour Event		95th Percentile, 24-Hour Event	
		Depth (inch)[a]	Fraction Covered[b]	Depth (inch)[a]	Fraction Covered[b]
Southeast	49.02	1.13	0.63	1.79	0.87
South Central	32.67	1.19	0.58	1.99	0.82
Northeast	47.03	1.07	0.81	1.72	0.89
Southwest	9.68	0.76	0.62	1.26	0.83

[a] Calculated from National Climatic Data Center's TD Summary of the Day, for all precipitation days >0.1 inch for period January 1, 1950 – December 31, 2009
[b] Fraction of total annual precipitation covered by event standard

Physiographic Data

General Methods

This section of the report covers the soils, groundwater, and topographic data underlying the analyses. Soil characteristics are largely a product of climate, geology and topography. The characteristics of most interest for this study were those controlling infiltration of surface water and percolation to an aquifer. Although there is variation within each climate region, the major soil orders can be used to identify regional characteristics. The Natural Resources Conservation Service (NRCS) website[6] describing the major soil orders and their locations was the initial source of these data. Maps generated by Miller and White (1998) gave information from the State Soil Geographic Database (STATSGO), including characteristics such as soil texture and hydrologic soil group. These resources were employed to gain a broad view of the soils in each of the four regions.

To extend the scope of the study, soils were investigated in the Upper Midwest, in addition to the Southeast, South Central, Northeast, and Southwest climate regions. Upper Midwest and Northeast soils share general similarities. Both regions also have temperate, seasonal, humid climates. While average annual precipitation is overall somewhat greater in the Northeast compared to the Upper Midwest, the two regions were deemed similar enough physiographically and climatologically to be considered together. This report henceforth groups them as the Northeast – Upper Midwest climate region.

To validate the regional patterns emerging from the general sources, custom "soil resource" reports for four cities were generated using the NRCS Web Soil Survey[7] tool. These reports collected characteristics related to infiltration rates and runoff including soil texture, hydrologic soil group, drainage classification, representative slope, and depth to water table. Using this tool requires selecting an "area of interest". This examination utilized a size of at least 8,000 acres (10,000 acres is the maximum allowed) to insure a representative sample of soil and related conditions.

Hydrologic soil group assignment is a means of generally categorizing soils according to their tendency to admit and transmit water. The hydrologic soil group (HSG) is determined with respect to the water-transmitting soil layer with the lowest saturated hydraulic conductivity and depth to any layer that is more or less water impermeable (such as a fragipan or duripan) or depth to a water table. Box 1 summarizes the characteristics of the four HSGs (NRCS 2007).

The position of the groundwater table is a crucial determinant of whether or not stormwater infiltration should be promoted by applying ground-based ARCD practices. A seasonal high water table too close to the surface results in rapid saturation of a thin soil column and retarded infiltration. Ponding water longer than 72 hours can permit mosquito growth, damage vegetation, and promote clogging of the facility by microorganism growths and polysaccharide organic materials that form in the reduced-oxygen environment accompanying excessive ponding time (Mitchell and Nevo 1964, Ronner and Wong 1996). Also, storm runoff flow through a short soil column or very rapidly through a coarse-textured soil can potentially convey contaminants to groundwater. To avoid entertaining stormwater management strategies threatening development of these problems, data on depth to groundwater was obtained from the U.S. Geological Survey's (USGS) Groundwater-Level Annual Statistics (USGS 2011).

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[6] Natural Resources Conservation Service, Distribution Maps of Dominant Soil Orders (http://soils.usda.gov/technical/classification/orders/, last accessed December 16, 2011).

[7] Natural Resources Conservation Service, 2011, Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm).

Topographic slope influences runoff production by setting incident precipitation in motion downslope, thus producing a horizontal component of velocity vector partially counteracting the tendency to penetrate the soil vertically. This study investigated that importance of that effect by considering two slopes typical of urban development sites. As discussed during the presentation of results, below, this factor did not have a large effect on the analysis.

Box 1. Summary of Hydrologic Soil Groups (NRCS 2007)

Group A—Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The saturated hydraulic conductivity of all soil layers exceeds 5.67 inches per hour. The depth to any water-impermeable layer is greater than 20 inches. The depth to the water table is greater than 24 inches. Soils deeper than 40 inches to a water-impermeable layer are in group A if the saturated hydraulic conductivity of all soil layers within 40 inches of the surface exceeds 1.42 inch per hour.[a]

Group B—Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The saturated hydraulic conductivity in the least transmissive layer between the surface and 20 inches ranges from 10.0 1.42 to 5.67 inches per hour. The depth to any water-impermeable layer is greater than 20 inches. The depth to the water table is greater than 24 inches. Soils deeper than 40 inches to a water- impermeable layer or water table are in group B if the saturated hydraulic conductivity of all soil layers within 40 inches of the surface exceeds 0.57 inch per hour but is less than 1.42 inch per hour.

Group C—Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. 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 textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments. The saturated hydraulic conductivity in the least transmissive layer between the surface and 20 inches is between 0.14 and 1.42 inch per hour. The depth to any water-impermeable layer is greater than 20 inches. The depth to the water table is greater than 24 inches. Soils deeper than 40 inches to a restriction or water table are in group C if the saturated hydraulic conductivity of all soil layers within 40 inches of the surface exceeds 0.06 inch per hour but is less than 0.57 inch per hour.

Group D—Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water-impermeable layer less than 20 inches and all soils with a water table within 24 inches of the surface are in this group, although some may have a dual classification if they can be adequately drained. For soils with a water-impermeable layer at a depth between 20 and 40 inches, the saturated hydraulic conductivity in the least transmissive soil layer is less than or equal to 0.14 inch per hour. For soils deeper than 40 inches to a restriction or water table, the saturated hydraulic conductivity of all soil layers within 40 inches of the surface is less than or equal to 0.06 inch per hour.

[a] While Group A soils are present across large areas of the country, our analysis considers only Group B, C, and D soils to provide a conservative assessment of infiltration potential in urban areas, and to account for potential issues such as soil compaction that may occur for lawn and other landscaping in urban and suburban development.

Southeast Climate Region

The major soil order found throughout the southeastern United States is Utisols, sub-order Udults. The humid climate with frequent rainfall gives the soils an udic moisture regime; soils are rarely dry for more than 45 consecutive days. Utisols are highly weathered and are deficient in calcium and other bases. Georgia is known for its red soils, which are the unhydrated iron oxides left in the weathered material. Pre-European contact, these soils supported mixed conifer and deciduous woodlands. Due to its relatively flat topography and warmer temperatures, Florida has primarily Spodosols, Alphisols and Histosols (Soil Survey Staff, NRCS 2011).

This region has a variety of soil textures, ranging from sand and sandy loam throughout Mississippi, Alabama, and Georgia; silty loam soils near the Appalachian Mountains; and some areas with significant organic materials in Florida. The major soil hydrologic groups of the region are varied as well, with C and D soils dominating the Georgia coastline and most of Florida. Group A and B soils are more prevalent in the interior parts of the region, in central Georgia and Alabama (Miller and White 1998).

A NRCS web soil survey was conducted for an area of interest (AOI) centered in Alpharetta, GA. The selected AOI did not have complete soil survey coverage, and findings were compared with another AOI of 8990.5 acres north of the city in Fulton County. In both AOIs, the leading HSG is B (86 percent of AOI), followed by group C (11 percent of AOI). Approximately 97 percent of the AOI has a sandy loam soil texture. The leading drainage classification was well drained (86 percent of AOI), followed by somewhat poorly drained (10 percent of AOI). The selected AOI was moderately steep, with approximately 70 percent of the AOI having slopes between 8 and 12 percent.

Fulton County, Georgia has four wells in the USGS record, three with depth-to-groundwater data. Two wells have only one recorded depth: site 08CC08 had a depth of 2.447 ft in 1986, and site 10DD01 had a depth of 16.131 ft in 1968. Site 10DD02 has been monitored annually from 1977-2010 and has an annual well-depth average in this time period of 6.292 ft.

South Central Climate Region

The major soil order in Texas is Mollisols, sub-order ustolls. These soils span the sub-humid and semiarid climate zones, and are common on the western Great Plains and throughout the Rocky Mountain States. These soils originally supported grasslands and (in mountainous regions) forests, and now are ranched or farmed. Houston black soils are also characteristic of the region and are important in agriculture and urban areas, occurring throughout central Texas. Dry soils in the Order Aridisols, sub-orders Argids and Calcids, are found in west Texas and large portions of New Mexico as well. These soils were formerly sparsely vegetated areas, now used for rangeland or wildlife habitat (Soil Survey Staff, NRCS 2011).

Soil characteristic maps generated by Miller & White (1998) indicate that the majority of soil types in the South Central climate region are diverse: sandy loam and clay dominate eastern Texas, clay soils are prevalent in central parts of the state and loam soils are in western Texas and New Mexico. Most soils tend to be in the C and D hydrologic groups, however B soils are found in bands in New Mexico (Miller & White, 1998).

A web soil survey was conducted for an area of interest of 8267.5 acres centered in Round Rock, TX. The leading HSG is D (68 percent of AOI), followed by group C (22 percent of AOI) and group B (10 percent). Primary soil textures are clay (33 percent), silty clay (27 percent), extremely stony clay (17 percent), and silty clay loam (10 percent). The leading drainage classification is well drained (79 percent of AOI) followed by moderately well drained (21 percent). The selected AOI is relatively flat; approximately 70 percent of the AOI has slopes under 2 percent, and 20 percent has slopes of 3-4 percent.

Travis County, Texas had three wells that were measured in 2003 and recorded by USGS (site YD-58-50-216) and 2004 (sites YD-58-50-216 and YD-58-25-907). Groundwater is very deep in each location, averaging 220 ft below the ground surface.

Northeast – Upper Midwest Climate Region

This climate region has significant variation in dominant soil orders. The Spodsols order, sub-order Orthods, dominates the northern portions (northern Minnesota, Wisconsin, Michigan, Vermont, and Maine) and is generally considered infertile without soil amendments. Inceptisols, sub-order Udepts, are also prevalent in the region, especially in New England states, through the Appalachian Mountains and northeastern Minnesota. Alfisols, sub-order Udalfs, too are prevalent in the region, extending from Minnesota east to New York. These two soils both have an udic moisture regime, and are rarely dry for more than 45 consecutive days due to the year-round precipitation in the area (Soil Survey Staff, NRCS 2011). The state soil of Massachusetts is the Paxton fine sandy loam and also extends into New Hampshire, New York and Vermont. These deep soils were formed in acid subglacial till and are derived from schist, gneiss and granite (NRCS undated).

Based on maps generated by Miller and White (1998), sandy loam and silt loam soils tend to dominate the region, with small areas of clay and silty clay soils. Hydrologic soil group B is most prevalent in the Midwestern states (Minnesota, Wisconsin, Illinois), and Group C is most common in the rest of the region, spanning from Indiana to Maine. The region primarily supported forest ecosystems before development.

A web soil survey was conducted for an area of interest centered in Framingham, MA with an AOI of 8645.6 acres. The region has relatively equal amounts of each HSG: 20 percent of the AOI in Group A, 19 percent in group B, 20 percent in Group C, and 24 percent in Group D. Soil textures represented are fine sandy loam (49 percent), muck (10 percent), loamy sand (9 percent), and moderately decomposed plant material (8 percent). The leading drainage classification is well drained (32 percent of AOI) followed by very poorly drained (16 percent), somewhat excessively drained (12 percent), and moderately well drained (11 percent). Fourteen percent of the AOI has slopes of 1 percent or less, with 18 percent at 2-5 percent, 23 percent at 6-8 percent, and another 23 percent at 8-12 percent slopes.

There are three wells in the USGS record for Middlesex County, MA including 5 years of record for an Acton well averaging 17.75 ft, 6 years for the Wakefield well with an average depth of 6.59 ft, and 11 years at the Wilmington well with an average of 8.09 ft.

Southwest Climate Region

There are multiple soil orders in California due to its variation in climate, topography and geologic history. Entisols occur in the southern parts of the state; sub-order Psamments is a frequently found sandy soil that makes productive rangeland. Order Mollisols, sub-order Xerolls, are freely drained and dry soils found in the Mediterranean climate along the coast of California. Pre-settlement ecosystems supported by these soils include oak savanna, grasslands, and chaparral. Current soils may be used as cropland or rangeland (Soil Survey Staff, NRCS 2011).

A web soil survey was conducted for an 8267.5-acre area of interest centered in San Marcos, CA. The leading HSG is D (58 percent of AOI), followed by group C (26 percent) and group B (14 percent). Soil texture include sandy loam (19 percent), coarse sandy loam (17 percent), silt loam (15 percent), very fine sandy loam (14 percent), loamy fine sand (12 percent), loam (7 percent), and clay (5 percent). The leading drainage classification is well drained (51 percent of AOI), followed by moderately well drained (34 percent). Approximately 10 percent of the AOI has slopes ≤ 5 percent, and 66 percent has slopes of 5-10 percent.

There are no groundwater records for San Diego County available on the USGS website. Data were collected from the California Department of Water Resource Water Data Library[8]. Ten wells west of San Marcos near Escondido were sampled in 1987. The depth to groundwater ranged from 2.0 to 28.1 ft for an average of 11.6 ft.

Summary of Physiographic Characteristics

Due to the large area of land encompassed in each climate region, it is difficult to select one location that is truly "representative" of the entire region. By selecting four cities that are spaced throughout the country with different climate and soil characteristics, however, this study can demonstrate the different potential for ARCD strategies in regions around the nation. Table 4 summarizes the major soils, groundwater, and topographic characteristics for these regions. Figure 3 shows the distributions of hydrologic soil groups in areas of interest investigated in the four metropolitan areas.

Table 4. Summary of Physiographic Data

Characteristic	Southeast	South Central	Northeast – Upper Midwest	Southwest
Main soil types	Sandy loam	Clay, clay loam	Sandy loam, silt loam	Sandy loam, loam
Hydrologic soil group near study site	B (GA, AL, SC)	D (TX)	C (Northeastern states)	D
Other hydrologic soil group in climate region	D (FL)	C (NM)	B (MN, WI, IL, MI)	C
Predominant pre-development land cover	Woods	Semi-arid herbaceous	Woods	Narrow-leaved chaparral
Predominant slopes	70% @ 8-12%	90% < 4%	65% < 12%	76% < 10%

LAND USE CASES

Five cases were selected to represent a range of urban development types considered to be representative of the nation. These cases involved: a multi-family residential complex (MFR), a relatively small-scale (23 homes) single-family residential development (Sm-SFR), a relatively large (1000 homes) single-family residential development (Lg-SFR), a sizeable commercial retail installation (COMM), and an urban redevelopment (REDEV).

Building permit records from the City of San Marcos in San Diego County, California provided data on total site areas for the first three cases, including numbers of buildings, building footprint areas (including porch and garage for Sm-SFR), and numbers of parking spaces associated with the development projects. Information was not as complete for cities in other regions, but what data was available indicated no substantial difference in these site features. Therefore, the San Marcos data were used for all regional case studies. This uniformity had the advantage of placing comparisons completely on the basis of the major variables of interest, climatological and soils characteristics.

[8] http://www.water.ca.gov/waterdatalibrary (last accessed December 16, 2011).

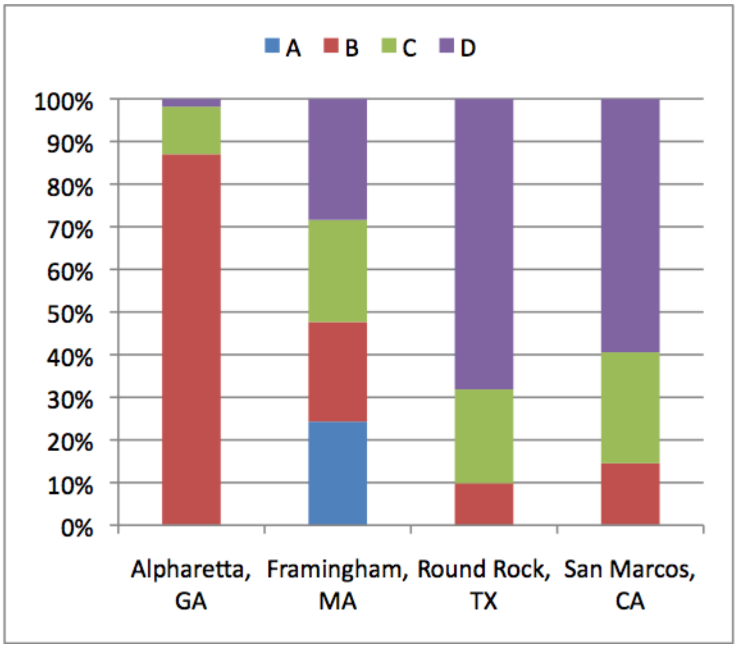


Figure 3. Distribution of Hydrologic Soil Groups in Four Study Cities

The REDEV case was taken from an actual project in Berkeley, California involving conversion of an existing structure, built originally as a corner grocery store, to apartments and addition of a new building to create a nine-unit, mixed-use, urban infill project. Space remained for a large side yard.

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 cases 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 below.

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. Parking spaces were estimated to be 176 square 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 square ft average. About 180 square 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 (Gibbons, 2009). The 176 square 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.

Each single-family residences (SFR) was assumed to have a lot area of 5749 square ft,, and a driveway 20 ft wide and 30 ft long. Assuming a square lot, each would have a sidewalk 76 feet by 4 feet wide, and a walkway that is 40 feet by 4 feet. .

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, an additional 10 percent was added to the building, parking lot, access road, and walkway area to represent the landscaping, on the belief that a typical retail commercial establishment would be mostly impervious.

Table 5 summarizes the characteristics of the five land use cases. The table also provides the recorded or estimated areas in each land use and cover type.

Table 5. Summary of Cases with Land Use and Land Cover Areas

	MFR[a]	Sm-SFR[a]	Lg-SFR[a]	COMM[a]	REDEV[a]
No. buildings	11	23	1000	1	2
Total area (ft^2)	476,982	132,227	5,749,000	226,529	5,451
Roof area (ft^2)	184,338	34,949	1,519,522	87,120	3,435
No. parking spaces[b]	438	-	-	500	2
Parking area (ft^2) [b]	77,088	-	-	88,000	316
Access road area (ft^2)	22,212	-	-	23,732	-
Walkway area (ft^2)	33,960	10,656	463,289	7,084	350
Driveway area (ft^2)	-	13,800	600,000	-	650
Landscape area (ft^2)	159,384	72,822	3,166,190	20,594	700

[a] MFR—multi-family residential; Sm-SFR—small-scale single-family residential; Lg-SFR—large-scale single-family residential; COMM—retail commercial; REDEV—redevelopment
[b] Uncovered

METHODS OF ANALYSIS

AVERAGE EVENT AND ANNUAL STORMWATER RUNOFF VOLUMES

Calculation Methods

Surface runoff volumes produced were estimated for both pre- and post-development conditions for each case study. The pre-development state was considered to be the predominant land cover for each region prior to European settlement.

For impervious areas, average event and annual runoff volumes were computed as the product of event or average annual precipitation, contributing drainage area, and a runoff coefficient (ratio of runoff produced to precipitation received) according to the familiar Rational Method equation. The runoff coefficient was determined from the equation 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 (USEPA 1983). With I = 100 percent for fully impervious surfaces, C is 0.95.

The basis for pervious area runoff coefficients, for both the pre-development state and landscaped areas in developments, was the NRCS's Urban Hydrology for Small Watersheds (NRCS 1986, as revised from the original 1975 edition). This model estimates storm event runoff (R, inch) as a function of precipitation (P, inch) and a variable representing land cover and soil, termed the curve number (CN, dimensionless). CN enters the calculation via a variable S, which is the potential maximum soil moisture retention after runoff begins. The equations for English units of measurement are:

$$R = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad S = \frac{1000}{CN} - 10$$

The runoff equation is valid for P > 0.2S, which represents the initial abstraction, the amount of water retained before runoff begins by vegetative interception and infiltration (NRCS 1986). According to this model, larger events are forecast to produce a greater amount of runoff in relation to amount of precipitation, 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 compute an average runoff coefficient representing the year.

Average pre- and post-development pervious area average runoff coefficients were derived by computing runoff from a series of precipitation events ranging from 0.1 inch up to the 95^{th} percentile, 24-hour event for the respective metropolitan areas, dividing by the associated precipitation, and averaging for all event amounts > 0.2S. Average annual runoff volumes for pervious areas were estimated based on these runoff coefficients and average annual precipitation quantities recorded at the respective gauging locations.

Curve Number Selection

Pre-development curve numbers were determined from existing studies and NRCS (1986) CN tables based on pre-European settlement land cover. Before development, woods predominated in Georgia and Massachusetts. Pre-development Texas had principally arid and semi-arid range with herbaceous cover. Chaparral was the predominant land cover in the San Diego area, however, this land cover type is not listed in the NRCS tables. For that region the selection came from a study by Easterbrook (undated) on curve numbers and associated soil hydrologic groups in an investigation of mainly chaparral lands before and after wildfires in the San Diego area.

Conversion to landscaping typical of development modifies soil and water infiltration characteristics by removing topsoil and even subsoil, compacting the remaining soil, and changing the vegetative cover. For pervious landscaping after development, CN was based on 1/8-acre urban development for all building types.

To demonstrate a range of results, runoff estimates were made for two soils in each region falling in B and C, B and D, or C and D HSGs. The more infiltrative soil was assumed to be in "good" condition and the less permeable one in "poor" condition, differentiations made in the NRCS tables. Table 6 summarizes the curve numbers used in the analyses. The paragraphs following the table detail how the selections were made for each region.

Table 6. Summary of Curve Numbers for Study Regions

	Southeast		South Central		Northeast – Upper Midwest		Southwest	
Hydrologic soil group-condition	B-good	D-poor	C-good	D-poor	B-good	C-poor	C-good	D-poor
Pre-development	55	83	74	93	55	77	77	90
Post-development	85	92	90	93	85	90	91	93

The Georgia Stormwater Manual Supplement recommends that watershed managers select curve numbers proposed by the NRCS based on hydrologic soil groups A through D and hydrologic condition of the site (Center for Watershed Protection 2009). As aforementioned, the pre-European land cover of the southeastern United States was forested. A study by Dyke (2001) in Forsyth and Hall Counties northeast of Atlanta confirmed that, immediately prior to development, approximately 50 percent of urban lands were forested, with 22 percent in agricultural use.

Because the region includes B soils in the interior of Alabama and Georgia, and poorly draining D soils in Florida and along the coasts, it was decided, for the purpose of demonstrating a range of results, to base NRCS Curve number values on B soils in good condition and D soils in poor condition. The corresponding pre- and post-development curve numbers are 55 and 83 and 85 and 92, respectively.

Prior to human development, approximately 80 percent of Texas, mostly in the central part, was covered in short and tall grassland communities; the western 10 percent of the state was desert grassland; and the eastern 10 percent was forested (University of Texas 2000). McLendon (2002) conducted a study on the observed and predicted curve numbers in 107 watersheds in Texas. For rural watersheds the CNs ranged from 48 to 88. The range in Austin was 49-89 and in Dallas 60-90. The Texas Department of Transportation's (2001) Hydraulic Design Manual Section 7 lists values for pre-development curve numbers for arid and semi- arid rangelands. Based on these sources, the respective pre- and post-development CN choices were 74 (C—good soil) and 93 (D—poor soil) and 90 (C—good soil) and 93 (D—poor soil).

Before European development, most of the Northeast – Upper Midwest region was covered in mixed hardwood and coniferous forests. A recent USGS report confirms that most urban development in the region from 1973 to 2000 has converted forestland (47 percent of all changes), followed by farmland (11 percent) (Auch undated). For this study's pre-development curve number, the woods cover type, soil group B in good condition and C soil in poor condition gave corresponding curve numbers of 55 and 77, respectively. Post-development curve numbers for these soil types at 1/8-acre development size were 85 and 90 for the good B and poor C soils, respectively. These post-development curve numbers are similar to a recent study in the Aberjona River watershed, an urban catchment northwest of Boston, where the authors used an overall CN of 89 to represent the more impervious parts of the watershed (Perez-Pedini et al. 2005).

With the lack of NRCS data for chaparral, CN selection for the San Diego area was based on an analysis performed in the area of the 2003 Cedar Fire in San Diego County by Easterbrook (undated). For pre-development C soils in good condition and D soils in poor condition, the choices were 77 and 90, respectively. Post-development curve numbers were selected from Easterbrook's estimation of CN after a high-burn fire; for good C soils CN = 91, and for poor D soils CN = 93.

Effect of Slope on Curve Number

NRCS documents developing the curve number concept and associated methods did not cover the effect of land slope. Independent researchers have given some attention to the question though. Sharpley and Williams (1990) introduced the empirical equation that has been most often used to adjust CN relative to slope:

$$CN_s = 0.333(CN_w - CN)(1 - 2e^{-13.86s}) + CN$$

where CN is the curve number reported in NRCS tables for an average soil moisture condition and assumed slope ≤ 5 percent, CN_s = slope-adjusted CN, CN_w = CN in an initially wet soil condition, and s = slope (ft/ft). Ward and Trimble provided factors to adjust tabulated CN values to obtain CN_w. Carrying through the analysis in this manner demonstrated that results deviated between two assessed slopes (5 and 10 percent) by only around 2-6 percent. This small difference was considered minimal in the context of the approximations and assumptions inherent in the modeling process. While the results presentation gives some additional data on slope effects, full coverage is given only for 5 percent, the topographic basis of the NRCS model and by far the subject of its greatest application.

ESTIMATING INFILTRATION CAPACITY OF THE CASE STUDY SITES

Infiltration Rates

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 groundwater 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. However, the intent of this investigation was to determine the ability of pervious areas to manage the site runoff, and their exclusion is consistent with the conservative approach to modeling taken in this analysis. This inquiry was accomplished by evaluating the ability of the predominant soil types identified for each region to provide an infiltration rate of at least 0.5 inch/hour, the rate often regarded in the stormwater management field as the minimum for the use of infiltration practices (e.g., Geosyntec Consultants 2008). The assessment considered soils that either would provide this rate, at a minimum, in their original condition or could be organically amended to augment soil water storage and increase infiltration, while also safeguarding groundwater. Therefore, prevailing groundwater depths were assessed in relation to runoff percolation times generally regarded as safe.

Infiltration rates were based on saturated hydraulic conductivities (obtained from Leij et al. 1996) typical of the basic soil types incorporated in the U.S. Department of Agriculture (USDA, 1987) soil textural triangle. Sand, loamy sand, sandy loam have conductivities well above 0.5 inch/hour. As Table 4 indicates, three of the four regions have a sandy loam as the dominant soil type. For such a soil in the B HSG in these regions, the infiltration rate was taken as 1.74

inch/hour (Leij et al. 1996). Other textures represented that would generally fall in the C group are mostly loam and silt loam. These soil types either have conductivities in excess of 0.5 inch/hour or, in the first author's experience, can be and have been successfully organically amended to produce such a rate and infiltrate accumulated water within 72 hours, and usually less time. The D soils in some study regions, silty clay and clay, were regarded as not amendable to reach 0.5 inch/hour conductivity to host conventional or ARCD-type facilities designed specifically for infiltration. Still, locations with these soils could distribute sheet flow over pervious areas for evapotranspiration and some infiltration at slow rates and could utilize roof downspout surface or subsurface dispersal.

Groundwater Protection Assessment

Avoidance of groundwater contamination was assessed by assuming a hydraulic conductivity generally regarded as the maximum rate for the use of infiltration practices, 2.4 inches/hour (e.g., Geosyntec Consultants 2008), and a minimum spacing to seasonal high groundwater from the bed of an infiltration facility of 4 ft. These conditions would provide a travel time of 20 hours, during which contaminant capture would occur through soil contact. This 20-hour travel time was regarded as a minimum for any soil type. For example, infiltrating on loamy sand with a hydraulic conductivity of 5.7 inches/hour would require minimum spacing from the infiltration surface to groundwater of 10 ft. This consideration did not actually become an issue for analyses in any region in this study, because all predominant soil types have infiltration rates under 2.4 inches/hour and groundwater spacings that exceed 4 ft.

Site Infiltration Capacities

Runoff volumes were estimated for the 85th and 95th percentile, 24-hour events as described previously. Bioretention cell surface area to accommodate these volumes was calculated based on a method in the City of Santa Barbara's Storm Water BMP Guidance Manual (Geosyntec Consultants 2008) (adapted from the Georgia Stormwater Manual (Atlanta Regional Commission, 2001)):

$$A = \frac{(V_{design})(l)}{(t)(k_{design})(d + l)}$$

where:

V_{design} = design volume of runoff to be infiltrated (ft3);

k_{design} = design infiltration rate (in/hr), taken as 0.5 times the typical rate for the soil type naturally or amended as a safety factor;

d = ponding depth (ft), assumed as 0.25 ft for a shallow landscape feature on the recommendation of the Georgia manual;

l = depth of planting media (ft), assumed as 4 ft on the recommendation of the Georgia manual;

t = required drawdown time (hr), taken as 48 hours.

The design variable selections are conservative in applying a safety factor to hydraulic conductivity, using minimum depths for economy and limiting site disruption, and applying a drain time lower than the maximum of 72 hours.

In considering the long-term capacity of a facility designed to infiltrate, the potential for groundwater mounding below or aside the unit is a concern. To avoid this problem a basic analysis was made using a groundwater rise equation from Zomorodi (2005):

$$\text{Rise} = 0.86\,\frac{(K_v)(W)}{(K_h - K_v)}$$

where:

Rise = mounding occurring in a year of use (ft);

K_v = vertical saturated hydraulic conductivity (ft/year);

W = bioretention cell width (ft); and

K_h = horizontal saturated hydraulic conductivity (ft/year).

This equation was solved for K_v for computation of the allowable annual infiltration rate, assuming a rise limited to 1 ft. It was assumed that the bioretention surface area would be broken up to have no more than one basin for each 5 acres of total site area, another measure safeguarding against groundwater mounding. Also assumed was a square cell (i.e., W was computed as the square root of the surface area calculated according to the equation for A above). Horizontal hydraulic conductivites for loams such as represented among the B and C soils in the study regions tend to run in the range of 10 to 1000 meters/year (0.1 to 9 ft/day. A conservative value of 3 ft/day was used in the analysis.

The yearly rate of infiltration from a bioretention cell can be expressed in terms of volume of runoff per unit infiltrating surface area, acre-ft/acre-year, which is equivalent to K_v expressed as ft/year. The K_v value avoiding groundwater monitoring was therefore used to assess maximum annual infiltration capacity by multiplying by the total available pervious surface area. However, the K_v value was capped at a rate found in a study of infiltration capacity and benefits for Los Angeles' San Fernando Valley by Chralowicz et al. (2001). The Los Angeles 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. Three types of soils predominate in the study area: sandy loams (35 percent of the area), a clay loam (23 percent), and a silty clay loam (29 percent). The balance of 13 percent includes small amounts at both ends of the textural spectrum, a clay and loamy sands. Infiltration rates are in the approximate range of 0.5-2.0 inches/hour, within the span generally regarded as ideal for successful infiltration without threatening groundwater. Computing the ratios of the rate and basin size data of Chralowicz et al. (2001), K_v maximized at approximately 20 acre-ft of runoff/acre infiltration surface-year under the most limiting conditions of soils and basin dimensions. This value was applied in this study if calculated rates were higher, another conservative feature to obtain the most realistic projections of infiltration potential.

In some cases analyzed, the maximum annual infiltration capacity was estimated at greater than post-development runoff volume production. In these instances complete retention would be possible with excess capacity left, and only a fraction of the available pervious area would have to be devoted to bioretention. That fraction was expressed as the ratio of annual runoff production to infiltration capacity.

STORMWATER RUNOFF VOLUME AND POLLUTANT DISCHARGES

Urban Land Use Pollutant Yields

Annual pollutant mass loadings prior to application of any stormwater management practices 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. General land use types (e.g., single-family residential, commercial) have typically been the basis for measuring and reporting stormwater pollutant data. However, an investigation of ARCD practices of the type of interest in this study 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). Table 7 summarizes the representative values used in the analysis.

Table 7. Pollutant Concentrations in Runoff from Developed Land Uses (after Herrera Environmental Consultants, Inc. undated)

Land Use	Total Suspended Solids (mg/L)	Total Copper (µg/L)	Total Zinc (µg/L)	Total Phosphorus (µg/L)
Residential roof	25	13	159	110
Commercial roof	18	14	281	140
Access road/driveway	120	22	118	660
Parking	75	36	97	140
Walkway	25	13	59	110
Landscaping	213	13	59	2040

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.

Estimating Retention

The principal interest of this study was to estimate how much of the post-development runoff volume for the various land use cases could be retained by ARCD measures and prevented from discharging from the site on the surface. The analyses initially evaluated the runoff volume that could potentially be infiltrated by using a portion or all of the available pervious area for bioretention facilities. In some instances judicious use of the pervious area could infiltrate the full volume. In other cases use of the pervious area for as much infiltration as possible plus special management of roof runoff would fully attenuate post-development runoff.

Complete retention would, of course, exceed any ordinary regulatory standard intended to govern discharge quantity and quality. To the extent that full retention could not be expected, the study was interested in assessing the degree to which bioretention and roof runoff management could meet the specific potential standards outlined earlier. Performance was estimated in terms of volume retained versus released, the extent to which pre-development groundwater recharge would be preserved, and the pollutant loading reduction accompanying volume retention in comparison to the quantities that would enter receiving waters with no stormwater management actions. These measures expressed in equation form are:

$$\text{Runoff retention (\%)} = \frac{(\text{Volume with no practices} - \text{Volume with ARCD practices})}{\text{Volume with no practices}} x100$$

(expresses amount of the theoretical maximum post-development runoff prevented from discharging by ARCD)

$$\text{Recharge retention (\%)} = [1 - \frac{(\text{Predevelopment recharge} - \text{Postdevelopment recharge with ARCD})}{\text{Predevelopment recharge}}]x100$$

Pre-development recharge = Rainfall volume – Predevelopment runoff volume

Post-development recharge = The smaller of rainfall volume or post-development infiltration volume

$$\text{Loading reduction (\%)} = \frac{(\text{Loading with no practices} - \text{Loading with ARCD practices})}{\text{Loading with no practices}} x100$$

It should be noted that runoff retention and recharge retention express different quantities and are not equal numerically.

When infiltration alone (Basic ARCD) could not accomplish full retention, roof runoff management strategies were selected as appropriate for the land use case (Full ARCD). For the retail commercial development (COMM), roof runoff management was assumed to be accomplished by harvesting, temporarily storing, and applying water to use in the building. To this end, the assumption was made that the commercial development would be able to manage and would have capacity to store and make use of the entire roof runoff volume. While this particular assumption is, on its own, speculative, the commercial development would, as discussed in the section on Application of ARCD Practices, earlier, see a reduction in runoff as a result of evapotranspiration, and would have the option to employ ARCD site design principles to reduce impervious surface area, to install a green roof to retain runoff, or to implement any of a number of other ARCD practices designed to reduce runoff volume and pollutant loading. As a result, the overall analysis of the commercial site remains conservative in its assessment of the potential to retain runoff onsite.

In the three multi-family and single-family residential cases it was assumed that the roof water would be dispersed on or within the pervious area according to accepted and standardized practices. For example, the Washington Department of Ecology's (2005) Stormwater Management Manual for Western Washington provides design criteria for two methods: splash blocks followed by vegetated dispersion areas and gravel-filled trenches. These devices can be used wherever space is sufficient regardless of infiltration rates, as they operate by evapotranspiration and slow infiltration. Even clay can infiltrate at an approximate rate of 0.2 inch/hour or higher (Leij et al. 1996; Pitt, Chen, and Clark 2002). Care was taken to assure that pervious area already allocated to infiltration would not also be counted upon for dispersion. While dispersion was assumed for simplification of the study analyses, in reality a site designer would have the option of using rain barrels, cisterns, and/or green roofs instead of or along with ground dispersion to manage roof water. Analyses for the final case, the redevelopment scenario (REDEV), assumed dispersion and/or small-scale harvesting of roof runoff above whatever level of infiltration could be accomplished given the soil condition.

<u>Additional Analyses When Full Retention Cannot Be Expected</u>

Retaining runoff from impervious and pollutant generating pervious surfaces is the best stormwater management policy, because it prevents the introduction of urban runoff pollutants to receiving waters as well as serves quantity discharge control requirements. Maintaining pre-development peak flow rates, volumes, and elevated flow durations prevents stream channel and habitat damage, flooding, and loss of groundwater recharge. When conditions were expected to render full retention technically infeasible for the study cases, estimates were made of the volume and pollutant loadings that would be discharged assuming the remaining surface runoff is released to a receiving water with and without treatment. Treatment was assumed to be provided by bioretention discharging either directly on the surface or via an underdrain. While not as environmentally beneficial as retention, such treatment is superior to conventional stormwater management practices like ponds and sand filters. It captures pollutants through a number of mechanisms as contaminants are held for a time in the facility and contact vegetation and soil, such as sedimentation, filtration by plants, and adsorption and ion exchange in soil.

The effectiveness of bioretention in removing pollutants from surface runoff was estimated according to measurements by Chapman and Horner (2010). This study was performed on a linear bioretention device located on a slope and made up of a number of cells separated by weirs (termed a "cascade"). While an estimated 74 percent of all entering runoff infiltrated or evapotranspired before discharging, the flows reaching the end in the larger storms would have less residence time in the facility than in a unit on flat ground percolating water through soil before surface discharge via an underdrain. Therefore, pollutant concentrations exiting such a unit could be less yet. On the other hand, some bioretention facilities bypass the relatively rare higher flows, affording no treatment, while the cascade was designed to convey all runoff, even beyond its water quality design storm flow, and provide some treatment. On balance between the advantage and disadvantage of the facility providing the data, the discharge concentrations are considered to be representative of bioretention.

Chapman and Horner (2010) computed volume-weighted average discharge pollutant concentrations by multiplying concentrations times flow volumes for each monitored storm, summing, and dividing by total volume. The resulting values for the contaminants considered in this study are: total suspended solids (TSS)—30 mg/L, total copper—6.3 µg/L, total zinc—47 µg/L, and total phosphorus—133 µg/L. In a few instances these concentrations are higher than those in Table 7, an expression of the observation sometimes made in stormwater management that treatment cannot reduce concentrations in relatively "clean" flows below certain minimum values. In these situations the concentrations in Table 8 were also used in computing discharge loadings; i.e., no concentration reduction was applied in estimating discharge loadings, although flow volume would still be decreased to the extent infiltration could occur.

RESULTS OF THE ANALYSIS

ASSESSMENT OF MAXIMUM ARCD CAPABILITIES

Runoff Retention and Groundwater Recharge

Basic ARCD

One goal of this exercise was to determine if ARCD practices could eliminate post-development runoff production, and the pollutants it transports, and maintain pre-development groundwater recharge. The first assessment, termed the Basic ARCD analysis in this report, was to estimate if each site's pervious area is sufficient for full infiltration if given to this purpose to the extent necessary without compromising other uses. Accordingly, shallow, unobtrusive bioretention cells (i.e., rain gardens) are envisioned, dispersed through sites at no more than one for each 5 acres. It bears reemphasis that no credit was taken for water loss through evapotranspiration in this assessment, although a substantial, but not necessarily easily quantifiable, amount would undoubtedly occur. Estimates of runoff retention are therefore conservative.

Table 8 presents comparisons, for the Southeast climate region, between estimated annual runoff volumes generated before development and then post-development with and without Basic ARCD stormwater management. The table also gives annual groundwater recharge estimates for these same conditions.

Table 8. Runoff and Groundwater Recharge Volumes with Basic ARCD: Southeast Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
B soil						
Pre-dev.	Runoff	0.046	0.013	0.56	0.022	0.001
	Recharge	44.7	12.4	539	21.2	0.51
Post-dev.	Runoff without stormwater practices	29.5	6.85	298	18.7	0.45
	Runoff retained with Basic ARCD	29.5	6.85	298	8.30	0.21
	Runoff released with Basic ARCD	0	0	0	10.4	0.25
	Runoff retention (%)	100%	100%	100%	44%	45%
	Recharge without stormwater practices	15.3	5.55	241	2.53	0.06
	Recharge with Basic ARCD	44.7	12.4	539	8.30	0.21
	Recharge retention (%)	100%	100	100%	39%	40%
	Pervious area needed (%)[b]	36%	22%	22%	100%	100%
D soil						
Pre-dev.	Runoff	13.5	3.76	163	6.43	0.16
	Recharge	31.2	8.64	376	14.8	0.36
Post-dev.	Runoff without stormwater practices	Full ARCD needed to maximize retention on D soil				
	Runoff retained with Basic ARCD					
	Runoff released with Basic ARCD					
	Runoff retention (%)					
	Recharge without stormwater practices	11.6	4.17	181	2.12	0.05
	Recharge with Basic ARCD	Full ARCD needed to maximize retention on D soil				
	Recharge retention (%)	37%	48%	48%	14%	14%
	Pervious area needed (%)[b]	Full ARCD needed to maximize retention on D soil				

[a] Pre-dev.—pre-development; post-dev.—post-development; ARCD—aquatic resources conservation design; MFR—multi-family residential; Sm-SFR—small-scale single-family residential; Lg-SFR—large-scale single-family residential; COMM—retail commercial; REDEV—infill redevelopment; Basic ARCD—infiltrating bioretention; runoff—quantity of water discharged from the site on the surface; recharge--quantity of water infiltrating the soil
[b] Proportion of the total pervious area on the site required for bioretention to achieve given results

In all cases the majority of the infiltration that would recharge groundwater in the undeveloped state would be lost to surface runoff after development. These losses would approach 90 percent in the most impervious developments. The greatly increased surface flow would raise peak flow rates and volumes in receiving water courses, increase flooding risk, and transport pollutants.

Basic ARCD could retain all post-development runoff and pre-existing groundwater recharge in the three residential cases on the B soils, using from less than one-fourth to just over one-third of the available pervious area for bioretention cells. Taking all available pervious area for the more highly impervious COMM and REDEV cases on B soil, bioretention would retain about 45 percent of the runoff generated and save about 40 percent of the pre-development recharge. To illustrate the relatively small role that slope increase from 5 to 10 percent plays in runoff retention, full retention would still be expected in the three residential cases and for the remaining two cases (COMM and REDEV) would decrease from 44-45 percent only slightly to 40-41 percent (not shown in table).

On the D soil, infiltrating bioretention may not be technically feasible and was not relied upon for retention estimates. Without the use of additional measures in the Full ARCD category, only incidental post-development runoff would be retained; and most pre-development recharge would be lost.

Tables 9-11 are companions to Table 8 for the South Central, Northeast – Upper Midwest, and Southwest climate regions, respectively. Results for the Northeast - Upper Midwest B soil are very close to those for the Southeast B soil, as would be expected given the similar precipitation quantities and soil characteristics. In the three regions having C soils, Basic ARCD can retain all runoff for the MFR, Sm-SFR, and Lg-SFR residential cases. With these soils, except in the Southwest, achieving full retention requires more of the available pervious area than with B soils, up to 69 percent, but is still fully attainable.

The effect of lower rainfall is evident in the South Central and, especially, the Southwest regions. In the latter location, not only the residential cases but also the COMM and REDEV scenarios can achieve full runoff retention with Basic ARCD on the C soil. The residential cases need much smaller percentages of the available pervious area for bioretention than for the same cases on C and even B soils elsewhere. Applying Basic ARCD to the South Central, C soil, REDEV case results in higher runoff retention than for the B soil cases in higher rainfall regions.

The study cases demonstrated two interesting points about groundwater recharge. First, with effective infiltrating bioretention it is possible for post-development annual recharge to exceed the pre-development quantity. This phenomenon is most evident in comparing the two amounts for cases with 100 percent runoff retention on C soils, which in the natural state produce much less recharge in relation to runoff than B soils. The B soils have a recharge-to-runoff ratio of about 500, whereas that ratio is only 4-6 for the C soils studied. One reason for higher post- compared to pre-development recharge is that bioretention is set up to hold water, increasing the time for infiltration to occur, instead of letting it run off. Another is that soils, especially in the C HSG, are often improved by organic amendments to yield both more water storage capacity and higher infiltration rates than the pre-existing soils.

A related point is that the percentage of pre-development recharge retained after development can be higher with C than B soils. This situation can best be seen in cases without full runoff retention, COMM and sometimes REDEV. In terms of recharge, installing bioretention conveys a greater advantage to the C than the B soils, which already have more pore space for water storage and higher infiltration and recharge rates.

Table 9. Runoff and Groundwater Recharge Volumes with Basic ARCD: South Central Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
C soil						
Pre-dev.	Runoff	4.10	1.14	49.4	1.95	0.05
	Recharge	25.7	7.13	310	12.2	0.29
Post-dev.	Runoff without stormwater practices	21.2	5.15	224	12.7	0.31
	Runoff retained with Basic ARCD	21.2	5.15	224	4.33	0.21
	Runoff released with Basic ARCD	0	0	0	8.32	0.10
	Runoff retention (%)	100	100	100	34	67
	Recharge without stormwater practices	8.62	3.11	135	1.51	0.03
	Recharge with Basic ARCD	29.8	8.3	359	4.33	0.21
	Recharge retention (%)	100	100	100	38	70
	Pervious area needed (%)[b]	51	23	30	100	100
D soil						
Pre-dev.	Runoff	18.5	5.14	223	8.80	0.21
	Recharge	11.3	3.13	136	5.36	0.13
Post-dev.	Runoff without stormwater practices	Full ARCD needed to maximize retention on D soil				
	Runoff retained with Basic ARCD					
	Runoff released with Basic ARCD					
	Runoff retention (%)					
	Recharge without stormwater practices	7.23	7.59	112	1.35	0.03
	Recharge with Basic ARCD	Full ARCD needed to maximize retention on D soil				
	Recharge retention (%)	64	83	83	25	24
	Pervious area needed (%)[b]	Full ARCD needed to maximize retention on D soil				

Table 10. Runoff and Groundwater Recharge Volumes with Basic ARCD: Northeast – Upper Midwest Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
B soil						
Pre-dev.	Runoff	0.04	0.01	0.54	0.02	0.001
	Recharge	42.9	11.9	517	20.4	0.49
Post-dev.	Runoff without stormwater practices	28.3	6.68	286	18.0	0.44
	Runoff retained with Basic ARCD	28.3	6.68	286	8.53	0.21
	Runoff released with Basic ARCD	0	0	0	9.43	0.23
	Runoff retention (%)	100	100	100	48	47
	Recharge without stormwater practices	14.6	5.32	231	2.42	0.06
	Recharge with Basic ARCD	42.9	11.9	517	8.53	0.21
	Recharge retention (%)	100	100	100	42	42
	Pervious area needed (%)[b]	34	21	21	100	100
C soil						
Pre-dev.	Runoff	7.87	2.18	94.8	3.74	0.09
	Recharge	35.1	9.72	422	16.6	0.40
Post-dev.	Runoff without stormwater practices	30.5	7.42	323	18.2	0.44
	Runoff retained with Basic ARCD	30.5	7.42	323	4.57	0.21
	Runoff released with Basic ARCD	0	0	0	13.6	0.24
	Runoff retention (%)	100	100	100	25	47
	Recharge without stormwater practices	12.4	4.48	195	2.17	0.05
	Recharge with Basic ARCD	42.9	11.9	517	4.57	0.21
	Recharge retention (%)	100	100	100	27	51
	Pervious area needed (%)[b]	69	31	40	100	100

Table 11. Runoff and Groundwater Recharge Volumes with Basic ARCD: Southwest Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
C soil						
Pre-dev.	Runoff	1.62	0.45	19.5	0.77	0.02
	Recharge	7.22	2.00	87.0	3.43	0.08
Post-dev.	Runoff without stormwater practices	6.41	1.57	68.5	3.77	0.09
	Runoff retained with Basic ARCD	6.41	1.57	68.5	3.77	0.09
	Runoff released with Basic ARCD	0	0	0	0	0
	Runoff retention (%)	100	100	100	100	100
	Recharge without stormwater practices	2.43	0.88	38.1	0.43	0.01
	Recharge with Basic ARCD	8.84	2.45	107	4.20	0.10
	Recharge retention (%)	100	100	100	100	100
	Pervious area needed (%)[b]	12	5	7	69	44
D soil						
Pre-dev.	Runoff	4.47	1.24	53.8	2.12	0.05
	Recharge	4.37	1.21	52.7	2.08	0.05
Post-dev.	Runoff without stormwater practices	Full ARCD needed to maximize retention on D soil				
	Runoff retained with Basic ARCD					
	Runoff released with Basic ARCD					
	Runoff retention (%)					
	Recharge without stormwater practices	2.14	0.77	33.3	0.40	0.01
	Recharge with Basic ARCD	Full ARCD needed to maximize retention on D soil				
	Recharge retention (%)	49	63	63	19	18
	Pervious area needed (%)[b]	Full ARCD needed to maximize retention on D soil				

Full ARCD

Infiltration is one of a wide variety of ARCD-based source reduction techniques. Where site conditions such as soil quality or available area limit a site's infiltration capacity, other ARCD measures can enhance a site's runoff retention capability. Such practices can also be used where infiltration capacity is adequate, but the developer desires greater flexibility for land use on-site. Among those techniques, this study considered special management of roof water in those cases where bioretention could not infiltrate all post-development runoff.

Specifically, water harvesting for supply of irrigation and/or non-potable indoor uses was investigated for the retail commercial development. In residential cases with insufficient capacity for infiltrative bioretention but remaining space not already devoted to infiltration, efficiently directing roof runoff into the soil through downspout dispersion systems was the method of choice. Such cases invariably occurred with HSG D soils. The Full-ARCD scenario applied to the redevelopment case was roof water dispersion, harvesting, or a combination of the two practices. Generally speaking, infiltration consumed all available pervious area in the REDEV cases on B and C soils, making roof runoff harvesting the mechanism to retain more water. With no bioretention facility on D soil, the pervious area would be available for dispersion. Of course, harvesting could be applied instead of or along with dispersion. Again, it was assumed that that the commercial and, as needed, redevelopment sites had capacity to harvest and make use of the full volume of roof runoff generated, however, the analysis remains conservative in terms of the potential for onsite retention as it does not consider the use of ARCD site design principles to reduce impervious surfaces, green roofs, and evaporation/evapotranspration from surfaces other than rooftops.

Table 12 gives Southeast climate region results with the addition of Full ARCD techniques: roof runoff management, consisting of harvesting for reuse in the COMM case, dispersion on or within pervious land for the three residential cases, and a combination of these measures for REDEV. On the B soil runoff retention would approximately double for the retail commercial land use and reach 100 percent for the redevelopment. Groundwater recharge would not be expected to increase over the Basic ARCD case, though; because harvesting still keeps water out of the soil system.

For development on the D soil, use of roof runoff management techniques was estimated to increase runoff retention from zero to about one-third to two-thirds of the post-development runoff generated, depending on the land use case. Groundwater recharge would not materially benefit, however; because harvest does not contribute to it. Also, no recharge credit was taken for dispersion, since infiltration is restricted and loss by ET would tend to occur before infiltration. Some small amount of recharge would still be likely though. To illustrate further the small role of topography, in this D soil, Full ARCD scenario runoff retention is forecast to decrease by only 1-2 percent at a 10 percent slope compared to a 5 percent slope (not shown in table).

Table 12. Runoff and Groundwater Recharge Volumes with Full ARCD: Southeast Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
B soil						
Pre-dev.	Runoff	0.046	0.013	0.56	0.022	0.001
	Recharge	44.7	12.4	539	21.2	0.51
Post-dev.	Runoff without stormwater practices	Complete retention possible with Basic ARCD			18.7	0.45
	Runoff retained with Full ARCD				16.1	0.45
	Runoff released with Full ARCD				2.66	0
	Runoff retention (%)				86%	100%
	Recharge without stormwater practices				2.53	0.06
	Recharge with Full ARCD				8.30	0.21
	Recharge retention (%)				39%	40%
	Pervious area needed (%)[b]				100%	100%
D soil						
Pre-dev.	Runoff	13.5	3.76	163	6.43	0.16
	Recharge	31.2	8.64	376	14.8	0.36
Post-dev.	Runoff without stormwater practices	33.1	8.23	358	19.1	0.46
	Runoff retained with Full ARCD	16.4	3.11	135	7.76	0.31
	Runoff released with Full ARCD	16.7	5.12	222	11.4	0.16
	Runoff retention (%)	50%	38%	38%	41%	66%
	Recharge without stormwater practices	11.6	4.17	181	2.12	0.05
	Recharge with Full ARCD	11.6	4.17	181	2.12	0.05
	Recharge retention (%)	37.2%	48.3%	48.3%	14.3%	13.6%
	Pervious area needed (%)[b]	100%	100%	100%	100%	100%

[a] Pre-dev.—pre-development; post-dev.—post-development; ARCD—aquatic resources conservation design; MFR—multi-family residential; Sm-SFR—small-scale single-family residential; Lg-SFR—large-scale single-family residential; COMM—retail commercial; REDEV—infill redevelopment; Full ARCD—infiltrating bioretention, roof runoff harvesting, and/or roof runoff dispersion; runoff—quantity of water discharged from the site on the surface; recharge--quantity of water infiltrating the soil

[b] Proportion of the total pervious area on the site required for bioretention to achieve given results

Tables 13-15 give data analogous to Table 12 for the South Central, Northeast – Upper Midwest, and Southwest climate regions, respectively. Results are similar to those reported for the Southeast region. Full ARCD can approximately double runoff retention from the Basic ARCD level for the COMM case and extend runoff retention to 100 percent for the redevelopment on both B and C soils. Once again, application of Full ARCD to the D soil cases increases runoff retention from zero to one-third to two-thirds of the volume produced, depending on land use case.

Table 13. Runoff and Groundwater Recharge Volumes with Full ARCD: South Central Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
C soil						
Pre-dev.	Runoff	4.10	1.14	49.4	1.95	0.05
	Recharge	25.7	7.13	310	12.2	0.29
Post-dev.	Runoff without stormwater practices	Complete retention possible with Basic ARCD			12.7	0.31
	Runoff retained with Full ARCD				9.51	0.31
	Runoff released with Full ARCD				3.15	0
	Runoff retention (%)				75	100
	Recharge without stormwater practices				1.51	0.03
	Recharge with Full ARCD				4.33	0.21
	Recharge retention (%)				35	72
	Pervious area needed (%)[b]				100	100
D soil						
Pre-dev.	Runoff	18.5	5.14	223	8.80	0.21
	Recharge	11.3	3.13	136	5.36	0.13
Post-dev.	Runoff without stormwater practices	22.6	5.68	247	12.8	0.31
	Runoff retained with Full ARCD	11.0	2.08	90.3	5.17	0.20
	Runoff released with Full ARCD	11.6	3.60	157	7.63	0.11
	Runoff retention (%)	49	37	37	40	66
	Recharge without stormwater practices	7.23	2.59	112	1.35	0.03
	Recharge with Full ARCD	7.23	2.59	112	1.35	0.03
	Recharge retention (%)	64	83	83	25	24
	Pervious area needed (%)[b]	100	100	100	100	100

Table 14. Runoff and Groundwater Recharge Volumes with Full ARCD: Northeast – Upper Midwest Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
B soil						
Pre-dev.	Runoff	0.04	0.01	0.54	0.02	0.001
	Recharge	42.9	11.9	51.7	20.4	0.49
Post-dev.	Runoff without stormwater practices	Complete retention possible with Basic ARCD			18.0	0.44
	Runoff retained with Full ARCD				16.0	0.44
	Runoff released with Full ARCD				2.00	0
	Runoff retention (%)				89	100
	Recharge without stormwater practices				2.42	0.06
	Recharge with Full ARCD				8.53	0.21
	Recharge retention (%)				42	43
	Pervious area needed (%)[b]				100	100
C soil						
Pre-dev.	Runoff	7.87	2.18	94.8	3.74	0.09
	Recharge	35.1	9.72	422	16.6	0.40
Post-dev.	Runoff without stormwater practices	Complete retention possible with Basic ARCD			18.2	0.44
	Runoff retained with Full ARCD				12.0	0.44
	Runoff released with Full ARCD				6.19	0
	Runoff retention (%)				66	100
	Recharge without stormwater practices				2.17	0.05
	Recharge with Full ARCD				4.57	0.21
	Recharge retention (%)				28	43
	Pervious area needed (%)[b]				100	100

Table 15. Runoff and Groundwater Recharge Volumes with Full ARCD: Southwest Climate Region[a]

Period	Volume (acre-ft) or Percentage Measure	MFR	Sm-SFR	Lg-SFR	COMM	REDEV
C soil						
Pre-dev.	Runoff	1.62	0.45	19.5	0.77	0.02
	Recharge	7.22	2.00	87.0	3.43	0.08
Post-dev.	Runoff without stormwater practices	Complete retention possible with Basic ARCD				
	Runoff retained with Full ARCD					
	Runoff released with Full ARCD					
	Runoff retention (%)					
	Recharge without *stormwater* practices					
	Recharge with Full ARCD					
	Recharge retention (%)					
	Pervious area needed (%)[b]					
D soil						
Pre-dev.	Runoff	4.47	1.24	53.8	2.12	0.05
	Recharge	4.37	1.21	52.7	2.08	0.05
Post-dev.	Runoff without stormwater practices	6.70	1.68	73.2	3.80	0.09
	Runoff retained with Full ARCD	3.25	0.62	26.8	1.53	0.06
	Runoff released with Full ARCD	3.45	1.07	46.5	2.26	0.03
	Runoff retention (%)	49	37	37	40	66
	Recharge without stormwater practices	2.14	0.77	33.3	0.40	0.01
	Recharge with Full ARCD	2.14	0.77	33.3	0.40	0.01
	Recharge retention (%)	49	63	63	19	18
	Pervious area needed (%)[b]	100	100	100	100	100

Pollutant Loading Reductions

The examination of maximum ARCD capabilities considered the reductions of annual mass loadings of four water pollutants that would accompany runoff retention. Since retention means no surface discharge, these loading reductions are, at a minimum, equal to the percentages of runoff retention. In those cases with less than full runoff retention, there is good reason to expect pollutant loading reductions higher than the percentage of runoff retained. The early runoff (“first flush”), occurring when the soils are least saturated, is more likely to be retained than later runoff. It is frequently observed that the first flush has higher pollutant concentrations than later runoff, particularly in the wash off after relatively extended dry periods.

For the B and D soil and the residential cases on C soils, the reductions were very consistent among regions:

- B and C soils, Basic ARCD, residential cases—100%;
- B soil, Basic ARCD, COMM and REDEV cases—44-45%;
- B soil, Full ARCD, COMM and REDEV cases—86-100%;
- D soil, Full ARCD, SFR and COMM cases—38-41%;
- D soil, Full ARCD, MFR case—50%; and
- D soil, Full ARCD, REDEV case—66%.

For the most highly impervious cases, COMM and REDEV, on C soils reduction was variable and dependent on precipitation. With Basic ARCD the range was from 25 to 100 percent, going from relatively high to low precipitation. Full ARCD is expected to raise the lowest reductions to 100 percent for REDEV and at least 66 percent for COMM.

Therefore, taking the greatest advantage of what ARCD offers could prevent the addition to receiving waters of all or almost all pollutant mass that would otherwise discharge from a range of urban developments on B and C soils. With D soils, Full ARCD can accomplish loading reductions approaching or somewhat exceeding 50 percent.

ABILITY TO MEET POTENTIAL STANDARDS

General Summary

This section evaluates the ability of the Basic and Full ARCD strategies to meet each of the five potential stormwater management standards enumerated in the beginning of the report. It also examines the extent of pollutant loading reduction if the standards are just met; i.e., if runoff is retained at the minimum needed to meet the standard. It has already been demonstrated that retention of all post-development runoff and full pollutant attenuation is possible in some circumstances. Table 16 summarizes the results for all regions and cases and both ARCD strategies.

Ability to Meet Standards

The projected ability to meet the standards overall varies mostly in relation to soil type (B or C versus D) and the relative imperviousness of development, and much less across climate regions. The one exception to this generality is that implementing Basic ARCD practices on the Southwest region C soil would meet all five standards. This uniformity does not occur elsewhere on either B or C soils, and is apparently primarily a function of the relatively low precipitation in the region.

Setting aside the Southwest region, success in complying with standards is mostly comparable among the various B and C soils, with a small number of instances where a development type meets a standard on B but not on C soil. Basic ARCD methods invariably can meet all standards on B and C soils for the residential development cases (MFR and Sm- and Lg-SFR). Full ARCD practices are forecast to meet all standards for the redevelopment case on B soils but only standards 1 and 5 consistently on C soils. The combination of infiltration and roof runoff management applied to the retail commercial development allows meeting these same two standards on B soils but only the latter on both of the C soils occurring outside the Southwest region. The only standards that cannot be met on B and C soils by the ARCD methods considered are standards 2-4 for the COMM case. Therefore, of the 125 standards assessments, ARCD practices are projected to meet 113 (90.4 percent) with B and C soils.

The ability to meet these standards is much reduced on D soils. Standard 1 can be met occasionally with Full ARCD used in the redevelopment. All cases with Full ARCD comply with standard 4 on this soil where pre-development runoff is estimated to be relatively high, reflecting a low overall requirement for retention volume. Standard 5 can be met with Full ARCD with the exception of one COMM case. Standards 2 and 3 were never estimated to be met in any D soil case. All in all, with this soil 26 of the 75 scenarios (34.7 percent) are expected to meet a standard.

Table 16. Ability to Meet Potential Regulatory Standards with Basic/Full ARCD Practices

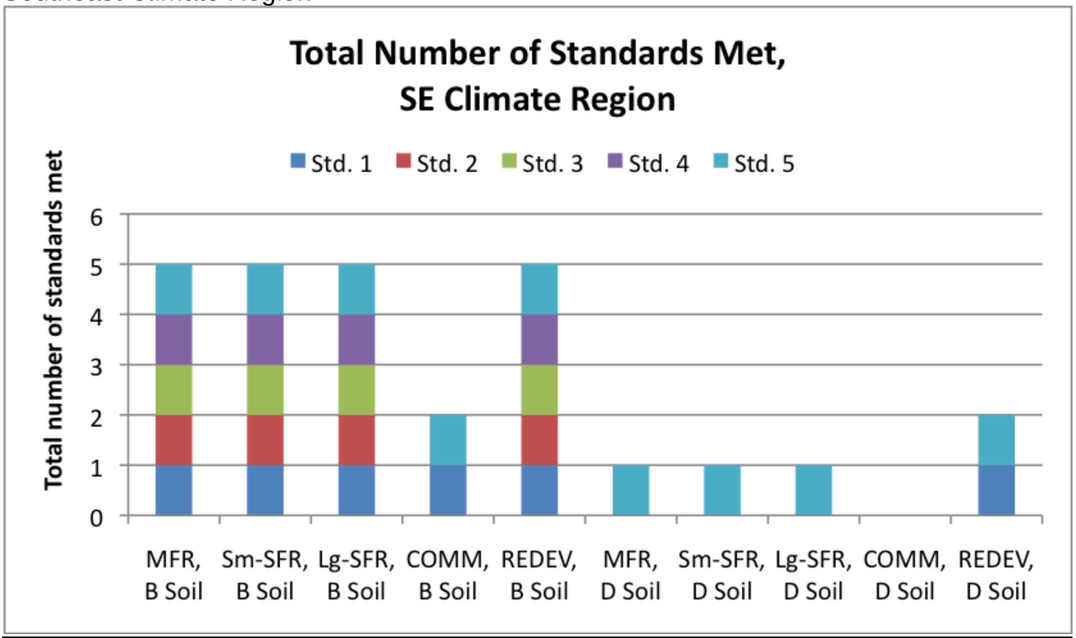
Region-Case[a]	Standards Met—Basic ARCD[b]	Standards Met—Full ARCD[b]	Runoff Retention and Pollutant Loading Reduction (%)[b, c]				
			Std. 1	Std. 2	Std. 3	Std. 4	Std. 5
SE(B)-MFR	1, 2, 3, 4, 5		63	87	90	>99	63
Sm-SFR	1, 2, 3, 4, 5		63	87	90	>99	63
Lg-SFR	1, 2, 3, 4, 5		63	87	90	>99	63
COMM		1, 5	63	86	86	86	63
REDEV		1, 2, 3, 4, 5	63	87	90	>99	63
SE(D)-MFR		5	50	50	50	50	37
Sm-SFR		5	38	38	38	38	34
Lg-SFR		5	38	38	38	38	34
COMM			41	41	41	41	41
REDEV		1, 5	63	66	66	66	42
SC(C)-MFR	1, 2, 3, 4, 5		58	82	90	81	47
Sm-SFR	1, 2, 3, 4, 5		58	82	90	78	45
Lg-SFR	1, 2, 3, 4, 5		58	82	90	78	45
COMM		1, 5	58	75	75	75	49
REDEV		1, 2, 3, 4, 5	58	82	90	84	49
SC(D)-MFR		4, 5	49	49	49	18	10
Sm-SFR		4, 5	37	37	37	10	6
Lg-SFR		4, 5	37	37	37	10	6
COMM		4, 5	40	40	40	31	18
REDEV		1, 4, 5	58	66	66	32	18
NM(B)-MFR	1, 2, 3, 4, 5		81	89	90	>99	81
Sm-SFR	1, 2, 3, 4, 5		81	89	90	>99	81
Lg-SFR	1, 2, 3, 4, 5		81	89	90	>99	81
COMM		1, 2, 5	81	89	89	89	81
REDEV		1, 2, 3, 4, 5	81	89	90	>99	81
NM(C)-MFR	1, 2, 3, 4, 5		81	89	90	74	60
Sm-SFR	1, 2, 3, 4, 5		81	89	90	71	57
Lg-SFR	1, 2, 3, 4, 5		81	89	90	71	57
COMM		5	66	66	66	66	64
REDEV		1, 2, 3, 4, 5	81	89	90	80	64
SW(C)-MFR	1, 2, 3, 4, 5		62	83	90	75	46
Sm-SFR	1, 2, 3, 4, 5		62	83	90	72	44
Lg-SFR	1, 2, 3, 4, 5		62	83	90	72	44
COMM	1, 2, 3, 4, 5		62	83	90	80	49
REDEV	1, 2, 3, 4, 5		62	83	90	80	49
SW(D)-MFR		4, 5	49	49	49	33	21
Sm-SFR		4, 5	37	37	37	27	16
Lg-SFR		4, 5	37	37	37	27	16
COMM		5	40	40	40	40	27
REDEV		1, 4, 5	62	66	66	44	28

[a] Region (hydrologic soil group)—land use; regions: SE—Southeast, SC—South-central, NM—Northeast-Upper Midwest, SW—Southwest; land uses: MFR—multi-family residential, Sm-SFR—small single-family residential, Lg-SFR--large single-family residential, COMM—retail commercial, REDEV--redevelopment

[b] Standard (Std.) 1—Retain the runoff produced by the 85th percentile, 24-hour precipitation event
Standard 2—Retain the runoff produced by the 95th percentile, 24-hour precipitation event
Standard 3—Retain 90 percent of the average annual post-development runoff volume
Standard 4—Retain the difference between the post- and pre-development average annual runoff volumes
Standard 5—Retain the difference between the post- and pre-development runoff volumes for all events up to and including the 85th percentile, 24-hour precipitation event

[c] Reduction estimated to result from meeting the standard, to the extent it can be met (fully met if so indicated in preceding columns), without treatment of remaining discharge. Where a standard can be met using Basic or Full ARCD application it is indicated in black, where a standard cannot be met using Basic or Full ARCD it is highlighted red.

Figure 4a. Ability to Meet Potential Regulatory Standards with Basic/Full ARCD Practices for Southeast Climate Region



MFR—multi-family residential, Sm-SFR—small single-family residential, Lg-SFR--large single-family residential, COMM—retail commercial, REDEV—redevelopment. Standard (Std.) 1—Retain the runoff produced by the 85th percentile, 24-hour precipitation event; Standard 2—the 95th percentile, 24-hour precipitation event; Standard 3—90 percent of the average annual post-development runoff volume; Standard 4—the difference between the post- and pre-development average annual runoff volumes; and, Standard 5—the difference between the post- and pre-development runoff volumes for all events up to and including the 85th percentile, 24-hour precipitation event

Figure 4b. Ability to Meet Potential Regulatory Standards with Basic/Full ARCD Practices for South Central Climate Region

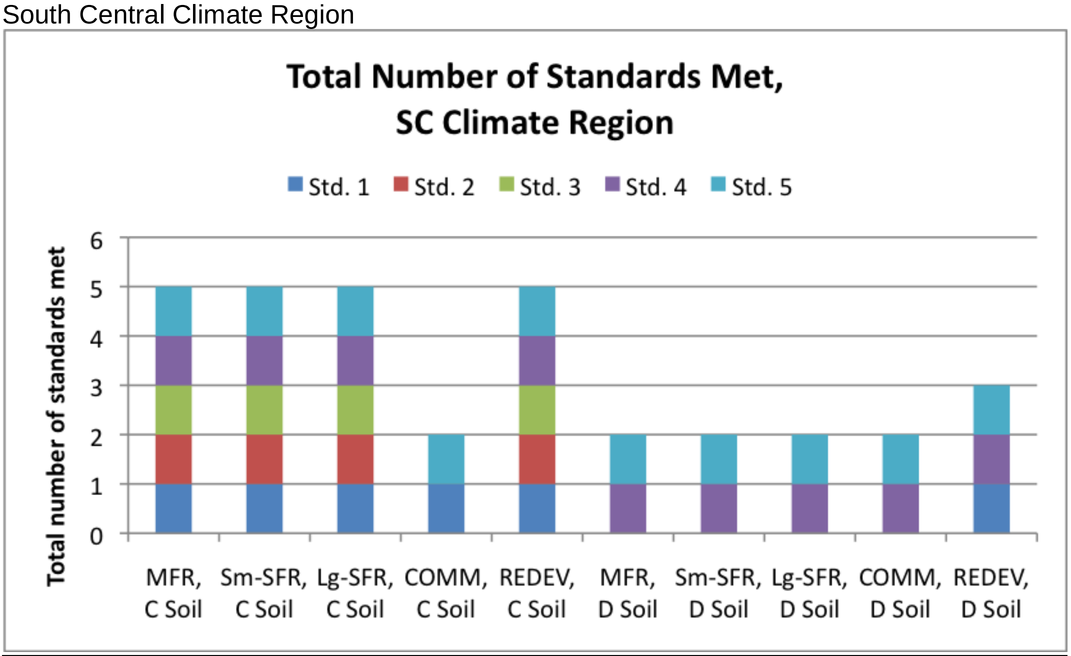


Figure 4c. Ability to Meet Potential Regulatory Standards with Basic/Full ARCD Practices for Northeast-Midwest Climate Region

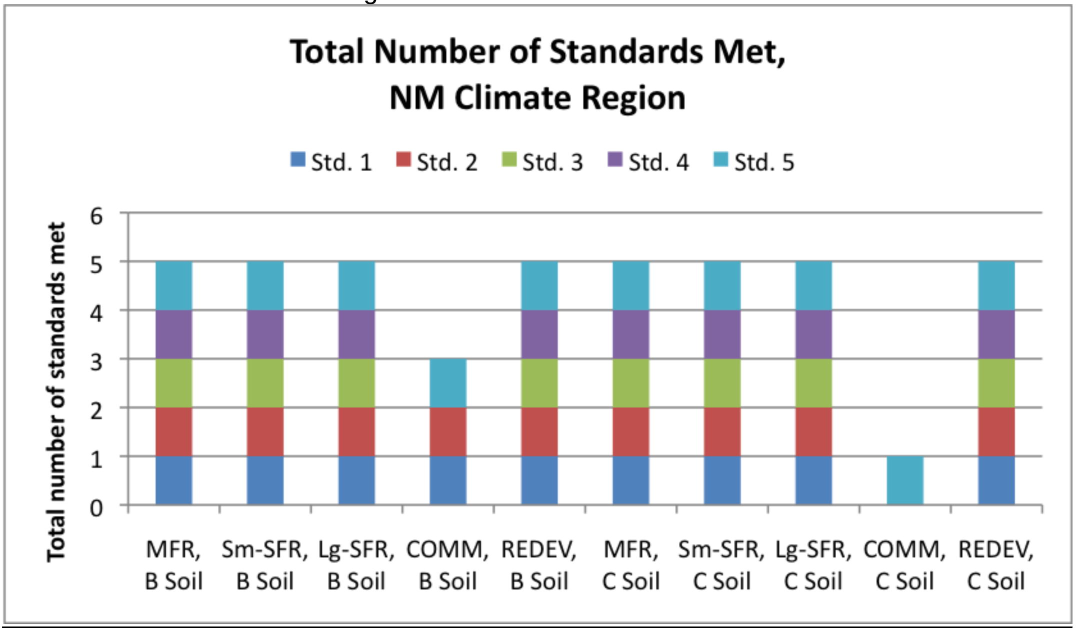


Figure 4d. Ability to Meet Potential Regulatory Standards with Basic/Full ARCD Practices for Southwest Climate Region

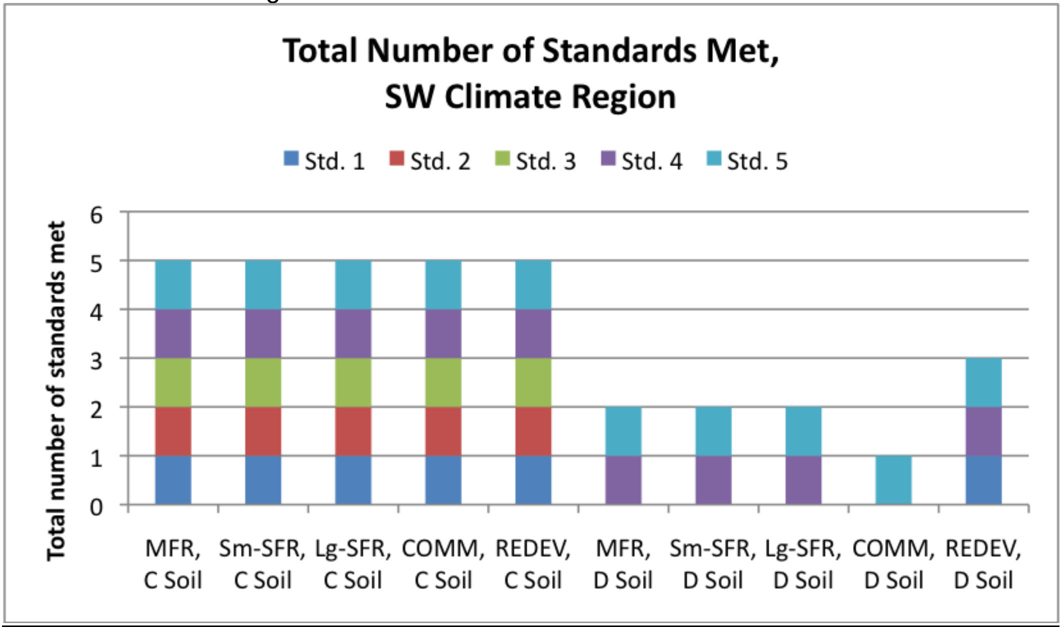
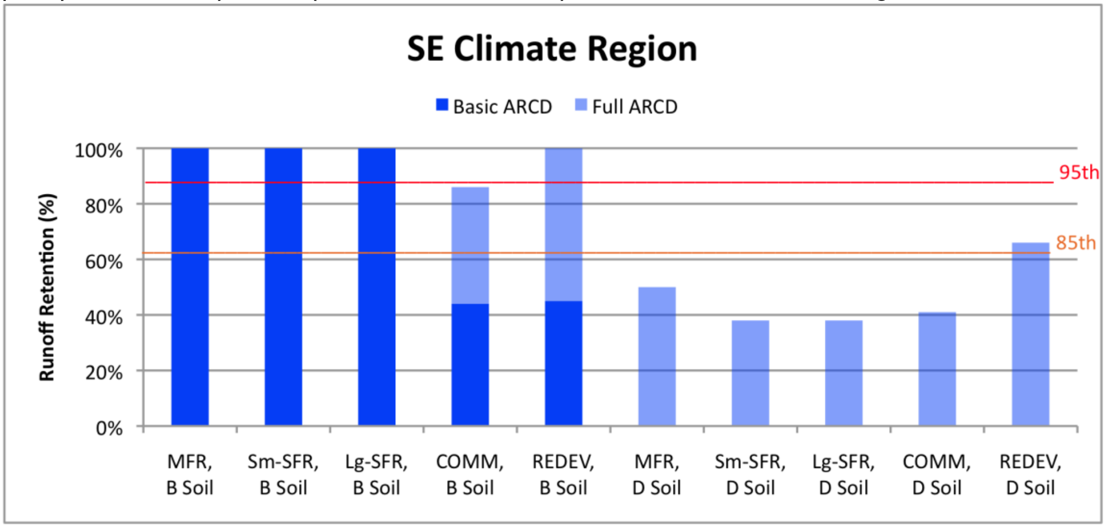


Figure 5a. Percentage of Runoff Retained Relative to Standards 1 (85th Percentile, 24-hour precipitation event) and 2 (95th Percentile event) for Southeast Climate Region



MFR—multi-family residential, Sm-SFR—small single-family residential, Lg-SFR--large single-family residential, COMM—retail commercial, REDEV—redevelopment. Standard (Std.) 1—Retain the runoff produced by the 85th percentile, 24-hour precipitation event; Standard 2—the 95th percentile, 24-hour precipitation event; Standard 3—90 percent of the average annual post-development runoff volume; Standard 4—the difference between the post- and pre-development average annual runoff volumes; and, Standard 5—the difference between the post- and pre-development runoff volumes for all events up to and including the 85th percentile, 24-hour precipitation event

Figures 5a-d show the percentage of runoff that can be retained for each development type, in each region, using either Basic or Full ARCD practices, in comparison with Standard 1 (retention of the 85th percentile, 24-hour precipitation event) and Standard 2 (retention of the 95th percentile, 24 hour event). Even where Standards 1 and 2 cannot be met in full, ARCD practices can still result in substantial compliance, and retention of significant runoff volume.

Figure 5b. Percentage of Runoff Retained Relative to Standards 1 (85th Percentile, 24-hour precipitation event) and 2 (95th Percentile event) for South Central Climate Region

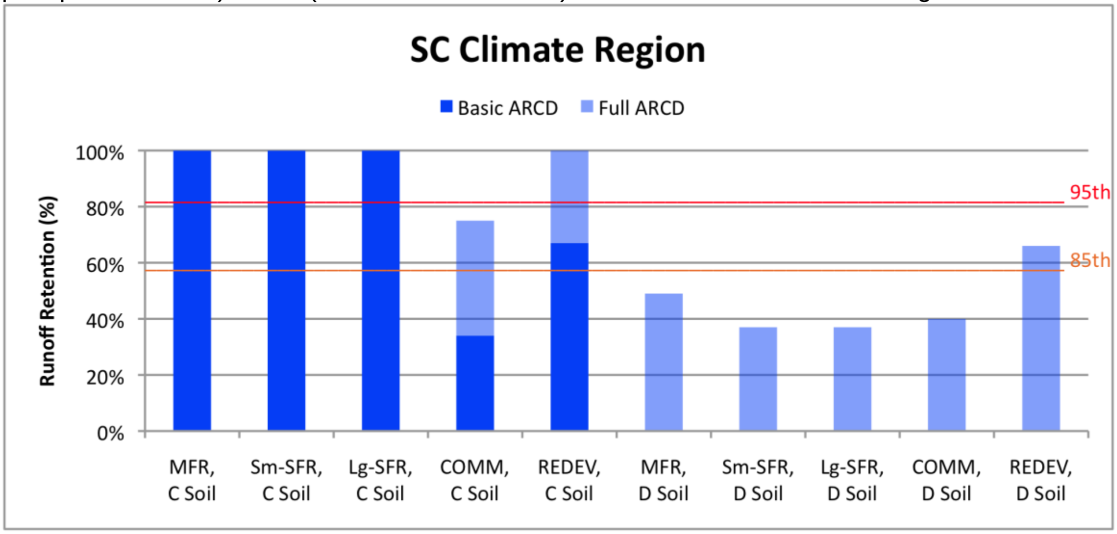


Figure 5c. Percentage of Runoff Retained Relative to Standards 1 (85th Percentile, 24-hour precipitation event) and 2 (95th Percentile event) for Northeast-Midwest Region

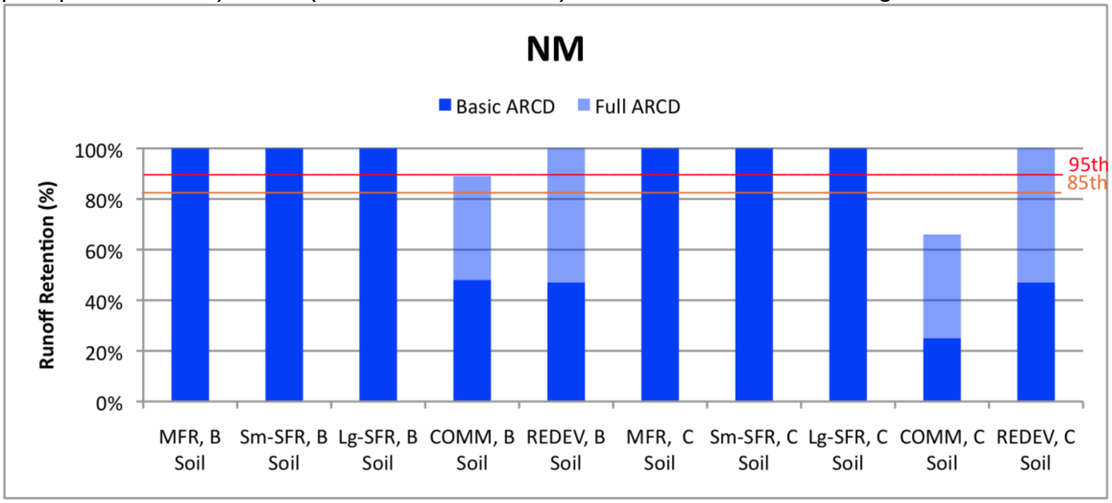
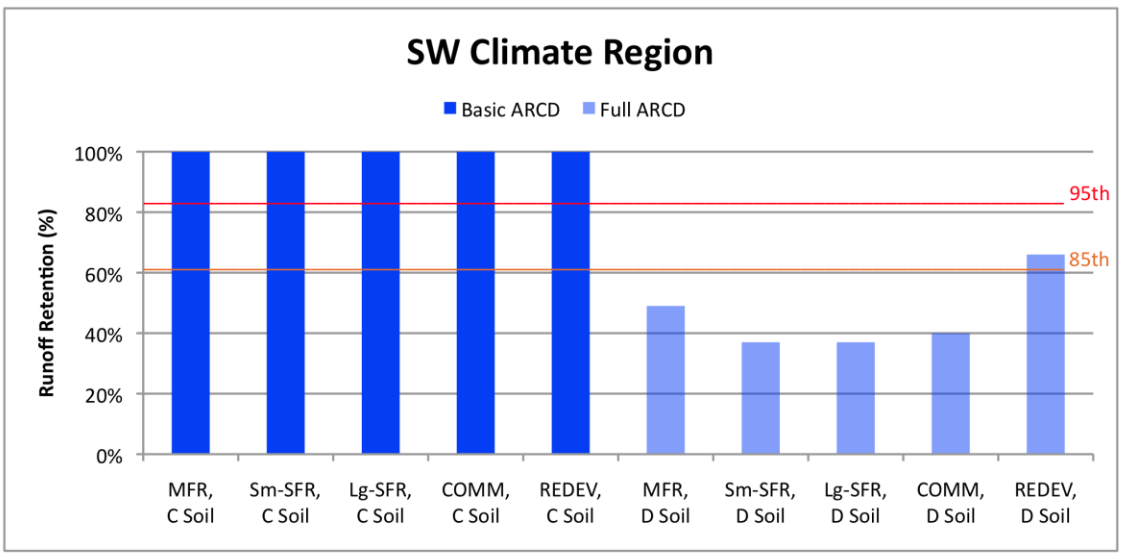


Figure 5d. Percentage of Runoff Retained Relative to Standards 1 (85th Percentile, 24-hour precipitation event) and 2 (95th Percentile event) for Southwest Region



<u>Effectiveness of Standards in Environmental Protection</u>

Standard 3 (retain 90 percent of the average annual post-development runoff volume) would be the most protective standard. Meeting or coming as close as possible to meeting, but not exceeding, this standard is estimated to lead to 66-90 percent runoff retention and pollutant loading reduction on B and C soils and 37-66 percent on D soil. Standard 2 (retain the runoff produced by the 95th percentile, 24-hour precipitation event) would yield only slightly less protection with B and C soils and, with D soil, retention and loading reduction equivalent to standard 3.

Standards 4 and 5, based on the differential between pre- and post-development runoff volume, are highly inconsistent in retaining runoff and reducing pollutants, in that they are relatively protective where pre-development runoff is estimated to be very low relative to post-development flow, but result in progressively lower retention and pollutant loading reduction as pre- and post-development volumes converge, such as in several cases on D soils. Standard 5 is especially weak in this regard. The potentially low level of retention and pollutant loading reduction renders these standards based on the change in pre- versus post-development runoff volume poor candidates for national application, at least as formulated in these terms.

Fully meeting standard 1 (retain the runoff produced by the 85th percentile, 24-hour precipitation event) would yield runoff retention and pollutant mass reduction ranging from 58 to 81 percent, depending on climate region. This level of inconsistency decreases the utility of this standard for widespread use. Standard 2, based on the 95th percentile event, is much better in this respect, with variability in runoff retention and loading reduction across the nation in the much narrower 82-89 percent range. However, standard 1 remains more consistent across regions, and more protective of water quality for development on D soils than either standard 4 or 5, and is preferable to those standards in this regard.

In summary, standards 2 and 3 are clearly superior to the other three options. Standard 3 is entirely consistent from place to place in degree of environmental protection, and standard 2 does not deviate much. Analysis of the five development cases on two soil groups in each of four regions demonstrated the two standards are virtually identical in the runoff retention and pollutant loading reduction they would bring about.

Management or Runoff in Excess of Standards Requirements

All of the analysis reported above assumed that any remaining runoff after the application of ARCD and meeting, or coming as close as possible to meeting a standard, would discharge with no treatment. In fact, additional treatment could further decrease pollutant loadings. Treatment without further runoff retention could be accomplished by many conventional or ARCD methods designed to lower contaminant concentrations. The most effective of the alternatives is probably bioretention discharging non-retained runoff either on the surface or through an underdrain, assumed in the analysis conducted for this study according to the methods cited above. Treatment of all remaining runoff with underdrained bioretention cells where space remains but all infiltration capacity is used can raise the pollutant removals given in Table 16 to the levels in Table 17. These estimates apply to the four pollutants considered, TSS and total copper, zinc, and phosphorus. Space would most likely be available in the three MFR and SFR cases but not the COMM and REDEV scenarios.

While there is substantial variability in these results, they demonstrate that discharging effluent of relatively consistent, high quality can be accomplished with a comprehensive ARCD strategy. This strategy would embrace, first, retaining as much urban runoff as possible and then utilizing treatment based on soil and vegetative media to capture contaminants from the remainder.

Table 17. Estimated Pollutant Loading Reduction Benefits of Bioretention Treatment of Runoff Remaining After ARCD Implemented to Meet or Approach Standards

Range of Table 16 Values (%)	Approximate Pollutant Removal Increase (%)	Total Estimated Pollutant Removal Range (%)
35-45	30-45	65-90
45-55	25-35	70-90
55-65	20-30	75-95
65-75	15->20	80->95
75-85	10->15	85->95
>85	5->10	90->95

SUMMARY AND CONCLUSIONS

STUDY DESIGN

This study was performed to investigate the degree to which low-impact development ARCD practices can meet or exceed the requirements of various potential stormwater management facility design standards and the resulting environmental benefits. The investigation was performed by estimating the stormwater retention possible with full application of ARCD practices to five land use cases in four representative climatic regions in the United States on two prominent soil types in each region. Retention is defined as preventing the conversion of precipitation to surface runoff. Retaining runoff from impervious and pollutant generating pervious surfaces prevents the introduction of urban runoff pollutants to receiving waters as well as reduces runoff volume to prevent stream channel and habitat damage, flooding, and loss of groundwater recharge. Infiltrating bioretention was first applied in the analysis of each case, a strategy termed Basic ARCD. When Basic ARCD could not fully retain post-development runoff, a Full ARCD strategy was added, involving roof runoff harvesting in the most impervious development cases and roof water dispersion in those with substantial pervious area. Benefits were assessed with respect to reduction of the annual average surface runoff volume from the quantity estimated without any stormwater management practices, and associated maintenance of pre-development groundwater recharge and water quality improvement through preventing discharge to receiving waters of pollutants generated with developed land uses.

A number of conservative assumptions were built into the analysis to ensure that the capabilities and benefits of ARCD would not be over-estimated. In summary, these assumptions are:

- No retention credit for evapotranspiration in the Basic ARCD strategy, although generally a substantial amount would occur, and consideration of evapotranspiration only for roof runoff in the Full ARCD strategy;

- Letting aside many available ARCD practices and site design principles that could be employed to reduce the runoff quantity, and the pollutants it transports, by reducing impervious surface area or directing the runoff to bioretention, harvesting, and dispersion facilities;

- The assumption of no infiltration on hydrologic soil group D soils, although some infiltration occurs at finite rates even on clay;

- Application of a safety factor to estimated infiltration rates;

- Minimum bioretention cell depths, so that these facilities would not be disruptive to site design and could be put to other uses;

- Requiring a 48-hour drawdown time for bioretention, instead of the 72-hour maximum;

- An analysis to guard against groundwater mounding under bioretention cells, with conservative assumptions for horizontal and vertical hydraulic conductivity rates; and

- An analysis demonstrating that doubling topographic slope changes results by only a few percent.

CAPABILITIES OF FULL ARCD APPLICATION

Comparison of estimated runoff production in the pre- and post-development states demonstrated that the majority of the infiltration that would recharge groundwater in the undeveloped state would be lost to surface runoff after development with no stormwater management practices. These losses would approach 90 percent in the most impervious developments. These observations apply in in all climate regions and with the full range of soil conditions.

Basic ARCD could retain all post-development runoff and pre-existing groundwater recharge, as well as attenuate all pollutant transport, in the three residential cases on B soils in the two climate regions where these soils were analyzed. Bioretention cells to accomplish this retention would use from less than one-fourth to just over one-third of the available pervious area for infiltration. Taking all available pervious area for the more highly impervious COMM and REDEV cases, bioretention would retain about 45 percent of the runoff and pollutants generated and save about 40 percent of the pre-development recharge. Adding Full ARCD measures in these cases would approximately double retention and pollutant reduction for the retail commercial land use and raise it to 100 percent for the redevelopment. Groundwater recharge would not increase, however, because the additional retention is accomplished by harvesting or dispersion.

In the three regions having C soils, Basic ARCD can again retain all runoff and reduce urban runoff pollutant mass loading to zero for the MFR and Sm-SFR and Lg-SFR residential cases, although generally requiring more of the available pervious area to do so than in B soil cases. The effect of lower rainfall is evident in the South Central and, especially, the Southwest regions. In the latter location, not only the residential cases but also the COMM and REDEV scenarios can achieve full runoff and groundwater recharge retention and pollutant loading attenuation with Basic ARCD on C soil. Full ARCD can approximately double runoff retention and pollutant removal from the Basic ARCD level for the COMM case and extend these measures to 100 percent for the redevelopment.

For development on the D soils in all climate regions, use of roof runoff management techniques was estimated to increase runoff retention and pollutant reduction from zero to between about one-third to two-thirds of the post-development runoff generated, depending on the land use case. These strategies would offer little groundwater recharge benefit with this soil condition, but would still have the potential to significantly reduce runoff volume and pollutant loading.

Therefore, taking the greatest advantage of what ARCD offers is expected to retain the great majority of post-development runoff and pre-development groundwater recharge. This strategy would also prevent the addition to receiving waters of all or almost all pollutant mass that would otherwise discharge from a range of urban developments on B and C soils. With D soils, Full ARCD can accomplish runoff retention and loading reductions approaching or somewhat exceeding 50 percent, and opportunities to use ARCD practices or site design principles not modeled in this analysis can further increase runoff retention volume.

ABILITY TO MEET STANDARDS

ARCD methods were assessed for their ability to meet five potential regulatory standards, the first two pertaining to retention of the 85th and 95th percentile, 24-hour precipitation events, the third to retain 90 percent of the post-development runoff, and the last two to retain the difference between the post- and pre-development runoff, the final standard capped at the 85th percentile, 24-hour event. The projected ability to meet the five standards varies mostly in relation to soil type (B or C versus D) and the relative imperviousness of development, and much less across climate regions, except for the relatively arid Southwest.

The only standards that cannot be fully met on B and C soils by the ARCD methods considered are standards 2-4 for the COMM case. Of the 125 standards assessments, ARCD practices are projected to meet 113 (90.4 percent) with B and C soils. The ability to meet these standards is much reduced on D soils. Only standards 1 (85^{th} percentile, 24-hour precipitation event, and 4 and 5 (related to the difference between the post- and pre-development runoff) can be met occasionally and under limited conditions using Full ARCD methods. However, even on D soils, all cases for Standard 1 were able to retain greater than 50 percent of the required runoff volume.

Standard 3 (retain 90 percent of the average annual post-development runoff volume) would be the most environmentally protective standard. Meeting or coming as close as possible to meeting, but not exceeding, this standard was estimated to lead to 66-90 percent runoff retention and pollutant loading reduction on B and C soils and 37-66 percent on D soil. Standard 2 (retain the runoff produced by the 95^{th} percentile, 24-hour precipitation event) would yield equivalent protection on D soils and only slightly less protection with B and C soils.

Standards 4 and 5, based on the differential between pre- and post-development runoff volume, are very inconsistent in retaining runoff and reducing pollutants. They are highly protective where pre-development runoff is estimated to be very low relative to post-development flow, and then to result in progressively lower retention and loading reduction as pre- and post-development volumes converge. Standard 5 is especially weak in this regard. This inconsistency makes these standards poor candidates for national application, at least as formulated in these terms.

Fully meeting standard 1 (retain the runoff produced by the 85^{th} percentile, 24-hour precipitation event) would yield runoff retention and pollutant mass reduction ranging from 58 to 81 percent, depending on climate region. This level of inconsistency decreases the utility of this standard to some degree. Standard 2, based on the 95^{th} percentile event, is much better in this respect, with variability in runoff retention and loading reduction across the nation in the much narrower 82-89 percent range. However, standard 1 remains more consistent across regions, and more protective of water quality for development on D soils than either standard 4 or 5, and is preferable to those standards in this regard.

In summary, standards 2 and 3 are clearly superior to the other three options. Standard 3 is entirely consistent from place to place in degree of environmental protection, and standard 2 does not deviate much. Analysis of the five development cases on two soil groups in each of four regions demonstrated the two standards are virtually identical in the runoff retention and pollutant loading reduction they would bring about.

All five standards are based on some stipulated runoff retention. Pollutant mass loading reduction is at least equal to the amount of retention that occurs. It is possible to decrease loadings further by treating excess runoff. Analysis showed that subjecting that runoff to bioretention treatment before discharge could reduce loadings of TSS and total copper, zinc, and phosphorus by at least two-thirds and as much as over 95 percent. This conclusion applies to all climate regions and soil types for land use cases where space is available for the additional bioretention cells. The three residential cases are in this group but not the COMM or REDEV cases, where all pervious land would have already been used for retentive or roof water dispersion practices.

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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 (µg/L)	TPb (µg/L)	TZn (µg/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.

OC MS4 Tentative Order No. R8-2008-0030 (R8-2009-0030)
Comments/Responses

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
1	Lake Forest	General	N/A	The Draft Permit does not have a Table of Contents	Add a Table of Contents to allow easier navigation to various sections	Comment noted. Due to time constraints, the recommendation could not be implemented.
2	Irvine, County of Orange, Anaheim, Lake Forest,	Finding A5.c	The Permittees have the authority to levy service charges, fees or assessments to pay for compliance with this order.	Assessments to pay for compliance with this order must meet voter approval	Remove Section A.5c	Permit language has been revised to reflect the need for voter approval for some assessments.
3	County of Orange-Attachment B	General	Reference to Permittees	Reference to the Permittees is inconsistent throughout the permit.	Use the recommended language.	Permit language has been revised.
4	County of Orange-Attachment B	Finding A.3, Fact Sheet page 13	MEP definition	The definition of maximum extent practicable stated in the permit and the fact sheet are different and are not consistent with the case law.	Use recommended language.	Permit language has been revised.
5	Irvine	Finding C.8 and Section XVIII.B.3	This order is intended to regulate the discharge of pollutants…from anthropogenic…sources…not… background or naturally occurring pollutants	While this finding indicates an appropriate focus of the permit, Section XVIII, which addresses selenium in rising groundwater is not consistent with Finding C.8. Selenium should be addressed under the TMDL and NSMP programs.	Revise Section XVIII to make it consistent with Finding C.8.	Permit language has been revised to describe the co-operative process that is being used to address the selenium and nutrient impacted groundwater in the San Diego Creek Watershed.
6	Irvine	Finding C.10	Regional Board recognition that the permittees may lack jurisdiction over certain discharges	While this finding appropriately identifies the legal limitations of the co-permittees, Section XVIII requires co-permittees to address selenium in rising groundwater and copper in receiving waters when it's beyond their ability to eliminate those pollutants.	Revise Section XVIII to make it consistent with Finding C.10	Permit language has been revised to describe the co-operative process that is being used to address the selenium and nutrient impacted groundwater in the San Diego Creek Watershed. The sources of copper include controllable sources such as industrial sites.
7	Irvine	Finding 16.b, Finding K.56, Section	The 2007 DAMP includes all activities the permittees propose to undertake during the next permit	This finding references the Draft 2007 Drainage Area Management Plan, which has not been reviewed by the co-permittees.	Ensure that the co-permittees have had an opportunity to review and approve the entire 2007 DAMP prior to permit adoption.	The 2007 Draft Drainage Area Management Plan (DAMP) was submitted with the ROWD on July 21, 2006 by the principal permittee.

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		II.B.2 and Section XIX.3	term.			
8	Irvine	Finding F.18	The County's storm water conveyance systems include an estimated 400 miles of storm drains	The 2002 MS4 permit stated that there were an estimated 400 miles of storm drains in the County and that number should have increased.	Revise estimate.	Finding has been updated to current conditions.
9	Irvine	Finding G.21	This order prohibits the construction of treatment BMPs within waters of the U.S.	This language is overly broad and appears to prohibit trash booms and Natural Treatment System facilities that are installed in retrofitted channels and basins.	Eliminate or narrow the prohibition against natural and structural treatment BMPs.	As stated in the current language of the draft permit, if discharge treatment sufficiently protects the beneficial uses of the receiving water, additional polishing within waters of the U.S. may be considered. Street sweeping, catch basin inserts/filters and catch basin cleanouts result in discharges that, for the most part, protect the beneficial uses of those receiving waters. The use of trash booms primarily protects the downstream beaches. Finding 21 indicates that treatment systems within waters of the U.S. could be considered on a case-by-case basis.
10	Irvine	Finding H.30	It is anticipated that many of the inspections required under this order can be carried out by inspectors currently conducting other types of inspections for the permittees.	It should not be assumed that additional duties added to current inspections do not lead to any additional workload or City resources.	Remove that language.	The permit language does not assume that no additional workload will result from these duties being carried out by inspectors currently conducting other types of inspections, but rather identifies possible workload savings using this strategy, rather than always sending out an additional inspector to address only storm water issues.

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11	Irvine	Finding I.38 and O.74	Theses findings discuss the use of debris booms within apparent waters of the U.S.	This statement would appear to violate the restriction identified in Finding G.21, prohibiting the implementation of treatment BMPs in waters of the U.S.	Please clarify.	See response to comment 9.
12	Irvine	Finding J.43	TMDLs have been established by the Regional Board for… the San Diego Creek / Newport Bay watershed.	It is the City's understanding that the San Diego Creek/Newport Bay watershed is referred to as the Newport Bay watershed.	Please clarify.	Permit language has been revised.
13	Irvine	Finding K.55	The permittees have adopted grading and erosion control ordinances, guidelines and BMPs for municipal, commercial, and industrial activities.	The co-permittees have not adopted BMPs but instead the DAMP and LIPs contain guidelines for the implementation of minimum BMPs	*Revise to read: The permittees have adopted grading and erosion control ordinances and guidelines for the implementation of minimum best management practices (BMPs) for municipal, commercial, and industrial activities.*	Permit language has been revised.
14	Irvine	Finding L and throughout	NEW DEVELOPMENT/ SIGNIFICANT REDEVELOPMENT – WQMP/LIP/LID	Throughout the draft order there should be a distinction between the model WQMP and the project WQMP.	Please differentiate between the project and model WQMPs	Permit language has been revised.
15	Irvine	Finding L.61	Finding identifies that the Southern California Coastal Water Research Project (SCCWRP) is developing a Low Impact Development Manual for Southern California.	It is our understanding that SCCWRP is not developing this manual.	Please clarify.	Permit language has been revised.
16	Irvine	Finding L.62	Finding identifies that USEPA has determined that by limiting the effective impervious area (EIA) of a site, downstream	USEPA has not determined that prescriptively limiting EIA to 5% or less is the best way to minimize receiving water impacts in all watersheds and for all physical conditions. With	Revise this finding to recognize other white papers and information submitted to the Regional Board and revise the New Development and Significant Redevelopment provisions to use a volume	Permit language has been revised.

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			impacts could be minimized. A limited study conducted by Dr. Richard Horner concluded that a 3% EIA standard for development in Ventura County is feasible.	regards to Dr. Horner's study, additional white papers produced in meetings regarding this Orange County permit indicate that a 3% EIA standard may be inappropriate for incorporation into this permit.	treatment performance standard for LID implementation, more specific exemption criteria for when LID may be undesirable, and establish timelines for the development of watershed plans and LID/hydromodification control standards.	
17	Irvine	Finding L.66	Finding states that if certain BMPs are not properly designed and maintained, they could become sources of groundwater pollution, nuisance, etc.	While the City supports the more stringent requirements for use of LID BMPs, if LID infiltration BMPs are used in inappropriate conditions, they may be sources of pollution or nuisance.	Revise findings to indicate technical and environmental constraints on LID infiltration BMPs.	Permit language has been revised.
18	Irvine	Finding L.67	Finding states that if the BMPs in Finding L.65 are not properly designed and maintained, they could become sources of nuisance and/or habitat for vectors.	If LID infiltration BMPs are not properly designed or maintained, they may become sources of nuisance and/or habitat for vectors.	Revise findings to indicate that LID infiltration BMPs may become sources of nuisance and/or habitat for vectors if not properly designed or maintained.	Permit language has been revised.
19	Irvine	Finding M.68	Finding discusses de minimus discharges and states that municipal de minimus discharges generally do not require separate coverage under the Regional Board's de minimus permit.	This finding can be interpreted to mean that all de minimus discharges are prohibited in the San Diego Creek/Newport Beach watershed.	The language should be clarified. Further, the City supports the County comment that all de minimus discharges should be allowed unless a finding is made that those discharges are a significant source of pollutants.	Permit language has been revised to clearly state that a separate de minimus permit is required for non-storm water discharges to the MS4 in the San Diego Creek/Newport Beach watershed.
20	Irvine	Finding M.69	Finding points out the high nitrate and/or selenium levels in the soils and/or groundwater in the San Diego Creek/Newport	LID infiltration BMPs can also potentially mobilize nitrogen and selenium.	The findings should recognize that fact.	While the comment is valid, it was not the intent of Regional Board staff to identify <u>all scenarios</u> that could lead to mobilization of nitrogen and selenium in Finding 69.

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			Bay watershed and that dewatering activities could mobilize these pollutants.			
21	Irvine	Finding N.71	The principal permittee in collaboration with the co-permittees is to develop guidelines for the competencies and training schedules for municipal storm water positions.	While training is necessary, the City wants the flexibility to design and conduct training as well as the methodology for assessing the competency of staff.	Revise this finding and add an option to enable individual co-permittees to provide in-house training using curriculum developed by the principal permittee in collaboration with the co-permittees.	Permit language has been revised.
22	Irvine	Finding O.76	The finding discusses the importance of cooperation by public agency organizations within Orange County that have an impact on storm water quality.	More needs to be done to secure the participation of some of the larger public agencies within the Newport Bay Watershed, such as UCI.	Encourage state institutions and other major dischargers in the watershed, such as UCI, to join the NSMP and other applicable watershed efforts.	Regional Board staff will continue to work with the stakeholders whose activities and/or discharge contributes to the selenium/nutrient impacts in the watershed.
23	Irvine	Finding R.83	The finding discusses the elimination of illegal discharges and illicit connections to the MS4.	The terms ‘illegal’ and ‘illicit’ should not be used interchangeably	Determine correct/consistent terminology and use throughout the permit.	Permit language has been revised.
24	County of Orange, Riverside County Flood Control	General comment	General comment	The proposed permit increases administrative burden.	Adjust the current reporting requirements rather than increasing the reporting requirements.	Draft permit amended to streamline reporting requirements.
25	Riverside County Flood Control	General comment	General Comment	The basis for the Riverside County MS4 Permit should be the 2002 Riverside County MS4 Permit, not the Draft OC MS4 permit	The basis for the Riverside County MS4 Permit should be the 2002 Riverside County MS4 Permit	Comment noted
26	San Bernardino Stormwater Program	I.B.12	Requires permittee to develop adequate guidelines for competency	This requires developing an entire training program to be placed upon the shoulders of the Principal Permittee	These competencies are in a large part already well-established by CASQA and other organizations. It would be appropriate for the	Although guidance documents have been created by various organizations, it is the

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			requirements for stormwater managers, inspectors etc.		Principal Permittee to coordinate only the training effort	responsibility of the Principal Permittee to collaborate with co-permittees to develop a competency program specific to the requirements within this permit.
27	Irvine	Section I.B.12	Develop guidelines for defining competencies of municipal managers and inspectors	The competency of staff and the outcome of any evaluation of competency are confidential	The permittee cannot commit to providing any competency evaluations or reporting on confidential documents that are part of an employees' performance.	The permit language has been revised, with the understanding that deficiencies in a permittee's program that are the result of either management or staff's lack of understanding of the program will result in enforcement actions.
28	Orange County-Attachment B, Riverside County Flood Control	III.3.	Discharge limitation/prohibition	Make the prohibitions consistent with the federal regulations.	Retain language from Order No. R8-2002-0010.	Language revised to be consistent with the federal regulations, 122.26(d)(2)(iv)(B)(1).
29	Orange County-Attachment B, Riverside County Flood Control	III.3.	Public education to reduce non-storm water discharges	Remove the requirements for public education and outreach to reduce non-storm water discharges.	Retain language from Order No. R8-2002-0010.	Reducing non-storm water discharges could possibly reduce the pollutant load to the MS4s.
30	Orange County-Attachment B, Riverside County Flood Control	III.3.	Categories of non-storm water	Irrigation water from agricultural sources.	Runoff from agricultural sources should be addressed through other programs.	Permit language has been revised.
31	Irvine	Section III.3.i	The discharges identified below need not be prohibited by the permittees if they have been determined	The wording reverses the presumption found in Federal regulations that these de minimus discharges are not significant sources unless a	No submitted recommendation was submitted for this comment.	Permit language has been revised.

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			not to be substantial contributors of pollutants to the MS4 and receiving waters.	finding is made to the contrary.		
32	Irvine	Section III.3.i.l	Discharges of potable water (i.e., fire hydrant flushing) would have to be addressed as a de minimus discharge.	Discharges from fire hydrant flushing would require capture, analysis and volumetrically and velocity controlled discharges.	Change III.3.i.l to existing de minimus permit requirements by cross-referencing that permit.	The proposed permit conditions for the discharge of fire hydrant flushing waters remain the same as the de minimus permit with regard to residual chlorine concentrations. The proposed language regarding volumetrically and velocity controlled to prevent resuspension of sediments has been revised to read "…prevent hydrologic conditions of concern in receiving waters."
33	Irvine	Section III.3.i.l and XXI.5	With regards to emergency fire fighting flows, where possible, when not interfering with health and safety issues, BMPs should be implemented.	BMPs should only be required during controlled fire exercises and/or training. BMPs should not be required, even as 'where possible' for emergency situations.	Delete sentence referring to implementation of BMPs during emergency fire fighting operations, as well as the requirement in XXI.5.	While the sensitivity of implementing BMPs during actual fire fighting activities is understood, it is not unreasonable to expect BMPs to be implemented where feasible to meet the Maximum Extent Practicable threshold for permittee action.
34	County of Orange-Attachment A, Riverside County Flood Control	III.3.i.c	Irrigation runoff from agricultural sources	Runoff from agricultural sources is exempt from NPDES requirements.	Agricultural sources should not be included in this category.	Permit language has been revised.
35	Irvine	Section III.3.i.c	Irrigation water from agricultural sources.	Agricultural sources are non-point source, are not subject to NPDES permits, and are not currently the subject of Waste	The category 'irrigation water from agricultural sources' should be amended to read 'irrigation water' and the category 'irrigation water	Permit language has been revised.

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				Discharge Requirements or a Conditional Waiver of WDRs. Federal regulations do not specify agricultural irrigation runoff as a de minimus discharge to MS4 systems.	from agricultural sources' should be addressed through other Regional Board regulatory mechanisms.	
36	SDGE	III.3	Prohibition of non-storm water discharges unless the following conditions are met:	As the permit is currently worded, there could be some misunderstanding that non-storm water discharges covered under a separate permit may be considered prohibited	Revise sentence to read: The permittees shall prohibit the following categories of non-stormwater discharges unless such discharges are authorized by a separate NPDES and/or the stated conditions below are met.	Permit language has been revised.
37	Cypress	III.3 (ii)a	Discharge Limitations/Prohibition: Discharges from potable water sources, including water line flushing, superchlorinated water line flushing, fire hydrant system flushing , and pipeline hydrostatic test water: Planned discharges shall be dechlorinated to a concentration of 0.1 ppm or less, pH adjusted if necessary , and volumetrically and velocity controlled to prevent resuspension of sediments.	The Orange County Stormwater program has developed BMP Fact Sheets FP-6 – Water and Sewer Utility Operation and Maintenance, FP-7 Fire Department Activities and IC-23 Fire Sprinkler Testing/Maintenance. In the absence of any Finding that existing control efforts are inadequate,	Specific requirements for the discharges identified in Section 3.ii.a should reference these Fact Sheets	Although the information contained within the Orange County Storm water program's Fact Sheets may be consistent with the requirements illustrated within this Section of the Draft Order and have been developed in order to comply with previous iterations of the Order, the Order itself sets the requirements for compliance. Fact Sheets have been prepared as a guidance tool to be used by co-permittees.
38	State Water Resources Control Board	III.3(ii)c	Dechlorinated swimming pool discharges: reduce volume and velocity to	Is the intent to prevent resuspension of sediments in the receiving water, the MS4 or the BMP?	Clarify information concerning comment and revise paragraph heading to read "Swimming Pool Discharge"	The proposed language regarding volumetrically and velocity controlled to prevent resuspension of sediments

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			prevent resuspension of sediments			has been revised to read "…prevent hydrologic conditions of concern in receiving waters." The paragraph heading as been revised.
39	Cypress	III.3(ii)c	Dechlorinated swimming pool discharges: reduce volume and velocity to prevent resuspension of sediments	Placing numeric limits for pool discharges affirms that the City is already doing by distributing the County's "Tips for Pool Maintenance" brochure.	The City wants to be certain the intent is not to make the City test each discharge or have the City require residents to obtain permits for such.	The criteria listed in this section should be used to establish municipal codes and enforcement procedures. In most cases, we do not anticipate the need for residual chlorine testing or permitting.
40	County of Orange	Section IV of the M&RP	Program Effectiveness Assessment	Use existing and newly generated data for program assessment in accordance with the CASQA Guidance.	Make program assessment requirements consistent with the recommendations in the ROWD.	The permit provides the permittees the option of using the CASQA Guidance or other technically sound methodology.
41	Orange County-Attachment B	Section VI	Reporting of State's General Permit violations.	Permittees do not enforce the State's General Permit.	Revise language as suggested.	Enforcement requirements have not changed from the 2002 permit; this approach avoids duplicative efforts and fosters cooperation among various regulatory/local agencies.
42	Irvine	Section VI.1,VI.3, VII.1	Such legal authority must address all illegal connections and illicit discharges into the MS4s, including those from all industrial and construction sites.	The legal authority documents (ordinances, etc.) give authority to the permittee to develop a program to control illicit discharges and illegal connections, but does not set forth the specific components of the program. Legal authority should not be confused with procedures and methods to accomplish compliance.	Revise the language of this requirement to indicate the role of the DAMP and LIPs in setting forth the program to address illegal connections and illicit discharges.	Permit language has been revised.

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43	Lake Forest	VI.2	The permittees shall progressively and decisively take enforcement actions against any violators of their Water Quality Ordinance	This language (progressively and decisively) creates ambiguity about what is actually required.	None offered	The language in question reflects the progressive enforcement actions as referenced in the permittee adopted Orange County Enforcement Consistency Guide.
44	Anaheim, Villa Park, Cypress	VI.2	The permittees' ordinance must include adequate legal authority to enter, inspect, gather evidence (pictures, videos, samples, documents, etc.) from industrial, construction and commercial establishments	Concern about search and seizure laws and the necessity to obtain a Court Order are being looked into, should the current iteration of the proposed permit language remain as is. Villa Park states: Proposed language may be viewed as a violation of 4th amendment	Therefore, in order to ensure inspections may be conducted as intended through legal authority via municipal codes, the permit language should be retooled to avoid unnecessary efforts	Permit language has been revised.
45	Irvine	Section VI.2	The permittee's ordinance must include adequate legal authority to enter, inspect and gather evidence from industrial, construction and commercial establishments.	The City agrees with the County comments that this provision could impose entry requirements on the co-permittees that violate the 4th Amendment rights of property owners	"The permittees shall carry out inspections, surveillance, and monitoring necessary to determine compliance with their ordinances and permits. The permittees' ordinance must include adequate legal authority, to the extent permitted by California and Federal Law and subject to the limitations on municipal action under the constitutions of California and the United States, to enter, inspect and gather evidence (pictures, videos, samples, documents, etc.) from industrial, construction and commercial establishments…"	Permit language has been revised.
46	Lake Forest	VI.3	"these penalties shall be issued in a decisive manner	The term *decisive* creates ambiguity about what is actually required	None offered	The term decisive was used to infer a directly definitive, results-oriented enforcement process.
47	Villa Park, Cypress, Laguna Hill	VI.6	Permittees are to provide quarterly notifications w/	Quarterly reporting of enforcement activity is an administratively burdensome	Maintain current enforcement activity reporting requirements	Reporting requirements have not changed with respect to the information to be

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			inspection results to RB, for all inspections conducted at sites covered under the Statewide General Industrial and Construction Permits.	requirement for medium and small cities with little to no staff resources.		submitted. However, the frequency has been changed. Historically, many permittees have submitted inspection information on a monthly basis or immediately following the inspection event.
48	Fullerton, Costa Mesa, Brea, Irvine	Various	Additional reporting requirements throughout various Sections	The draft Order requires additional reporting to the Regional Board staff. The City believes that adjusting the existing reporting processes rather than creating additional reporting requirements is the most effective approach to increasing transparency and accountability	None	Information collected during the (third term permit) MS4 audits, concluded that additional reporting requirements were warranted. In order to ensure compliance with data collection requirements within the permit, various reporting requirements have either been sustained or introduced accordingly
49	Orange County-Attachment B	Section VII.5	Trash Characterization	Each Permittee should not be required to characterize trash.	Principal Permittee should be responsible for this.	While trash sources may not significantly vary among municipalities, the relative quantities of trash type will vary between municipalities and even within municipalities. The purpose of this study is to focus municipal resources (education and enforcement) on the most prevalent trash sources within the municipality in an effort to avoid a possible, future trash TMDL.
50	Orange	VII.5	Permittees to review their trash control ordinance. To determine the need for	Is the intent of the Permit to have each permittee carry out this requirement? It makes no sense to have each permittee conduct a	Revise the paragraph to require the principal permittee instead of the co-permittees to conduct the county-wide study over the 5 year	Permit language has been revised. See response to Comment #49

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			any revisions/ determine sources and proper BMPs to control urban runoff. Include findings in the Annual Report	county-wide study, since trash sources do not vary significantly among municipalities	permit term to characterize trash sources	
51	Orange, Cypress, Riverside County Flood Control	VIII.2	Construction site inventory to include all sites, within each co-permittee's jurisdiction for which building or grading permits have been issued where activities at the site include …..	The first part of the paragraph requires the inventory list is limited to sites with issued building or grading permits that raise concerns regarding water quality, but later contradicts itself by stating "all sites". This would include plumbing, encroachment or other indoor permits.	Change language to make it not contradictory. Exclude the GIS requirement from construction projects within the public right of way as well.	Permit language has been revised. .
52	Irvine	VIII.2	Construction site inventory to be maintained and updated quarterly	This requirement will be burdensome and unnecessary as it will just be created to satisfy a draft tentative order. Since construction project timelines are not short enough to result in meaningful additions to the inventory within the period of three months.	Updates should only be required on a biannual basis (in September, preparatory for the rainy season and rainy season inspections).	Maintaining and updating the site inventory quarterly is to ensure that records remain current concerning the regular and constant oversight of construction activities within each permittee's jurisdiction.
53	Irvine	Section VIII.4	Each permittee shall conduct construction inspections for compliance with its ordinances (grading, Water Quality Management Plans, etc.), local permits (construction, grading, etc.), the Model Construction Program…	Water Quality Ordinances do not include a reference to project WQMPs, which are post-construction documents.	Remove parenthetical entries. "Each permittee shall conduct construction inspections for compliance with its ordinances, local permits, the Model Construction Program…"	Permit language has been revised.

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54	Riverside County Flood Control		Construction site inspection requirement to include review of the Erosion & Sediment Control Plan	In addition to requiring a significant increase in the level of training and expertise of construction site inspectors, this requirement will significantly increase the amount of time needed for each construction site inspection	Exclude requirement from the draft Riverside County MS4 permit	The current (2002) OC MS4 permit already requires, inspection staff to have sufficient expertise in construction inspection processes as they relate to water quality and storm water related issues.
55	Lake Forest	VIII.6	"[e]ach permittee shall respond to complaints received by a third party in a *timely* manner to ensure that the construction sites are not a source of pollutants in the MS4s and the receiving waters	The term "timely" creates ambiguity about what is actually required	None offered	Response to complaints must be handled in order of severity, with respect to the sites' potential to act as a pollutant source to the MS4. Therefore, the term "timely manner" was listed with the understanding that municipal staff receiving the complaint would be properly trained and equipped to determine how potentially grievous the pollutant threat could be and address it accordingly. The setting of an arbitrary time limit (e.g., within 1 business day) could put permittees in violation of the permit by not addressing very low priority complaints in that time limit.
56	County of Orange – Attachment A	Sections VIII, IX and X	Inspection requirements	The inspection requirements are well beyond federal law.	Make requirements in the permit consistent with the federal laws and regulations.	The inspection requirements are consistent with the federal laws and regulations. See 40CFR112.26(d)(2)(F) and the MEP provisions in Clean Water Act at Section 402(p)(3)(B)(iii).
57	County of Orange – Attachment A	Sections VIII, IX and X	Inspection requirements	Requirements beyond the federal requirements tantamount to unfunded mandate.	Unfunded mandates should not be part of this permit.	The permit requirements are consistent with the federal laws and regulations and,

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						therefore, are not unfunded mandates.
58	County of Orange – Attachment A	Sections VIII, IX and X	Inspection requirements	The inspection requirements violate the fourth amendment.	Make changes to the inspection requirements consistent with the state and federal laws and regulations.	Permit language amended.
59	San Bernardino Stormwater Program	VIII,IX,X	Inspection requirements	Requirement within these sections have new specific actions, such as electronic database, to check if sites have filed NOI, photos that need to be taken and included in the database, requirements for on-site enforcement actions.	We suggest that the permittees be allowed to prioritize and take enforcement actions based on their own criteria.	While the permittees have the ability to prioritize enforcement activities based on their own criteria to a certain extent, the Regional Board still has the obligation to set a minimum standard in the permit to ensure a level of consistency amongst the permittees.
60	Orange	IX.2	Facilities Covered under the General Industrial Permit are automatically considered as High Priority and therefore are required to be inspected.	History has shown that once a facility has been inspected at least once, there is an increased awareness of water quality impacts and facilities will implement BMPs to minimize storm water and non storm water discharges.	Allow redesignation of mandatory high priority facilities based on the suite of factors in the DAMP used to rank a facility.	The criteria by which facilities are identified for coverage under the General Industrial Permit are based on either their industry's potential to pollute and/or the actual exposure of materials, wastes, or processes to storm water. This criteria alone is sufficient for a mandatory 'high' priority.
61	Irvine	Section IX.3	Industrial inspections shall include a review of material and waste handling and storage practices, written documentation of pollutant control BMP implementation and	The written documentation, in the form of storm water pollution prevention plan, is only required for facilities with industrial storm water permits. The burden of SWPPP review for compliance with the State's General Industrial permit should remain	Please clarify the intent of the industrial facility document inspections consistent with the City's comments.	Permit language has been revised to clarify that the '… written documentation of pollutant control BMP implementation and maintenance procedures …', refers to one of the four items required to be in a permittee-

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			maintenance procedures and digital photographic documentation for any water quality violations, as well as, evidence of past or present unauthorized, non-storm water discharges and enforcement actions issued at the time of inspection.	with the Regional Board staff. The City's inspections should continue to assure no ICs/IDs and compliance of facilities with City water quality ordinances and requirements		prepared inspection report. Those four items include: a written review of material/waste storage procedures; the written documentation of BMP implementation; photographic documentation of evidence of discharges; and, a listing of enforcement actions resulting from the inspection.
62	Westminster	IX.6 & X.5	Electronic inspection database submittal requirement in each annual report for Industrial and Commercial inspection programs	Clarify if permittees should submit only inspection inventory or the entire inspection database for these categories.	None. Request for clarification only	Permit language has been revised to allow the submittal of all inspection documentation/information in hardcopy form if a municipality's database uses a proprietary program (not Access or Excel compatible)
63	County of Orange	Section X	Commercial inspections	The permit extends the regulatory reach of local jurisdictions without technical justification.	Unjustified inspections should not be required.	Quantifiable inspection requirements are included to ensure an equitable level of effort across all permittees.
64	Irvine	Section X.1	Each permittee shall continue to maintain and quarterly update an inventory of the types of commercial businesses listed below.	Section X.1 requires 11 new, additional categories to be added to the commercial facilities inventory. It does not make sense to increase the commercial facility inspection burden so significantly in the time of budget constraint. Further, there's no indication in the ROWD that commercial facilities are currently such significant sources of pollutants to warrant this increase in inspections.	The new categories should be deleted until such a time that these types of facilities have been determined to contribute a significant pollutant load to the MS4.	The Fact Sheet and the findings have been revised. The revised permit language requires the Principal Permittee to prioritize these new categories based on potential threat to water quality.

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65	Orange County-Attachment B	Section X.1	Municipal inspections of commercial facilities.	There are 11 new categories included in the draft permit with out any technical justification.	These resource intensive inspection requirements should be deleted.	The Fact Sheet and the findings have been revised. The revised permit language requires the Principal Permittee to prioritize these new categories based on potential threat to water quality.
66	Orange County-Attachment B	Section X.1	Commercial inspection frequencies	Some of the facilities listed under the commercial inspection program should be under the industrial program.	Move industrial type of facilities under the industrial program.	Permit language has been revised.
67	Orange County-Attachment B	Section X.2	Commercial inspection frequencies	The permit arbitrarily assigns priorities for inspections.	The Permittees should be allowed to develop a prioritization system.	Audits conducted by Regional Board staff indicated that some Permittees were ranking all their commercial facilities as "low" even though similar facilities were ranked as "high" by other Permittees.
68	Orange County-Attachment B	Section X.8	Mobile businesses	No technical basis. Difficulty in regulating mobile businesses.	Principal Permittee to develop a pilot program.	A uniform prioritization criteria and inspection requirements are acceptable alternatives. Permit language has been changed.
69	Villa Park, Yorba Linda, Tustin	X.1	Permittees to maintain and update commercial facility inventories quarterly, in a computer-based database system with all third term permit inventory criteria, as well as information on ownership, size, location, GIS w/ Lat/Longitude	Quarterly updating of the commercial facilities database and the implementation of GIS tracking of commercial fixed facilities is a burdensome requirement that for medium to small cities with little to no staff resources is not viable	Maintain current commercial facility tracking requirements	Third term permit recommended annual updating of commercial inventories with GIS tracking capabilities. During the 3rd term permit, MS4 Audits conducted by Regional Board staff indicated the need for more regimented oversight regarding commercial inventory management. Therefore this recommendation transitioned into a requirement within the fourth term permit.

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70	Laguna Hills	X.1	Permittees to maintain and quarterly update an inventory of commercial facilities within its jurisdiction.	This section should be modified to allow the permittees to update the commercial inventory annually and submit it with the annual NPDES report	The requirements within this section should not be changed from the current 3rd term permit.	The purpose of maintaining an updated inventory list is to ensure that adequate oversight controls are in place. During the 3rd term permit, MS4 Audits conducted by Regional Board staff indicated the need for more regimented oversight regarding commercial inventory management.
71	Irvine	Section X.2 and X.3	Commercial facility inspection criteria	The mandate that 10%, 40% and 50% of commercial facilities be ranked high, medium and low is not based on technical data or on demonstrated risk posed by commercial facilities.	The DAMP and LIP provisions should instead be reviewed and revised to assure that the criteria result in adequate oversight. Secondly, high ranked sites should be inspected once per permit cycle rather than once a year and medium and low site inspections be dropped.	During the third permit term, the permittees were given the opportunity to design a commercial facility ranking system based on a number of criteria including type/size of activity, potential for pollutant discharge and history of pollutant discharges. Despite this opportunity, in the most recent annual report, some permittees are reporting few or no high priority commercial sites out of hundreds to thousands of sites that met one or more of the 11 categories listed in the third term permit. The 10/40/50 breakdown should be used to ensure that the 10% of commercial facilities with the highest potential for pollutant discharge be ranked 'high' and be inspected annually, similarly for the medium and low priority rankings.

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72	OC Public Works, Huntington Beach, Costa Mesa, Orange, Brea, Westminster, Villa Park, Lake Forest, Cypress, Laguna Hills, Yorba Linda, Tustin	X.2	10% of all commercial sites (excluding restaurants) shall be ranked "high" , 40% ranked medium and the remaining 50% ranked low	This new requirement will increase the annual inspection requirements to a point where resources are incapable of complying with the requirements. The inventory should be determined solely on a risk-based instead of a mandatory curve-based criterion.	Each permittee conduct inspections of its commercial facilities as indicated below. To establish priorities for inspection, the perrmittees shall continue to prioritize commercial facilities/businesses within their jurisdiction as a high, medium or low threat to water quality based on such factors as the type, magnitude and location of the commercial activity, potential for discharges, proximity and sensitivity of receiving waters, material used and wastes generated at he site. Within 6 mos. Of the adoption of this order, the Permittees shall review their existing prioritization system, criteria and results based on the inspections and determine if any modifications are necessary. The modifications shall be completed within 6 months of the determination and reported on in the annual report.	During the 3rd term permit, MS4 Audits conducted by Regional Board staff indicated the need for more regimented oversight regarding commercial inventory management and inspections within this section. The percentages indicated within this section were developed following extensive review of inspection information within PEAs submitted by co-permittees during the 3rd term permit.
73	Irvine, Westminster	Section X.3 and X.5	Commercial facility inspection documentation	The commercial inspection section that requires photographic documentation for all aspects of the inspection is too onerous.	Photographic evidence should only be required in the case of water quality ordinance violations and only in manner consistent with local, state and federal ordinance, regulations and laws.	Photographic evidence of all aspects of commercial inspections will assist permittees in supporting the appropriate enforcement action and will provide evidence during Regional Board audits that site conditions during inspections by municipal staff, are receiving the appropriate enforcement actions, if any.

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74	County of Orange	Section X.8	Mobile businesses	A new regulatory oversight is prescribed for mobile businesses.	The permittees have already developed BMPs for these businesses; additional requirements are not warranted.	Complaints received in the Regional Board office and Board staff's field observations indicate that these discharges have not been fully eliminated and additional measures are needed to control discharges from mobile businesses.
75	Villa Park, Cypress, Laguna Hills	X.8	Mobile businesses shall implement appropriate control measures within 3 months of being notified by permittees	It's unrealistic to expect that over any period of time it would be possible for the principal permittee to notify all mobile businesses operating within the County, of minimum source controls and pollution prevention measures that they must develop and implement.	…modify the requirement to read that "…the principal permittee shall utilize all reasonable resources to notify mobile businesses…"	Permit language has been revised.
76	ProntoWash	X.8	Mobile businesses shall implement appropriate control measures within 3 months of being notified by permittees	Require mobile operators to be inspected and trained in water quality control measures during the business licensing process.	During the licensing process, the mobile operations should be inspected and the operators should be trained on water quality protection procedures.	Many municipalities currently do not issue business licenses. Listed within Section X.8, are requirements for the permittee to distribute educational materials to businesses as well as a training program requirement.
77	Lake Forest	X.8	Mobile businesses shall implement appropriate control measures within 3 months of being notified by permittees	The regular, effective practice of unannounced inspections is difficult to impossible to implement. Identifying mobile businesses is difficult because they are often not permitted or licensed. Mobile businesses are transient in nature, advertise a mobile phone number as the only means of contact and may have geographic scope of several cities or the entire region.	Remove the mobile business requirements from the draft permit and instead, require the permittees to develop their own program for implementation during the next permit cycle.	Permit language has been revised.

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78	County of Orange, Villa Park, San Bernardino Stormwater Program	Section XI	Each permittee shall develop and implement a residential program to reduce the discharge of pollutants from residential facilities to the MS4 to MEP…	No technical justification for the residential program. Remove the Residential Program from the Order completely	Recognize the fact that the current public education programs are working. Remove the Residential Program from the Order completely.	Despite implementation of public education programs, residential areas continue to be a significant source of pesticides, herbicides, nutrients and nuisance flows. Additional actions are necessary to further address these problems.
79	Irvine	Section XI.2	Identification of residential areas and activities that are potential pollution sources and requiring residents to implement pollution prevention BMPs.	Many aspects of this proposed requirement are already covered by Public Education activities. Further it may require passage of new ordinances forcing residents to implement specific minimum BMPs and those types of ordinances are unpopular.	Retain the residential program as part of the Public Education section and revise the key provision in the draft permit to : "The permittees shall ~~require~~ *encourage* residents to implement pollution prevention measures via the public education and outreach Program …".	Despite implementation of public education programs, residential areas continue to be significant sources of pesticides, herbicides, nutrients and nuisance flows. Additional programs are needed to address these problems. Some changes made to the provisions.
80	Orange County-Attachment B,	Section XI.2	Residential program	The requirement for a residential program is duplicative of existing public education and outreach activities.	Avoid duplicative requirements.	Permit language has been amended.
81	Anaheim, Fullerton, Costa Mesa, Brea, Cypress, Laguna Hills, Yorba Linda, Tustin	XI.2	The permittees shall require residents to implement pollution prevention measures	Requiring residents to implement best management practices is problematic	Change the wording to state: "The permittees shall *encourage* residents to implement pollution prevention measures."	Permit language has been revised.
82	Cypress	XI.3	The permittees, collectively or individually, shall facilitate the proper collection and management of used oil, toxic and hazardous materials, and other household wastes.	The city is concerned with the funding for conducting collection events.	The current County of Orange Household Hazardous Waste Collection Program has been working well since its implementation and agencies continue to do a good job making residents aware of this service. Change language from "shall" to "…***should** facilitate the proper collection and management*."	Requirements within this section have not changed essentially from requirements within Section I.4 of the 3rd term permit.

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83	Irvine	Section XI.4	Control measure requirements for common interest areas and areas managed by Home Owner Associations.	A limited pilot HOA program has been initiated by the City to educate certain property managers on the economic and water quality benefits of improved irrigation and landscaping practices. But the draft tentative order as currently written mandates that co-permittees must develop and implement new BMPs for common interest areas, including, we presume, structural treatment control BMPs as well as source control BMPs.	Revise the first sentence of this section as follows: "The permittees shall develop ~~and implement~~ a public education and outreach component to encourage owners …".	The tentative order requires the permittees to develop and implement a public education and outreach component to <u>encourage</u> HOAs to implement BMPs. Nothing in that section requires permittees to build or maintain BMPs on private property.
84	Cypress, Irvine	Section XII.A.2	Inclusion of LID requirements in WQMPs.	The 6-month time frame for this requirement is too aggressive and does not allow time to collect info on watershed characteristics, stakeholder participation and the time required for adoption of the revisions by local governments.	A more reasonable time frame should be established.	Much of the groundwork for this requirement has been completed through a series of meetings between permittees, environmental NGOs and development representatives. It should be noted that this deadline refers to the default plan. Watershed specific plans can be delivered after that date. Some changes have been made to the new development section of the permit.
85	Irvine	Section XII.A.4	The first annual report following adoption of this permit must include a review of the inclusion of LID principals in the General Plan and other city documents.	This requirement is out of sync with the actual requirements for updating the DAMP, LIPs and model WQMPs.	Revise the requirements so that a single, integrated update of these documents is implemented.	Permit language has been revised.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
86	Irvine	Section XII.B.2	The list of priority development projects requiring a WQMP	Items f and g of this section would require treatment control BMPs for single-family homes, if they were large enough. This would be too much of a burden on homeowners and on City staff required to review and inspect these BMPs.	Do not require WQMPs or treatment control BMPs for single-family homes.	This permit requirement will only affect projects on hillsides with a natural slope of 25 percent or more and projects that are within 200 feet of an Area of Biological Significance (ASBS). As such these projects need the extra level of protection afforded by the development of a WQMP and implementation of appropriate control measures.
87	Irvine	XII.B.2.c	Priority Development Projects would include commercial/industrial developments greater than 10,000 square feet.	The threshold has been lowered in this permit from 100,000 square feet to 10,000 square feet.	The fact sheet should explain the basis for lowering the threshold criterion.	Fact sheet has been revised to provide basis.
88	Irvine	XII.B.2.i	Priority Development Projects would include streets, roads, highways and freeways of 5,000 square feet or more.	Road projects as small as 5,000 do not and cannot properly involve changes to the drainage facilities. Further it is not feasible to implement a 5%EIA or LID BMPs for the 85^{th} percentile design treatment volume.	Reconsider this requirement.	The permit will be revised including the incorporation of the concepts presented in "Managing Wet Weather with Green Infrastructure: Green Streets" (U.S. EPA, 2008)
89	Irvine	XII.B.5.a	Use of structural infiltration treatment BMPs shall not cause or contribute to groundwater water quality objective exceedances.	In the Newport Bay Watershed, there are areas where the use of any infiltration BMPs will result in mobilization of nitrogen and/or selenium.	Explicitly preclude the use of LID BMPs and exempt projects from LID implementation and hydromodification control performance standards in areas with shallow groundwater, polluted groundwater, inappropriate geotechnical conditions or rising groundwater.	The current Draft Permit language already contains sufficient warnings regarding the use of infiltration BMPs, including LID-type BMPs, without having to specifically add this language.
90	NAIOP	Section XII.C	Treatment and Low Impact Development (LID) BMPs.	It appears that the permit is biased against the use of a watershed-based or regional type solutions.	Allow as much flexibility as possible in order to achieve the permit's goals across the jurisdiction regulated by the permit.	Comment noted. The permit provides sufficient flexibility for regional and sub-regional type solutions.

OC MS4 Tentative Order No. R8-2008-0030 (R8-2009-0030)
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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
91	Irvine	XII.C.1	Requirements that LID site design principals be implemented to reduce runoff to the maximum extent practicable.	The list of site design BMPs provided is a confusing mix of goals, tasks and work products that don't provide a clear basis for compliance.	Separate the provisions to distinguish between recommended site design BMPs and other goals for the new development and redevelopment program.	Permit language has been revised.
92	Irvine	XII.C.2	Requirements for source control BMP implementation.	It is not clear why the major discussion of LID also includes prescribed source control BMPs.	Section XII.C.2 should be deleted from the current section and proposed as a separate section.	While the primary focus of Section C is on LID BMP implementation, source control BMPs, particularly when they're implemented through proper site design, play a play a role in LID.
93	Irvine	XII.C.4	Conditions for the substitution of treatment control BMPs for LID measures.	One of the conditions is for EIA to be 5% or less. How does one achieve an EIA of 5% or less without implementing LID?	Delete this section.	Permit language has been revised.
94	Irvine	XII.D	Hydromodification	It is not clear how the 5% or less hydrologic impact standard would be measured and does the standard allow for dense infill and transit oriented development as required by SB 375?	Revise and clarify section.	Permit language has been revised.
95	Irvine	XII.E.2	Structural treatment control BMP requirement met by regional treatment systems.	No mention of obtaining Executive Officer determination on regional treatment systems.	Please revise to clarify the need for Executive Officer approval of common project BMPs.	Permit language has been revised.
96	Irvine	XII.G.3	Prior to occupancy, permittees shall verify through visual observation that the BMPs are operational.	It will be impossible to ascertain the operation of BMPs prior to occupancy unless it rains between construction and occupancy	Revise to verification that BMPs are built according to approved plans prior to occupancy.	Permit language has been revised.
97	Irvine	XII.H	Change of ownership and recordation	The City already has a non-recorded mechanism that tracks the transfer of long-term maintenance and operation responsibilities from a developer to an appropriate operator upon completion of	Delete reference of recording any documents and explicitly allow other methods of tracking ownership and responsibility.	Permit language has been revised.

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				development. The recordation requirement should be left to the discretion of the permittees.		
98	ConTech	Section XII	5% Effective Impervious Area (EIA)	Reliance on a 5% EIA standard is inappropriate. The water quality benefits of applying a 5% EIA standard on a site-by-site basis are unknown.	Support the approach outlined in the January 2009[1] white paper. Use delta volume (post minus pre-development) from the water quality design storm event.	Permit language has been revised based on the water quality design storm event.
99	ConTech	Section XII	Treatment and Low Impact Development (LID) BMPs.	Treatment and LID BMPs inspection and maintenance requirements are not well defined.	All water quality and/or water quantity control BMPs should have maintenance and inspection requirements.	Permit language has been revised.
100	ConTech	Section XII	Post-construction	There is no standard for selection of post-construction BMPs	Provide standards for selection of post-construction BMPs.	There are a number of handbooks (e.g., CASQA[2] BMP handbooks) available for this purpose.
101	ConTech	General	Potential pollutants of concern	Match potential pollutants with control BMPs.	The permit should require that pollutants be controlled by matching with appropriate BMPs.	There are a number of handbooks (e.g., CASQA[3] BMP handbooks) available for this purpose.
102	NRDC/OCC[4]	Section XII	Need for LID metrics	To ensure compliance with the Clean Water Act, quantifiable measures must be included.	Support the use of an EIA limitation in the permit; a 3% EIA limitation is recommended.	Comment noted. The 5% EIA metric in the permit has been replaced with a volume capture metric.
103	NRDC/OCCCI CWQ	Section XII	EIA definition	Change the EIA definition to include full onsite retention of a design storm event. EIA is not clearly defined.	The design storm should not be the delta volume from a 2-year storm event; it should be the full volume. Include a design storm volume.	The draft permit has been amended to incorporate appropriate design storm criteria.
104	NRDC/OCC	Section XII	EIA definition	The tern "percolate" is not defined.	Revise the permit such that BMPs are required to have the capacity to "infiltrate, harvest for reuse, or evapotranspire".	Permit language has been changed.

[1] January 2009 white paper=
[2] CASQA=California Stormwater Quality Association
[3] CASQA=California Stormwater Quality Association
[4] OCC=Orange County Coastkeeper

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
105	NRDC/OCC	Section XII	Waiver Provisions	Existing waiver provisions are very broad. The permit's waiver provisions should include a floor for all projects to meet.	The permit should include a provision to implement all feasible LID BMPs and must include a provision for offsite mitigation of storm water not retained onsite. The permit should define technical infeasibility. Rewrite the waiver provisions to include establishment of an "urban runoff fund". Include time limitations for the expenditure of funds.	Permit language has been revised to provide clarification.
106	NRDC/OCC	Section XII	Waiver provisions	The permit must impose limits on water quality credit system to ensure equivalent benefits within the watershed.	Having a cap of something like 50% or less of the volumetric requirement should be considered.	Waiver provisions have been revised.
107	NRDC/OCC	Section XII	Prioritize LID BMPs	A hierarchy of BMPs should be included.	Include a preferred approach of BMPs.	Permit language has been revised.
108	NRDC/OCC	Section XII	Treatment Control BMPs	LID should not be a substitute for treatment control BMPs.	Any project exercising this option should be required to provide 1:1.5 mitigation offsite.	Permit language has been revised to provide clarification.
109	NRDC/OCC	Section XII	Hydrologic conditions of concern	No waiver should be provided for discharges to engineered hardened conveyance channels.	Do not allow this waiver provision.	The waiver provision has been revised.
110	NRDC/OCC	Section XII	Priority projects	Support the inclusion of projects with a threshold of 5,000 sq ft impervious area.	Add clarifying language to Section XII.B.2.(a)	Permit language has been revised.
111	NRDC/OCC	Section XII	Groundwater Protection	The 10' separation requirement may be overly restrictive.	A 5' separation requirement may be appropriate.	The 10' separation is a conservative approach; there is an option for a case-by-case consideration of other options.
112	NRDC/OCC	Section XII	LID Metrics	A critique[5] of the January 2009 white paper (see footnote 1).	The critique provides some arguments in support of a 3-5% EIA metric and provides an analysis of some of the other findings of the January 2009 white paper (see footnote 1).	The January 2009 white paper and its critique have been considered in the revision of some of the LID provisions in the permit.

[5] Critique of Certain Elements of "Low Impact Development Metrics in Stormwater Permitting" by Dr. Richard Horner.

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113	CICWQ[6]	Section XII	LID/Regional BMPs LID BMPs should be preferred	Support LID; regional BMPs and off-site solutions should be considered.	Both provisions are in the current draft.	Comments noted.
114	CICWQ	Section XII	LID design storm	A 2-year, 24-hour design storm is not appropriate.	Consider a design storm as specified in the DAMP.	Permit language has been revised.
115	CICWQ	Section XII	LID	LID BMPs should be the preferred approach.	LID BMPs should be required of all projects.	Permit language revised.
116	CICWQ	Section XII	HCOC	HCOC should be considered on a watershed specific basis.	A technically sound hydromodification plan should be permitted.	Permit language has been revised.
117	CICWQ	Section XII	Watershed Master Plan	Support such a plan.	Include a provision in the permit to require development of a watershed master plan or plans.	Permit language has been revised and a new section has been added.
118	NAIOP	Section XII	Watershed Master Plan	The entire issue surrounding hydromodificaton, infiltration and addressing water quality is very complex. The draft permit seems to want to approach it with a focus on a project by project basis.	Watershed Master Plans can be developed such that water resource goals can be integrated to address water quality, hydromodification, water supply and habitat issues.	Comment noted. Some changes have been made to the new/re-development section of the permit.
119	CICWQ	Section XII	Capture volume	Permit should not require make up of capture volume off site or require a fee.	Delete all requirements for off site mitigation.	The preferred option is 100% LID implementation on site. Off site mitigation is one option where full on site implementation of LID BMPS are not feasible.
120	CICWQ	Section XII	LID feasibility	Permittee should decide whether LID is feasible.	Permittees should have the option to require conventional or LID BMPs on a site-specific basis.	LID BMPs are cost effective and provides water quality and quantity benefits. As such, LID should be the preferred option. Permit does provide other options.
121	CICWQ	Section XII	LID guidance	Additional time is needed to develop LID guidance	Provide 12 months to develop LID guidance and revise WQMP.	Much of the required information is already in the WQMP and six months should be enough to consolidate readily available information.

[6] CICWQ=Construction Industry Coalition on Water Quality

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122	CICWQ	Section XII	WQMP Contents	Revise the requirements specified in the draft permit for revising the WQMP.	Delete Section XII.B.3(a) of the permit.	While some revisions to the permit have been incorporated, Section XII.b.3(a) is still applicable.
123	CICWQ	Section XII	Design volume	Capture volume should be SUSMP volume.	Delete references to 5% EIA and include a capture volume design based on the SUSMP design criteria.	The design volume has been changed to SUSMP criteria.
124	CICWQ	Section XII	HCOC	Hydromodification control strategies should be those recommended in the GeoSyntec white papers[7].	Use control strategies as defined in Attachment 4 (see footnote 7).	Some changes have been made to the permit based on this white paper and other discussions at the stakeholder meetings.
125	CICWQ, NAIPO	Section XII	Areas of agreement	1) EIA or other metrics may be used for LID. 2) Capture volume design may be based on WQMP criteria. 3) LID BMPs should be prioritized. 4) Offsite mitigation needed if on site treatment is not provided		Comments noted and agreed upon items are reflected in the revised draft.
126	County of Orange	Section XII.G	Field verification of BMPs	The requirement to inspect treatment control BMPs is burdensome.	Allow self certification and/or third party verification.	An option is added for self-certification and/or third party verification.
127	County of Orange	Section XII	LID/HCOC	The Model Water Quality Management Plan addresses LID and HCOC; additional mandates and metrics need careful consideration.	Areas of agreement: A performance standard other than the 5% EIA. Water quality design volume at 85th percentile. Prioritize LID BMPs.	LID and HCOC sections have been amended to reflect areas of agreement and to provide clarity.
128	County of Orange-Attachment A	Section XII	Land use authority/LID	The permit intrudes upon local land use authority.	Requirements, such as the 5% EIA requirement, are in contravention to the separation of powers.	As an agency of the State of California, the Regional Water Board has full legal authority

[7] Orange County MS4 Permit Stakeholder Sub-Group Examining LID BMP and Hydormodification Control Sizing Alternatives, prepared by Geosyntec for the January 27, 2009 Sub-Group meeting.

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						to implement LID requirement in this permit, including the 5% EIA requirement. Furthermore, the 5% EIA requirement was one of the options provided as a quantifiable measure for determining compliance with the LID/HCOC provisions of the permit. Other options were also provided in the permit. Providing several tools for compliance determination does not intrude into local land use authority. (The 5% EIA requirement has been amended.)
129	County of Orange-Attachment A	Section XII	Land use authority/LID	Prescribing a method of compliance is a violation of Section 13360 of the Water Code.	Do not specify a method of compliance.	As indicated above, the 5% EIA was one of the tools for compliance determination. Further, the Regional Board is well within its legal authority to determine what is included in the MEP standard.
130	Orange County-Attachment B	Section XII	New Development/re-development	Revisions to proposed land development provisions are needed.	Revise “grandfathering” provision.	Permit language has been revised.
131	Orange County-Attachment B	Section XII.A.2	WQMP guidance	Revisions should be in the LIP.	Modify permit language.	Permit language has been revised.
132	Orange County Attachment B	Section XIIA.6	CEQA review	Annual review of CEQA process is unnecessary.	Modify permit language.	Permit language has been revised.
133	Orange County Attachment B	Section XII.B.2	Commercial/industrial development	The threshold has been changed w/o technical justification.	Provide justification for changing it from 100,000 to 10,000 square feet.	Fact Sheet has been revised.
134	Orange County Attachment B	Section XII.B.2.(c)	Streets, roads and highways	The LID provision is difficult to implement.	Make it consistent with the U.S. EPA requirements.	Permit language has been revised.

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135	Orange County Attachment B	Section XII.B.2.(j)	Retail gasoline outlets	The DAMP includes BMPs for these types of facilities.	Avoid duplicative efforts.	The BMPs in the DAMP, along with LID and other requirements, should be considered for these types of facilities.
136	Orange County Attachment B	Section XII.B.3.	WQMP goals	Goals are written as specific requirements.	Revise permit language.	Permit language has been revised.
137	Orange County Attachment B	Section XII.B.5	Structural infiltration BMPs	No technical basis for the 10 feet separation for infiltration systems, light industrial category and for high vehicular traffic.	Consider the proposed regulations developed by State Board for onsite wastewater treatment systems.	Permit language provides for other options on a case-by-case basis.
138	Orange County Attachment B	Section XII.B.7	WQMP for non-priority projects	Certain non-priority projects may not require a WQMP.	A WQMP should not be required of all projects.	The permit language provides other options.
139	Orange County Attachment B	Section XII.C.1	LID design principals	The design BMPs is a confusing mix of goals, tasks and work products.	Revise the list.	Permit language has been revised.
140	Orange County Attachment B	Section XII.C.2	LID site design	Source control BMPs should not a part of this discussion.	Should delete this section.	Permit language has been revised.
141	Orange County Attachment B	Section XII.C.3	LID/EIA	5% EIA is not appropriate.	Use other LID metric.	Permit language has been revised.
142	Orange County Attachment B	Section XII.C.4	Substitution of LID/treatment controls	This provision, as written, does not appear to be correct.	Provide clarification.	Permit language has been revised.
143	Orange County Attachment B	Section XII. D.1	HCOC	An assessment of a project's impact on the hydrologic regime should not be required for all projects.	For some projects, there may not be a hydrologic condition of concern.	Permit language has been revised.
144	Orange County Attachment B	Section XII.D.2	HCOC	5% EIA should not be the metric for hydrologic conditions of concern.	Express the metric in terms of runoff volume.	The metric for hydrologic condition of concern has been changed.
145	Orange County Attachment B	Section XII.D	HCOC	An additional provision should be added to this section to include HCOC mapping as an option.	Add an interim provision till development of an appropriate LID metric.	Permit language has been revised.

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146	Irvine	XIII.J.1	The LID and hydrologic conditions of concern provisions are not applicable to projects that have an approved WQMP as of the date of adoption of this order.	Under the DAMP and LIPs, project WQMPs are prepared at a conceptual level to be used as planning documents and at a project level, to implement the concept project WQMP planning document. It is unclear whether the conceptual level WQMPs will be grandfathered in as were the land use approvals in the 2002 permit.	Revise to specify land use approvals that will determine development projects that are grandfathered and those that are not.	Permit language has been revised to further identify the level of approval/stage of planning where the requirements of this permit do not apply.
147	Irvine	XIII.3	Public education requirements include making 10 million impressions per year.	There must be a clear definition for an impression. Currently an impression can consist of anything from driving past a pollution prevention banner to and extended face-to-face interaction with a member of the public.	Consider a more effective way of evaluating the effectiveness of a public education program rather than relying on impressions. If impressions must be used, develop a standardized method of determining what qualifies as an impression.	While it is agreed that a more precise method of measuring the impacts of each and every public education interaction would be advantageous, trying to evaluate the effectiveness of City bus placards (depends on the route of the bus), City bill mailing inserts (determining percentage of inserts dumped without seeing, glanced at or actually read), etc., may be more tedious.
148	County of Orange-Attachment B	Section XIII.4	Public Education and Outreach	Requirements for annual business-related workshops may not be very useful.	Suggest modifying the language to include chamber of commerce or other outreach efforts.	Permit language has been revised.
149	County of Orange-Attachment B	Section XIV	Municipal facilities	Annual inspection requirement should be only for open channel systems.	Change annual inspection requirements to open channels only.	Permit language has been revised.
150	Irvine	XIV.7	Report on the effectiveness of debris boom	Do debris booms violate the restriction on treatment BMPs being employed in waters of the U.S.?	Clarify the Regional Board's position.	No violation exists (see Comment 9).
151	Irvine	XIV.10	Permittees shall examine opportunities to retrofit existing	A 2005 retrofit study performed by RBF Consultants has not been adopted or approved by the	The 2005 RBF Retrofit Study should not be mandated as the basis for co-permittee retrofit	The permit requires that a retrofit study be performed and a report on the study be

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			storm water conveyance systems and parks with water quality protection measures and report within 12 months of permit adoption	principal permittee, is still in draft form and co-permittees have not had the opportunity to review the draft.	programs until the co-permittees have had an opportunity to review, comment, and approve the final draft, as required in the current MS4 permit for any program developed by the principal permittee.	submitted within a year of permit adoption. If the 2005 study is still current/valid, that study could be submitted after review, and if not then a new study would have to be initiated.
152	County of Orange-Attachment B	Section XVI	Training program	Revise annual training requirement to be consistent with the County program (2 year frequency).Permittees should be given an option to have their own training programs.	Change training frequency requirements.	Permit language has been revised.
153	Irvine	XVI.2	Water quality training program curriculum	Permittees should be able to tailor their training programs. Non-management staff should not be responsible for knowing the whole storm water program, just their discrete tasks.	Revise order to allow greater flexibility in tailoring course curriculum to be appropriate to an employee's area of responsibility.	Permit language has been revised.
154	Irvine	XVI.3	Training modules should include an outline of the curriculum, a training procedure at the end and Certificate of Completion.	Mandatory training and practical application workshops should provide an alternative to a Certificate of Completion, which raises employment and labor issues.	Delete reference to testing requirements, certifications and Certificates of Completion.	Permit language has been revised.
155	Irvine	XVI.4, XVI.5 and XVI.6	At least on an annual basis, the principal permittee shall provide training to staff on Fixed Facility Model Maintenance procedures, Field Program Model Training, etc.	While this section explicitly states that the principal permittee shall provide training, where city management is competent in the storm water program, they should be allowed to provide that training in-house. Cities with a demonstrated or perceived deficiency may benefit from training provided by the principal permittee.	Revise the tentative order to allow individual cities to provide in-house training rather than participate in training administered by the principal permittee or by their consultants.	Permit language has been revised with the understanding that deficiencies in a permittee's program that are the result of either management or staff's lack of understanding about the program could result in enforcement actions.
156	Irvine	XVI.7	The principal permittee shall notify Regional Board staff at least 30	This notification requirement should not be applied to the initial training given to new	Revise the tentative order to allow documentation of training summary information in the annual report	By notifying Regional Board staff, by email, prior to conducting training, it gives

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			days prior to conducting training sessions.	employees, but only to the annual training given to all appropriate staff. Further, providing a summary training in the annual report be used in lieu of contacting Regional Board staff.	rather than notifying Regional Board staff of it's occurrence, but at minimum clarify that new employee training sessions do not require Regional Board notification.	Regional Board staff the opportunity to sit in on the training to ensure that the quality of the training meets the requirements of the permit. The Regional Board is also interested in the initial training for new storm water program employees
157	Irvine	XVI.8	Permittee shall adequately train staff within 60 days of being assigned duties related to the storm water permit.	It would be impractical for the principal permittee or their consultant to provide training within 60 days of every new co-permittee hire. If co-permittees are responsible for this training then it makes sense for co-permittees to be responsible for training existing staff.	Add an option to enable individual co-permittees to provide in-house training for new hires using curriculum developed by the principal permittee in collaboration with the co-permittees.	Permit language has been revised.
158	Irvine	XIV	None	Sections are misnumbered	No recommendation submitted.	Section numbers corrected.
159	U.S. EPA	XVIII.B.2	TMDL applicability	Although 2007 TMDL listed in this section have been adopted by the Regional Board, they have not been submitted to the State Board for approval. Until the State Board, OAL and the EPA have approved these TMDLs, they are not applicable.	Continue to implement the currently approved 2002 TMDLs until the 2007 TMDLs have been approved by the State Board, OAL and EPA	Permit language has been revised to include both 2002 and 2007 TMDLs.
160	U.S. EPA	XVIII Tables 1A/B		These tables do not accurately reflect the WLA's for urban runoff in EPA's 2002 TMDLs. Additionally, the table should clarify that the WLAs are intended to be enforceable effluent limits.	Compliance with WLAs could be required in accordance with the time frame envisioned by the Board's implementation plan, since this would be consistent with the intent of the EPA TMDLs.	Tables have been revised
161	County of Orange-Attachment A	Sections III.3.i and XVIII.B.3	Selenium in rising groundwater	The source of selenium in the rising groundwater should be considered as a non-point source	Since selenium is from a non-point source, it should not be regulated under the NPDES permit.	The release of selenium has been caused, in part, due to anthropogenic

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				and should not be subject to the NPDES permit.		hydromodification of the watershed. 40 CFR 122.26 requires the prevention of illicit discharges, which includes selenium contained in rising groundwater, into the MS4 system.
162	County of Orange-Attachment B, U.S. EPA	Section XVIII.B.3	Selenium and nutrient TMDL	Make the collaborative language more explicit.	Use suggested changes.	Permit language has been revised to describe the co-operative process that is being used to address the selenium and nutrient impacted groundwater in the San Diego Creek Watershed.
163	County of Orange-Attachment B, U.S. EPA	Section XVIII.E	Numeric effluent limits	The reference to numeric effluent limit is not accurate.	Recognize these as wasteload/load allocations.	Permit language has been revised.
164	County of Orange-Attachment A	Section XVIII.B.4	San Gabriel River metals TMDL	The permit inappropriately implements TMDLs developed by the U.S.EPA.	The requirements in the permit are for Coyote Creek; the upper reach of Coyote Creek is not listed as an impaired waterbody and therefore this requirement is inappropriate.	While the San Gabriel River metals TMDL lists the portion of Coyote Creek that lies within the Los Angeles Region, the upstream portion of Coyote Creek that lies within Orange County is one of the sources of pollutants responsible for the exceedances in the lower Coyote Creek, San Gabriel River and San Gabriel Estuary. The San Gabriel River metals TMDL contains a specific Waste Load Allocation of the MS4 discharge to the upper Coyote Creek. Moreover, the Coyote Creek TMDL was

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						promulgated by USEPA, and pursuant to 40 CFR 122.44, the Regional Board is required to incorporate this TMDL into the NPDES permit. The Regional Board does not have the authority to revisit and revise a USEPA promulgated TMDL.
165	County of Orange-Attachment A	Section XVIII.B.4	San Gabriel River metals TMDL	Since the Santa Ana Regional Board's Basin Plan does not include an implementation plan for Coyote Creek TMDL, this requirement is not consistent with the Clean Water Act and the TMDL requirements. For San Gabriel River.	This TMDL's requirements are outside the scope of authority given to the Regional Board by the Clean Water Act's NPDES program.	These TMDLs where promulgated by US EPA and notification and the opportunity to comment was given to the entities that discharge to these impacted waters. There is no state or federal law requirement that the Regional Board adopt the USEPA promulgated TMDL into the basin plan (and develop an associated implementation plan), prior to incorporating the TMDL into the NPDES permit pursuant to 40 CFR 122.26.
166	U.S. EPA	XVIII.C Tables 5a & 5b	Tables illustrating future Fecal Coliform TMDL's	These tables contain errors in that the first two rows of each table both include "TMDL for Fecal Coliform". It appears that one of these rows should present the WLA for urban runoff.	Make necessary changes in tables as deemed appropriate. Additionally, clarification language should be added to reflect that urban runoff WLA's are intended to be permit effluent limits	Tables corrected and clarification added.
167	U.S. EPA	XVIII.D.1	Diazinon and chlorpyriphos TMDLs for San Diego Creek and Newport Bay	The permit does not explicitly state that diazinon and chlorpyriphos WLAs are intended to be permit effluent limits and that the permittees shall comply with the wasteload allocations in	Add language in this section that states "The permittees shall comply with the following wasteload allocations in tables 6a and 6b." Additionally, the Fact Sheet should discuss the current compliance	Permit language has been revised.

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				tables 6a and 6b.	status of the permittees with the WLAs; given the phase-out of these pesticides within urban areas.	
168	U.S. EPA	XVIII.D.4	Sediment load allocations for Newport Bay and San Diego Creek	The permit should include firm dates for the submittal of monitoring data presenting the 10-year running averages.	The permit should include firm dates for the submittal of monitoring data presenting the 10-year running averages.	Permit language has been changed.
169	U.S. EPA	XVIII.E.2	Compliance with TMDLs	Language should be clarified for consistency with the rest of section XVIII.	Recommend revising language to read: “Based on the TMDLs, numeric effluent limits have been specified to ensure consistency with the wasteload allocations.”	Permit language has been revised.
170	Irvine	XIX.B.4	“The Management Committee shall meet at least six times a year to discuss issues related to permit…”	Has the Permittee Committee’s name been changed to the Management Committee?	Please clarify.	Permit language has been revised.
171	County of Orange-Attachment C	Monitoring and Reporting	Bioassessment	Integrate this requirement with the regional bioassessment programs.	Integrate monitoring programs.	Permit language has been revised.
172	County of Orange	Monitoring and Reporting	Land use correlation	This information has already been collected.	Eliminate the land use correlation element.	Permit language has been revised.
173	County of Orange	Monitoring and Reporting	Bacteriological monitoring	Intense bacteriological monitoring has been conducted for the last four years.	Reduce bacteriological monitoring requirements.	Permit language has been revised.

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174	NRDC	ROWD MRP IV.2.b	Permit renewal application	The permit renewal application is incomplete as it did not include an assessment of controls.	ROWD should have included an assessment of control measures and their effectiveness in removing pollutants.	The ROWD was posted for public comments. No comments were received and we accepted it as complete after providing 30 days of public notice and review period. We believe that the requirement in the Monitoring and Reporting Section of the draft order for program effectiveness analysis is an appropriate requirement to address this issue.
175	Orange	Fact Sheet	Section IX	Fact sheet still refers to 5% EIA	Delete this reference.	Fact sheet language has been amended.
176	BIA	General	Maximum extent practicable (MEP)	Some stakeholders misrepresent the meaning of MEP.	MEP is “hortatory” (i.e., merely encouraging or exhorting) and permit requirements should be based on the real meaning of MEP.	This comment appears to take issue with characterizations of the term MEP made by other stakeholders. Thus, the comment is noted, but no substantive response is given as the Regional Board cannot speak for other stakeholders.
177	Cypress			Please give further consideration to previously submitted recommendations.		Comment noted.
178	Contech Stormwater Solutions	Finding 66 and 67	Requires proper design of BMPs	Vortex systems, filters, and catch basin inlets have no connection to groundwater and cannot therefore cause groundwater pollution.	Remove these BMPs from this finding.	The finding also references these BMPs becoming a nuisance and/or cause surface water pollution. Improper maintenance of the aforementioned BMPs can result in these problems.
179	County of Orange	Various	Reporting requirements	The County believes that the refining of existing reporting	Revise reporting requirements.	The permit has been revised giving the permittees the

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				mechanisms is the most effective approach to increasing transparency and accountability		opportunity to propose alternative reporting methodologies contingent on the approval of the Executive Officer.
180	County of Orange, Irvine, Lake Forest	Various	Deliverables and submittal dates	Compliance submittals within 6 months or with the first annual report may not provide enough time to budget and complete work.	With the exception of the hydrologic conditions of concern mapping, revise compliance dates to at least one year after permit approval.	For the majority of these deadlines, the compliance dates have been revised.
181	NRDC	III	Non-storm water discharges	Prohibit non-storm water discharges.	Include a prohibition on non-storm water discharges.	The permit provisions are consistent with the Clean Water Act and the federal regulations (40 CFR 122.26(d)(2)(iv)(B). The federal regulations state that certain types of de minimus discharges need not be prohibited from the MS4s unless they are identified by the permittees as a significant source of pollutants.. Section III.1 of the draft order prohibits all other types of non-storm water discharges.
182	Golden State Water Company	III.3	De minimus discharge requirements	Does section III.3.ii refers to discharges from all entities or just municipal permittees?	Clarify requirement.	Permit language has been amended to clarify that this section only applies to discharges from municipal permittee owned/operated facilities and activities.
183	Laguna Hills	VI.6	Construction and industrial inspections	The new requirement that cities notify the Regional Board regarding violations at sites that are State General Permittees is unwarranted	Remove this requirement.	This requirement was in previous permit (Order R8-2002-0010 – Section VI.5). Further, coordinated enforcement actions will enhance water quality and meets the MEP threshold for this MS4 permit.

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184	County of Orange	IX.10 and X.11	Coordination of inspections with Regional Board staff	The current limited resources available to both the Regional Board and permittees to conduct inspections makes coordination of these activities a priority. It is recommended that a formal framework for inspection responsibilities be established.	Revise permit accordingly.	Permit language has been added identifying this goal.
185	Laguna Hills	X.1	Quarterly update of commercial facility inventory	The City already updates it's commercial inventory on a continuous basis.	Allow permittees to constantly track facilities.	The permit has been revised to give the permittees an opportunity to devise an alternate updating methodology that's approved by the Executive Officer.
186	Huntington Beach	X.2	Prioritizing commercial sites.	Requirement will increase number of inspections 10-fold.	Allow self-inspections of commercial sites 4 of 5 years and have cities inspect once per permit term.	While analysis of the permittee's commercial site database revealed numerous commercial businesses not listed in X.1.a-s, which could probably be dropped from their inspection database without threat to water quality, the permit has been revised to lower the Medium priority percentage to 20%. In the April 10, 2009 draft, Section XII.2 provides an option for the permittees to develop a scheme for prioritization and inspection of commercial sites.
187	Laguna Hills	X.2	Prioritizing commercial sites	The assignment of arbitrary percentages for high, medium and low priority sites means if a City has already assigned 100% commercial sites a High priority, it will have to downgrade at least 40% to meet the requirement.	Permittees should be given the flexibility as to designating its facilities without being restricted by the Regional Board.	During the 3rd term permit, MS4 Audits conducted by Regional Board staff indicated the need for more regimented oversight regarding commercial inventory management and inspections

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						within this section. If the example cited by the commenter arises, certainly, having 100% High priority ranked sites would be going beyond the minimum standards set by the permit and would not be viewed as a violation. Section XII.2 provides an option to develop a scheme for prioritization and inspection of commercial sites.
188	Irvine	X.2 and 3	Inspections of commercial sites	The new 10/40/50 High/Medium/ Low commercial breakdown will require that the City perform an additional 985 inspections per year resulting in an additional annual cost of $279,700.	Make use of the 10% High priority, but only require inspections of High priority sites.	While communication with the permittee has revealed some problems with their estimates, revisions to the permit have lowered the Medium priority percentage to 20%. In addition, Section XII.2 provides an option to develop a scheme for prioritization and inspection of commercial sites.
189	County of Orange	X.2 and 3	Commercial facility inspections	The permit should provide an opportunity to develop a risk-based scheme as an alternative to current permit language.	Revise permit accordingly.	Section X.2 now provides the permittees an opportunity to develop a prioritization scheme for inspections. The commercial inspection program was introduced in the 2002 permit cycle. The permit requirements prescribed a minimum of the program's structure. As a result of permittee's implementation of the program, further prescription of a minimum program was warranted.

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						Through implementation of the program proposed in the current draft permit, a more efficient program should evolve for the next permit cycle.
190	Huntington Beach, Irvine	X.3 and X.5	Photographic documentation of commercial sites	Permit requires photos of waste & material handling BMPs which is beyond the requirement for industrial sites.	Require photos only to document violations.	Photographic documentation of waste and material handling practices will ensure that sufficiently substandard storage is appropriately documented as a violation by the permittees and will allow Regional Board staff to more accurately evaluate permittee inspection/enforcement activities during audits.
191	Orange	X.3	Commercial inspections	The proposed 10/40/50 (high/medium/low) priority breakdown will require an additional 900 inspections per permit cycle for the City.	Either maintain current flexibility or introduce the 10% mandatory 'High' priority and inspect remaining 90% as needed.	While the 900 additional inspections/permit cycle works out to 4 additional inspections a week, the priority breakdown has been adjusted to a minimum 10/20/70.
192	BIA	Section XII	CEQA	Integrate MS4 permit requirements into the CEQA documents.	Use CEQA to integrate LID principles into the project at an early stage.	We agree; there are a number of requirements in the draft permit requiring such integration (e.g., see Section XII.A.4 and 6)
193	NRDC	XII	New Development	This section should be revised to require meeting MEP standard.	Include clarifications to ensure that Permittees meet MEP standard.	Clarifications added.
194	NRDC	XII	Documents submitted for review and approval	The public should have an opportunity to review and comment on the documents submitted for approval.	Revise permit language.	Permit language revised (See Footnote 55).
195	Irvine	XII.A.7	Project approval process requirement	None	Clarify that the update of the project approval process is the same as for the DAMP finalization.	Permit language has been revised.

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196	Lake Forest	XII.B and C	Implementation of LID	Implementation of LID and hydromodification requirements will not always be feasible, in particular there is concern about implementing the USEPA's 'Green Streets' guidance document.	None	The permit addresses situations where requirements may not be feasible and provides suitable alternatives in these situations (See Section XII.E).
197	NRDC	XII.B.2	List of priority projects	Revise the list to make it clear.	Revise the list to make it clear.	List revised.
198	Orange	XII.B.2.b	New Development	By revising permit language to include subdivisions with less than 10 units, if there's a combined 10,000 sq. ft. of imperviousness, the permit may now require single family homes to be priority development projects.	Retain the language exempting subdivisions of less than 10 units.	If the threshold of 10,000 sq. ft. of impervious surface is exceeded there is the potential for a similar level of pollutant load and alteration of the hydrologic regime, whether that area is divided between 10 residential units or less than 10.
199	Orange	XII.B.2.c and j	Priority Development Project classification	It is unclear whether the 10,000 square feet refers to land area or building area.	Clarify	Permit language has been amended to indicate that 10,000 sq. ft. refers to impervious area.
200	Orange County Business Council	XII.B.2.h	WQMPs for streets	The requirement for adherence to US EPA's 'Green Infrastructure" for public streets will increase costs and may not be possible.	Remove this requirement.	The incorporation of the US. EPA guidance document was at the suggestion of some of the stakeholders. Further, XII.B.2.h only requires the incorporation of the US EPA guidance document to the Maximum Extent Practicable.
201	NRDC	XII.B.5	Infiltration systems	The specified separation needed for infiltration systems to groundwater of 10' should be revised.	Make the separation 5'.	Permit language revised.
202	Irvine	XII.B.5(a)	Structural infiltration BMPs	Structural infiltration BMPs should meet minimum requirements that they not increase seepage or exfiltration of contaminated groundwater	Clarify language.	Permit language states that infiltration systems shall not cause or contribute to groundwater water quality exceedances (Section XII.B.5.a).

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203	Orange County Water District	XII.b.5.f	LID – Infiltration requirements	Footnote 50 restricts infiltration in sites known to have soil 'and' groundwater contamination. The word 'and' should be replaced with the word 'or.'	Revise permit language.	The footnote (54 in 3rd draft) has been revised.
204	Orange County Water District	XII.B.5.f	LID – Infiltration requirements	There are some land uses that should be restricted from infiltration whether or not there is current contamination (e.g., gas stations).	Include restrictions on infiltration for sites that have a high threat to water quality	The tentative order includes restrictions on infiltration systems in high vehicular traffic areas. We believe that this restriction along with the underground storage tank regulations should provide the needed groundwater protection from infiltration systems.
205	Contech Stormwater Solutions	XII.B.5.f	Structural infiltration BMPs	In high traffic areas, infiltration BMPs should have a minimum 75 gallon spill retention capability for diesel/hydraulic fluid spills.	Add requirement.	Rather than risking groundwater contamination by spills greater than the design volume of a proposed BMP, it is more prudent to prohibit infiltration BMPs in the situations presented in XII.B.5.f.
206	Orange County Water District	XII.C	LID – Infiltration requirements	OCWD would encourage the creation of a comprehensive map of Orange County identifying areas suitable for infiltration.	Require data to be collected and a map to be prepared.	The permittees are encouraged to prepare a Watershed Master Plan (see Section XII.D.5) to address LID infiltration and hydrologic conditions of concern in a comprehensive manner. Also Section XII.E.1 of the order requires the permittees to develop feasibility criteria for implementing LID BMPs.
207	Orange County Water District	XII.C	LID – Infiltration requirements	From a management and monitoring standpoint, grouping or clustering infiltration systems on a regional basis would make sense.	Consider the grouping of infiltration systems.	Sections XII.D.5 and XII.E of the order provides an opportunity for the permittees to develop LID infiltration systems on a regional or sub-regional basis.

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208	Orange County Water District	XII.C	LID – Infiltration requirements	Data needs to be collected in Orange County to assess the potential impacts to groundwater quality due to dry wells, infiltration galleries and poorly maintained infiltrations systems.	Revise permit language.	A requirement for developing a monitoring program for the infiltration systems has been added to the tentative order (see Section XII.B.5.g).
209	Orange County Water District	XII.C	LID – Infiltration requirements	An anti-degradation analysis in terms of groundwater quality should be provided in the Order.	Revise permit language.	We do not believe that any further anti-degradation analysis is needed as the infiltration systems are required to be designed to mimic pre-development hydrologic conditions with proper controls for pollutant sources.
210	Orange	XII.C	LID requirements	Redevelopment and in-fill projects may not be able to meet the LID requirements.	Exempt redevelopment and in-fill projects from LID requirements where sites drain to hardened or engineered channels.	While permit language in the 3rd draft, acknowledges that sites for which all receiving waters are hardened do not need to meet hydrology modification requirements, LID implementation also addresses pollutant transport by reducing the runoff responsible for the transport. So were possible, LID BMPs should be implemented.
211	Irvine	XII.C	LID requirements	It should be made clear that “LID requirements do not apply to development of conceptual or project WQMPs approved prior to 12 months after permit adoption…”	Clarify language.	XII.J clearly states that the only fully grandfathered projects are those that already have an approved WQMP. For all projects for which conceptual or project WQMPs are approved after the adoption of the permit and prior 90 days after approval of the revised model WQMP must implement the provisions in Section XII of the permit to the maximum extent practicable.

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212	Irvine	XII.C	Hydrologic conditions of concern requirements	It should be made clear that "hydromodification control requirements do not apply to development of conceptual or project WQMPs approved prior to 12 months after permit adoption…"	Clarify language.	XII.J clearly states that the only fully grandfathered projects are those that already have an approved WQMP. For all projects for which conceptual or project WQMPs are approved after the adoption of the permit and prior 90 days after approval of the revised model WQMP must implement the provisions in Section XII of the permit to the maximum extent practicable.
213	Orange County Business Council	XII.C	LID requirements	The permit should make clear that capture and infiltration is not required where infeasible or impractical.	Clarify permit.	The permit already makes this clear. See Section XII.E.1.
214	CICWQ	Section XII.C.	Conventional treatment control BMPs	Conventional treatment control BMPs should be considered only as a last resort.	Require structural treatment controls only if LID BMPs are infeasible.	We agree.
215	CICWQ	Section XII.C	LID BMPs	NGOs references to more restrictive volume controls for MS4 permits are not relevant.	Most references are from guidance documents and are not included in the adopted MS4 permits.	We agree that most references are not from adopted MS4 permits. Nevertheless, some of these are useful guidance documents for implementing LID.
216	BIA	Section XII.C	LID BMPs	The Board should include filtration as an acceptable LID BMP.	Include "filtration" as an LID BMP.	We have no objection to considering filtration as a second-tier LID BMP. This should be done on a case-by-case basis.
217	BIA	Section XII.C	LID BMPs	100% on-site retention should not be mandated. Reject any "universal retention doctrine".	Allow for "natural flow doctrine".	The draft permit does not require 100% on-site retention.
218	NRDC	XII.C	LID	LID provisions should be clearly articulated with performance standards.	Revise daft permit language.	Permit language has been revised.

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219	NRDC	XII.C	LID	LID BMPs must meet the MEP standard.	Provide clarification.	Permit language revised.
220	County of Orange	XII.C.1 and 2	LID requirements	Clarifying text change recommendations were provided for these sections.	Revise permit accordingly.	Permit language has been revised to include some of the recommended changes.
221	Contech Stormwater Solutions	XII.C.2.b	LID BMPs	Permit should not limit permeable paving alternatives.	Allow alternatives to permeable concrete or porous asphalt.	Permit language has been amended.
222	Contech Stormwater Solutions	XII.C.2.b	LI D BMPs	The phrase “minimize pipes, culverts and engineered systems…” should be replaced.	Replace statement with a more general “minimize changes to the time of concentration on site.”	Recommended language has been incorporated into the permit.
223	Orange	XII.C.3	Infiltration BMPs	Dry wells are listed as an allowable BMP, but may result in groundwater contamination	Require consultation with local water district prior to approval of dry wells.	Permit language has been revised.
224	Contech Stormwater Solutions	XII.C.4	LID BMP design requirements	While the goal of LID BMPs might be capturing the 85th percentile event, it shouldn’t be a design requirement	Delete this section.	The permit already provides options for sites where conditions rule out treating the 85th percentile event through LID BMPs.
225	Contech Stormwater Solutions	XII.C.5	Treatment BMP requirements	This section does not specify any level of treatment that is required by BMPs.	Specify the treatment control BMPs must be designed to have medium or high effectiveness based on full-scale, in-field testing.	The current Model WQMP has a similar requirement and it will be carried over in the Model WQMP approved for this permit.
226	CICWQ	Section XII.C. 5 & 7	LID BMPs	The current language in provisions 5 and 7 restricts the application of all available LID BMPs. These provisions include a universal mandate to infiltrate.	Include a second tier option for biofiltration, bioretention, filter strips, etc.	We believe that the most effective LID BMPs are those that infiltrate or harvest and re-use storm water onsite. The bio-treatment types of BMPs should be considered on a case-by-case basis.
227	Contech Stormwater Solutions	XII.C.7.a-b	LID BMPs	It is overly prescriptive to dictate where BMPs should be implemented.	Delete these sections.	The intent of this permit language is to encourage mimicking natural conditions where localized detention areas address the majority of storm events.

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228	Orange County Business Council	XII.D	Hydrologic modifications	The permit should recognize that most, if not all, in-fill projects are incapable of mimicking the pre-development hydrologic regime.	Clarify permit	The permit already acknowledges that not all sites will be able to meet this requirement on-site and provides suitable alternative compliance mechanisms.
229	Orange, County of Orange	XII.D.2.b	Hydrologic Conditions of Concern (HCOC)	Second draft of the permit has added that HCOC may exist for downstream hardened channels if those channels are Waters of the U.S. In the City's experience, all conveyance channels have been considered Waters of the U.S. by the Army Corps of Engineers.	Delete the added statement.	Permit language has been revised.
230	Irvine	XII.D.2(b)	Hydrologic conditions of concern exemptions	The permit language that currently exempts hardened channels from requiring hydrologic controls should be expanded to include stabilized channels	Clarify language.	If channels are engineered and regularly maintained to ensure design flow capacity, they do not have a hydrologic condition of concern per the third draft permit language.
231	CICWQ	Section XII.D.2.(b)	HCOC	The addition of the last sentence eliminates any waivers for HCOC.	Delete the last sentence.	The last sentence has been deleted.
232	NRDC	XII.E	Alternatives and in-lieu programs	The alternatives should be better integrated.	Revise permit language.	We did not see the need for any additional changes.
233	County of Orange	XII.E.1	Alternative and In-lieu programs	Clarifying text change recommendations were provided for this section.	Revise permit accordingly.	It's the judgment of Regional Board staff that the language currently in the draft permit more accurately portrays staff's intent.
234	Irvine	XII.H	Structural treatment BMP tracking	This section requires permittees to establish a mechanism to track structural BMPs and ensure that proper easements are recorded and conveyed to new owners.	There are already procedures in place at the County Recorder's office and through permittee's WQMP approval processes that address these requirements.	If the permittees can ensure that the requirements set forth in XII.H are being addressed then XII.H is satisfied.

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235	Laguna Hills	XII.H.1	Ensure that structural treatment control information is tracked with ownership change.	Recorded information is already transferred to new owner and City should not be held responsible for keeping track of this.	Delete requirement.	If the permittees can ensure that the requirements set forth in XII.H are being addressed then XII.H is satisfied.
236	Lake Forest	XII.I.3	Structural treatment BMP database	It appears that the requirement is that all BMPs installed to date would have to be included.	Limit database to only newly constructed BMPs.	Permit language has been revised.
237	Irvine	XII.I.5	Structural treatment BMP inspections	Current permit language limits inspection of these BMPs to the dry season. Further, because the number of these BMPs will increase every year we request that the number inspected be dropped from 50% to 25%.	Revise permit	The need to ensure that the BMPs are functional during the wet season requires inspection prior to the wet season. However, the inspection quantities have been reduced to 25% per year with 100% coverage during every 4 year cycle.
238	Lake Forest	XII.I.5	Structural treatment BMP inspections	The number of these BMPs will be increasing every year, becoming burdensome.	The permit should allow self inspections or use a representative sampling	Permit language has been revised.
239	Laguna Hills	XIII.4	Commercial business training	Business owners will not attend training during the work day.	Rely on education during site visits.	Because site visits for some facilities may not occur until the end of the permit cycle, site visit education can only be one part of an overall business education system.
240	Orange	XVI.3 and 4	Permittee employee training	The requirement for testing and Certificates of Completion infringes on the City's right to set employee class specifications.	Allow attendance sheets or other proof that training has been completed in place of Certificates of Completion and allow other procedures to substitute for testing to verify an employee's understanding of the curriculum.	Section XVI.3 has been amended to include other methods of course completion.
241	NRDC	XVIII	TMDL	Specify that the wasteload allocations (WLA) are enforceable permit limits.	Make WLAs enforceable permit limits.	Permit language revised.

Summary of Comments and Responses on the Orange County Municipal Storm Water Permit						
11/10/08 Draft (Comments 1-173) ; 03/24/09 Draft (Comments 174-244) ; 04/10/09 Draft (Comments 245-260) ; Public Hearing (Comments 261-278) ; 05/01/09 Draft (Comments 279 – 315)						
Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
242	NRDC	XVIII	TMDL	Prohibit new sources and new dischargers from discharging into 303(d) listed waters.	Include a prohibition on new sources and new dischargers into impaired waters.	First, while new development or redevelopment in an urban area may change the characteristics of the discharge entering the MS4 and hence the receiving water, each new development or redeveloped area does not constitute a new source or discharge. Further, the intent of the current MS4 permit is to address pollutant loads through an iterative BMP process. Moreover, the case primarily relied on in this comment, *Friends of Pinto Creek v. USEPA*, 504 F.3d 1007, did not involve an MS4 permit. Rather, it involved an individual NPDES permit for an individual discharger discharging directly into a water of the United States. Here, NRDC asks that the Regional Board expand the holding of that case to prohibit discharges into an MS4 system. These are two very different contexts, as the regulatory scheme/NPDES permitting requirements for an MS4 system are distinct from that of an individual discharger discharging directly into federal waters. Thus, to the extent that *Friends of Pinto Creek* is factually, distinguishable from the current situation, the holding is not applicable to this permit.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
243	County of Orange, Lake Forest	XVIII.B.10	Coyote Creek TMDL	TMDLs adopted by another Regional Board should not be applied outside their jurisdiction. Regulated entities should have the opportunity to participate and dispute the adoption of a TMDL.	The Coyote Creek TMDLs should not be included in this permit.	This TMDL was promulgated by USEPA. While the San Gabriel River metals TMDL lists the portion of Coyote Creek that lies within the Los Angeles Region, the upstream portion of Coyote Creek that lies within Orange County is one of the sources of pollutants responsible for the exceedances in the lower Coyote Creek, San Gabriel River and San Gabriel Estuary. Further, the San Gabriel River metals TMDL contains a specific Waste Load Allocation of the MS4 discharge to the upper Coyote Creek. We also note that the permittees that discharge to the listed waters were notified during the TMDL stakeholder process and commented on the TMDL at that time. See also response to comment numbers 164 and 165.
244	Lake Forest	Distribution list	None	Saddleback Valley School District was not included.	Include the school district.	The school district has been added to the list of other entities with the potential to discharge pollutants to the Orange County storm water system.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
	COMMENTS RECEIVED ON THE APRIL 10, 2009 DRAFT					
245	NRDC	XII	The permittees shall incorporate LID site design principles to reduce runoff to MEP.	The language in this Section of the tentative order requires a feasibility analysis before any LID BMP is required, as opposed to providing an "out" in situations of true infeasibility. This would mean that you would have to prove feasibility in each situation which is very problematic for many reasons and cuts against the common agreement by all that LID is generally feasible at some scale.	Modify Permit language.	During the public hearing on April 24, 2009, staff proposed a change to address this issue. This change is reflected in the 4th draft of the permit. Further changes may be made to Sections XII.C.1 & 2 based on comments on the 4th draft and any revisions will be addressed at the May 22, 2009 Regional Board meeting..
246	NRDC	XII	LID design criteria	The permit language does not require retaining the water on site from the design capture storm unless Infeasible. Rather, it says to capture and if you cannot you can use LID and conventional treatment BMPs. This doesn't seem to provide any requirement to retain the design storm when it can be done.	Change language to include a clear measurable performance standard that requires landscape-based treatment, on-site retention, and/or storage for re-use. These should be written in order to incorporate clear, enforceable LID requirements. Qualifier language such as: 'to the extent feasible' and 'as practicable' should not be used.	During the public hearing on April 24, 2009, staff proposed a change to address this issue. This change is reflected in the 4th draft of the permit. Further changes may be made to Sections XII.C.1 & 2 based on comments on the 4th draft and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
247	EPA	XII.C.1	LID BMPs	The Tentative Order states that projects that "meet the feasibility criteria" shall implement the permit's specific LID provisions. The feasibility criteria are prepared as a separate deliverable by the permittees (under section XII.E), and require EO approval. With this language, LID requirements will not apply until the permittees prepare an approvable feasibility criteria.	Modify Permit language.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.

OC MS4 Tentative Order No. R8-2008-0030 (R8-2009-0030)
Comments/Responses

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
248	EPA	XII.C.2	LID criteria	As it is currently written, the tentative Ooder opens the door to allow the use of conventional treatment controls in-lieu of LID BMPs.	LID BMPs should be considered for each priority development project.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
249	Orange County Water District	XII.B.5(d)	The vertical distance from the bottom of the infiltration system to the seasonal high groundwater must be at least 5 feet.	The Water District was concerned about the uncertainty factor in determining historic high groundwater and recommended a minimum 10 feet separation.	It would be prudent to specify a 10 feet vertical separation in the permit.	Permit language was modified in the 4th draft permit.
250	County of Orange	Finding J.52		Reference to 40 CFR citation is wrong.	Modify Permit language.	Permit language was modified in the 4th draft permit.
251	County of Orange	XVIII		Technical TMDLs (TMDLs with no implementation plans) should not be included in the permit	Delete technical TMDLs from the permit.	40 CFR 122.44(d)(1)(vii)(B) requires that this MS4 permit be consistent with the applicable waste load allocations in TMDLs and does not exempt those without implementation plans.
252	Riverside County Flood Control	Various	`	Commenter references numerous findings and permit requirements and requests that either they not be included in the Riverside County permit or be included with changes.	None	Comment noted.
253	Latham & Watkins, CICWQ,	XII.C.2 and 7	LID Implementation	Approved LID BMPs should include bio-treatment.	Modify Permit language.	Bio-filtration has been added to XII.C.2 in the 4th draft permit and may need to be added elsewhere within the permit to achieve consistency.
254	County of Orange, OC Coastkeeper, CICWQ	XII	Watershed Master Planning	Commenters support the inclusion of Watershed Master Planning and want it to be mandatory.	CICWQ supports the use of Watershed Master Plans. The County of Orange and OC Coastkeeper jointly submitted language making Watershed Master Plans mandatory.	The permit language proposed by the commenters was incorporated in Section XII.D.5
255	Prontowash	X.8	Mobile Commercial Source Program	Permit should require mobile car detailer to contain all discharge.	Revise permit language	The permit currently prohibits mobile car wash discharge as a non-storm water discharge and requires municipalities to prohibit this discharge.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
256	CICWQ	XII.C.2	LID	Provide clarification for the word “capture”; does it include bio-treatment.	Make the definition of LID consistent with the USEPA definition to include bio-treatment.	The 4th draft of the permit addresses this issue.
257	CICWQ	XII.C.3	Design “strategy”	Request replacing the word “strategy” with the word “preference”	Modify permit language.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
258	Geosyntec, County of Orange	General	Assessment of Pollutant Reductions	Response to NRDC comments	Response to NRDC comments	Comments noted.
259	Geosyntec, County of Orange	General, LID	LID Metrics	A response to Dr. Horner’s critical comments on “LID Metrics in Storm Water Permitting”.	Response to critical comments.	Comments noted.
260	Latham& Watkins	General, New Discharges	“New “discharges to impaired waters	A response to NRDC’s comments regarding the applicability of Friends of Pinto Creek v. U.S. EPA.	Latham & Watkins analysis concludes that this case is not applicable to the Orange County MS4 permit.	Comments noted.
	ORAL COMMENTS RECEIVED AT THE APRIL 24, 2009 PUBLIC HEARING (Extracted From Audio Records, May Be Supplemented Based On Transcripts, When Available.) (Comments Reflected In Written Correspondence Not Duplicated.)					
261	City of Lake Forest	Various		Keep in mind financial considerations and maximize the flexibility of permit requirements.		Comment noted.
262	County of Riverside	Various		The County wants the opportunity to base their new permit on their old permit.		Comment noted.
263	County of Orange	XII.C.1	LID Implementation	Recommends phasing in the LID requirements over an 18-month period instead of immediately, as reflected in the U.S. EPA proposed language.	Revise implementation date to 18 months.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
264	County of Orange	XII.C.2	LID Implementation	If LID is required prior to the establishment of the feasibility criteria, as proposed in the U.S. EPA language, how do the permittees determine if LID is in fact infeasible at a site?		This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
265	County of Orange	XVIII.B.9	Coyote Creek TMDLs	The Los Angeles Regional Board should identify the load for dischargers in the Santa Ana Region. The Santa Ana Region should then determine impairment, list the impaired waters and develop TMDLs for those impaired waters. Only Santa Ana Board adopted TMDLs should be in the Santa Ana permit.	Modify Permit language.	The San Gabriel River TMDLs (including Coyote Creek) and the waste load allocations associated with those TMDLs were promulgated by the U.S. EPA and therefore this Permit must be consistent with those TMDLs as provided in 40 CFR section 122.26. Please see responses to comments number 164 and 165.
266	CICWQ	XII.C.1	LID Implementation	Put back the portion of XII.C.1, deleted in the proposed U.S. EPA language.	Modify Permit language.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
267	CICWQ, City of Irvine, County of Orange	XII.C.2	LID Implementation	Strike the language added in the U.S. EPA changes in XII.C.2.	Modify Permit language.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
268	CICWQ, Michael Recupero	XII.C	LID Implementation	Clarify that bio-filtration is consistent with U.S. EPA definition of LID	Modify Permit language.	Bio-filtration has been added to XII.C.2 in the 4th draft permit and may need to be added elsewhere within the permit to achieve consistency.
269	CICWQ	XII.C.3	LID Implementation	Replace the word ‘strategy’ with the word ‘preference’.	Modify Permit language.	The word “strategy” may be replaced with the word “goal” as discussed at the April 24, 2009 public hearing.
270	GeoSyntec	XII.C	LID Implementation	Keeping the design storm volume on site will not always work, in many cases evapotranspiration is the key transport mechanism and replacing that with infiltration may have unintended consequences.	None	Comment noted.
271	OC Coastkeeper	XII.C	LID Implementation	This permit should have a three-pronged approach with Watershed Master Plans and an internet based information	None	Comment noted.

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				system with hydrologic data for builders and planners.		
272	City of Irvine	XII.C	LID Implementation	It should be made clear that if the design storm volume is addressed through bio-treatment and there is subsequent discharge to the MS4, no further treatment or offset is required.	Modify Permit language.	This issue is under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
273	City of Orange	XII.J.1	Pre-Approved Projects	The permit language may not include all projects that have already received approval by the municipalities.	Ensure that permit language includes all projects approved by municipalities.	The current permit language recognizes this and requires implementation of LID BMPs consistent with the MEP standard.
274	Lennar Homes	XII.C.7	Regional Treatment	Regional treatment should be allowed without a waiver requirement and without additional treatment or offset.	Modify Permit language.	The draft permit includes provisions for regional treatment. The Watershed Master Plan, Section XII.D.5, should be used as another tool to incorporate regional treatment systems.
275	Michael Recupero	XII.C.1	Feasibility criteria	Does the language proposed by U.S. EPA strike the feasibility analysis?	None	While the feasibility analysis is not eliminated, the timing of LID implementation and the approval of a model WQMP (including feasibility criteria) are under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
276	Michael Recupero	XII.C	Feasibility criteria	What will be the threshold for infeasibility and who decides it and does every project not implementing LID for the full 85th percentile 24-hour storm require a Regional Board granted waiver?	None	These issues are under review and any revisions will be addressed at the May 22, 2009 Regional Board meeting.
277	Michael Recupero	XII.B.5(d)	The vertical distance from the bottom of the infiltration system to	Supports a 10' vertical separation.	Modify Permit language.	The 4th draft permit specifies a 10-foot vertical separation.

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			the seasonal high groundwater must be at least 5 feet.			
278	San Bernardino County Flood Control District, Storm Water Program	General	Various	Commenter requests that the Orange County Permit should not be used as a template for the San Bernardino County Permit. .	None	Comments noted.
	COMMENTS RECEIVED ON THE MAY 1, 2009 DRAFT					
279	U.S. EPA	XII.C.2	LID	Language should be added to clarify that compliance with XII.C.& or XII.E meets the permit's LID requirements.	Insert "Compliance with the permit's LID requirements may also be achieved by implementation of the alternatives specified in section XII.C.7 or by implementation of an approved waiver under section XII.E" at the end of XII.C.2.	With other changes made to subsections XII.C.1 and 2, insertion of the submitted language would not have clarified the intent of this permit requirement. It is thought that the other changes made to this section have sufficiently clarified these requirements.
280	U.S. EPA	XII.C.2	LID	The meaning of the term 'bio-filter' is unclear and the use may not be necessary.	Criteria for the design and operation of these systems should be specified in the permit or should be part of the feasibility criteria required pursuant to Section XII.E.	The term 'bio-filter' has been replaced by 'bio-treatment' and the requirement that design, operation, and maintenance criteria be developed as part of the model WQMP has been added.
281	U.S. EPA	XII.C.7	LID	The term 'treat' is used repeatedly in Section XII.C.7, which sets up an inconsistency with other permit requirements.	Either 'treat' should be deleted or with Board approval, changed to 'bio-treat'.	The references to 'treat' in Section XII.C.7 have been changed to 'bio-treat' or 'bio-treatment'.
282	U.S. EPA	XII.E	Waiver Approval	With regards to project-specific waivers generated by Section XII.E, commenter believes that the number of waivers will be small. While supporting the 4th	None made.	While waiver approval per Section XII.E remains the same, if the feasibility criteria required by that section is not approved within 12 months of

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
				draft permit language, the commenter would be open to revisions that do not require EO approval for waivers.		permit adoption, the resulting case-by-case feasibility determination by the municipalities on proposed projects will not require EO approval, but will be submitted for Regional Board staff review 30 days prior to municipal approval.
283	Paul Singarella, Latham & Watkins	Findings	None	A Finding should be added stating that the Regional Board does not expect on-site retention of 100% of the design capture volume to be feasible in all cases and that implementation of bio-treatment will still satisfy legal requirements and provide a significant advance on the previous Order.	Insert provided Finding.	The existing Findings clearly indicate that LID itself, much less LID with 100% on-site retention may not be feasible at all sites.
284	Larry McKenny, RBF Consulting	XII.C	LID	Commenter supports the CICWQ comments and notes that the MEP standard does not dictate full retention of a design storm volume on site.	None	Comment noted.
285	County of Orange	None	None	The County notes involvement in the development of their comments by the Cities of Anaheim, Buena Park, Cypress, Fountain Valley, Irvine, La Palma, Laguna Hills, Lake Forest, Newport Beach, Orange, Placentia, Tustin, Villa Park and Westminster , as well as their concurrence with the submitted comments.	None	Comment noted.
286	County of Orange	XII.C.1	LID	While the change in Section XII.C.1 made at the Public Hearing and further in the fourth	Language was submitted by the commenter for Section XII.C.1.	Many of the changes in language, proposed by the commenter were incorporated

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				draft were made to address the possibility that approval of the feasibility criteria may drag on, it has the possible effect of excessive administrative burden and project delays.		in the permit and are reflected in the Errata Sheet.
287	County of Orange	XII.C.2	LID	The consequence of changes to Section XII.C.2 in the fourth draft result in the need for a waiver and EO approval for any project not addressing 100% of the design storm volume through on-site LID BMPs.	Language was submitted by the commenter for Section XII.C.2.	Many of the changes in language, proposed by the commenter were incorporated in the permit and are reflected in the Errata Sheet.
288	County of Orange	XII.C.2	LID	The term 'bio-filter' was used instead of 'bio-treat'. Further, the language in footnote 56 identifies that bio-treatment can only be used if infiltration, harvest/reuse and evapotranspiration are infeasible.	Language was submitted by the commenter for Section XII.C.2 and footnote 56/57.	The term 'bio-filtration' has been used throughout Section XII.C. While much of the permit language suggested by the commenter has been used, the permit continues to require that the use of 'on-site' retention LID BMPs be implemented (where feasible) prior to the use of 'treat and release' lid BMPs.
289	NRDC/ Coastkeeper	General Comment and Section XII.C	LID	The language in the draft permit is not based on any consensus agreement among the stakeholders. There are key disagreements on certain issues.	NRDC and Coastkeeper believe that law requires a standard that retains on site the design storm whenever possible.	The draft permit language includes on site retention as the highest priority LID BMP.
290	NRDC/ Coastkeeper	Section XII.C	LID	Infiltration and reuse implements MEP requirements and is a wise policy.	Require infiltration and reuse.	Infiltration and reuse are the highest priority LID BMPs included in the draft permit.
291	NRDC/ Coastkeeper	Section XII.C.2	LID	Clarify permit language.	Use suggested permit language.	Draft permit language now includes the requested change.
292	NRDC/ Coastkeeper	Sections XII.C. 1 & 2	LID	Disagree with the inclusion of bio-filtration to meet the basic LID standard.	Remove references to bio-filtration	Permit language has been modified; it still includes bio-treatment as the lowest priority LID BMP.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
293	NRDC/ Coastkeeper	Footnotes 56 and 57	LID	Include a design standard for bi-filtration systems.	Use suggested language to modify the footnotes.	The footnotes have been revised and the permittees are now required to include specific design criteria in the WQMP for bio-treatment systems.
294	NRDC/ Coastkeeper	Section XII.C	LID	Other sections of the permit have references to "treatment". It should be replaced with bio-treatment.	Replace references to treatment with bio-treatment.	Permit language changed.
295	City of Cypress	XII.C	LID	Consideration should be given to leaving the language in Section XII.C as existed in the third draft.	Revise permit language to reflect that proposed in the third draft.	The changes proposed in the Errata sheet for the May 22, 2009 Regional Board meeting represent an effort to allow maximum flexibility in the implementation of post-construction BMPs while maintaining a set of minimum requirements designed to insure compliance.
296	City of Irvine			Support comments made by County of Orange and CICWQ	Refer to County of Orange and CICWQ	Comment noted.
297	CONTECH	XII.C.3	LID criteria	The word "bio-filter " should be replaced with "filter" The addition of the term bio-filter appears to be excluding non-vegetative media filters, which in some cases, may prove more effective.	Replace the term Bio-filter with filter.	Wording has been changed in this case by using the term "bio-treat" or "bio-treatment"
298	City of Orange	XI.C.1	LID implementation schedule	By deleting the phrase "that meet the feasibility criteria established pursuant to Section XII.E1" within this Section, this could be interpreted as making the Permittees begin immediate implementation of LID following permit adoption.	Maintain the existing language in Section XII.C.1 in order to maintain clarity	Permit language has been revised to address this issue within this Section
299	City of Orange	XII.C.2		The proposed language change to this paragraph can be interpreted to read that projects that cannot fully infiltrate,	Delete second sentence in Section XII.C.2 "Projects that do not comply with this requirement shall meet requirements established in	Permit language has been revised.

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				harvest, reuse or evapotranspire or capture will need to meet in-lieu programs and still require treatment by conventional BMPs.	Section XII.E for alternative and in-lieu compliance. Alternatively, adopt the County of Orange recommended language.	
300	City of Orange	(general) LID Systems		Concern has been raised about allowing only BMPs that capture the 85th percentile storm. This requirement will not allow the use of systems such as grass swales or vegetated strips. Use of these systems, under the new criteria will not be allowed, as they will be deemed only as "infiltration systems"	Comment only	Comment noted
301	CICWQ	Section XII.C	LID	Provided a marked up copy of Section XII.C	Make changes as per the marked up copy.	See revised permit language.
302	San Bernardino County Storm Water Program	Section XII	LID	Section XII lacks clarity.	Provide clarifying language or a flow chart.	Permit language amended to clarify some of the requirements.
303	San Bernardino County Storm Water Program	Section XII.B.4	Design capture volume	Does the design capture volume include all the options under Section XII.B.4?	Provide clarification.	The design capture volume only provides two of these options, "runoff produced from a 24-hour, 85th percentile storm event", as indicated in XII.B.4.A.1 and 2.
304	San Bernardino County Storm Water Program	Section XII.B.5.f	Infiltration	Is a feasibility analysis required for infiltration systems in industrial areas?	Provide clarification.	A feasibility analysis is not required for infiltration systems for the type of facilities listed under Section XII.B. 5.f.
305	San Bernardino County Storm Water Program	Section XII.C.2 And XII.E	Feasibility Criteria	Section XII.E requires the principal permittee to develop a "technically-based" feasibility criteria.	The MEP standard should be applicable here.	The co-permittees are governed by the MEP standard.
306	San Bernardino County Storm Water Program	Sections XII.C.1 & 2	Full retention	There is an overemphasis on full retention BMPs.	Consider other equally effective LID BMPs. A broader concept of LID BMPs should be included.	The permit language includes a hierarchy of LID BMPs mostly based on their effectiveness in protecting water quality and quantity.

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Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
307	Riverside County Water Flood Control and Water Conservation District	Section XII.C.2	On site retention	Avoid infiltration centric definition of LID.	Provide flexibility to implement proactive, effective, and economical LID BMPs.	Please note that the permit does provide other options, including bio-treatment.
308	Riverside County Water Flood Control and Water Conservation District	Section XII.C.2	On site infiltration	The permit does not allow properly designed filtration systems.	Include filtration as an option for implementing LID BMPs.	Bio-filtration is generally considered as an LID BMP and is included in the draft permit.
309	Riverside County Water Flood Control and Water Conservation District	Section XII.C.2	LID	The permit focuses on micro-scale LID	Allow broader implementation of LID BMPs.	Section XII.C.7 provides for sub-regional and regional LID implementation techniques.
310	Riverside County Water Flood Control and Water Conservation District	Section XII.C	LID	The goal should be to mimic pre-development hydrology.	Revise Section XII.C.	Section XII.C.3 notes that the design goal is to replicate pre-development hydrologic regime.
311	Riverside County Water Flood Control and Water Conservation District	Section XII.C	LID	Allow filtration and detention.	Revise Footnotes 56 and 57.	Minor changes have been made to Footnotes 56 & 57.
312	Riverside County Water Flood Control and Water Conservation District	Section XII.C	LID	The District's qualifications for submitting comments on LID	The District developed criteria for the use of LID BMPs.	Comments noted.

Summary of Comments and Responses on the Orange County Municipal Storm Water Permit						
11/10/08 Draft (Comments 1-173) ; 03/24/09 Draft (Comments 174-244) ; 04/10/09 Draft (Comments 245-260) ; Public Hearing (Comments 261-278) ; 05/01/09 Draft (Comments 279 – 315)						
Comment No.	**Commenting Parties**	**Section No.**	**Permit Requirement**	**Comment**	**Submitted Recommendations**	**Response**
313	Riverside County Water Flood Control and Water Conservation District	Section XII.C	LID	USEPA's guide includes filtration as an LID BMP.	Allow properly engineered filtration systems as an LID BMP.	Even though filtration per se is not included, bio-filtration is recognized as an LID BMP.
314	Riverside County Water Flood Control and Water Conservation District	Section XII.C	LID BMPs	On site vs. regional	Regional systems have many advantages, including ease of public maintenance, municipal inspections and nuisance reduction.	The permit language has provisions for regional and sub-regional systems (see Section XII.C. 7).

To Paulova Vitale	From Bruce Fujimoto
Co.	Co.
Dept.	Phone #
Fax #	Fax #

JAN - 9 1991

OFFICE OF GENERAL COUNSEL

MEMORANDUM

SUBJECT: Compliance with Water Quality Standards in NPDES Permits Issued To Municipal Separate Storm Sewer Systems

FROM: E. Donald Elliott
Assistant Administrator and
General Counsel (LE-130)

TO: Nancy J. Marvel
Regional Counsel
Region IX

In your memorandum of August 9, 1990, you have asked for our views on the following two issues:

ISSUES

1) Must NPDES permits for municipal separate storm sewer systems ("MS4s") issued under Section 402(p)(3)(B) of the Clean Water Act (CWA) include requirements necessary to achieve water quality standards (WQS), as generally required by Section 301(b)(1)(C) for all NPDES permits?

2) If permits issued to MS4s must comply with WQS, by what date must the permit ensure compliance?

SHORT ANSWERS

1) The better reading of Sections 402(p)(3)(B) and 301(b)(1)(C) is that all permits for MS4s must include any requirements necessary to achieve compliance with WQS.

2) Sections 402(p)(4)(A) and (p)(4)(B) give "large" and "medium" MS4s three years to comply with permit conditions from the date of permit issuance. This three year compliance date also applies to WQS-based permit requirements.

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DISCUSSION

1. Statutory Background

Section 402(a)(1) requires that all NPDES permits comply with the applicable provisions of section 301. This includes compliance with appropriate technology-based standards and effluent limits (sections 301(b)(1)(B), 301(b)(2)). Permits must include "any more stringent limitation" necessary to meet WQS. Section 301(b)(1)(C). In addition, Section 401 requires that any applicant for a federal permit (including NPDES permits issued by EPA) must provide the permitting agency a certification from the State in which the discharge originates that the discharge will comply with the State's WQS.

As part of the 1987 amendments to the Clean Water Act, Congress added Section 402(p) to the Act, related to storm water discharges. Congress exempted some storm water discharges from the requirement to obtain an NPDES permit until after October 1, 1992. Section 402(p)(1). For certain specific categories of storm water discharges, this permit "moratorium" is not in effect, including discharges "associated with industrial activity," discharges from large and medium municipal separate storm sewer systems (i.e., systems serving a population over 250,000 or systems serving a population between 100,000 and 250,000, respectively). Section 402(p)(2).

For industrial and municipal storm water discharges, EPA was instructed to promulgate new regulations specifying permit application requirements. Congress mandated EPA to issue permits no later than February 4, 1991 (for industrial and large municipal discharges) or February 4, 1993 (for medium municipal discharges). Section 402(p)(4). These permits shall provide for compliance "as expeditiously as practicable, but in no event later than 3 years after the date of issuance of such permit." Id.

Section 402(p) also specified the levels of control to be incorporated into storm water permits. Permits for discharges associated with industrial activity are to require compliance with all applicable provisions of Sections 301 and 402 of the CWA, i.e., all technology-based and water quality-based requirements. Section 402(p)(3)(A). By contrast, permits for discharges from municipal separate storm sewers "shall require controls to reduce the discharge of pollutants to the maximum extent practicable" ("MEP"). Section 402(p)(3)(B)(iii).

2. <u>Analysis</u>

A. <u>WQ-based Requirements in Municipal Storm Water Permits</u>

The relationship of Section 402(p)(3)(B)(iii) to Section 301(b)(1)(C) is not clear, either on the face of the statute or in legislative history. Section 402(p)(3) is clearly intended to draw a distinction between the requirements on industrial and municipal storm water discharges. Section 402(p)(3)(A) states that industrial discharges shall comply with the applicable provisions of section 301, i.e., BAT/BCT technology-based requirements as well as any more stringent WQ-based requirements pursuant to 301(b)(1)(C). In the next sub-paragraph, Congress requires municipalities to control storm water to the MEP standard; no mention is made of section 301. The juxtaposition of (p)(3)(A) and (p)(3)(B) gives rise to the argument that Congress may have intended to waive all section 301 requirements for municipal discharges in favor of the MEP standard. On the other hand, one could read (p)(3)(B)(iii) as modifying only <u>technology-based</u> requirements for municipal storm water (i.e., MEP substitutes for BAT/BCT); any WQ-based requirements would still be necessary in a municipal permit, even if those requirements are more stringent than "practicable." The legislative history of Section 402(p) provides no guidance as to how Congress intended the MEP standard to operate.

Where Congressional intent behind a statutory provision is ambiguous in light of the language or legislative history, the Agency charged with administering that statute may adopt any reasonable interpretation consistent with the goals and purposes of the statute. <u>Chevron, U.S.A.</u> v. <u>NRDC</u>, 467 U.S. 837 (1984). Therefore, EPA has a large degree of discretion to choose how it will interpret the applicability of WQS to municipal storm water discharges. The only interpretation by EPA to date, contained in its proposed rulemaking, has been that WQS would continue to apply to permits for municipal storm water discharges. <u>See</u>, <u>e.g.</u>, 53 Fed. Reg. 49,457 (Dec. 7, 1988) (priorities for controls in municipal storm water management programs will be developed to ensure achievement of water quality standards and the CWA).[1] There has been no intervening interpretation expressed by EPA on this issue. It is the opinion of the Office of General Counsel that the interpretation adopted by the Agency in the proposal is a reasonable one, for the following reasons.

---

[1] EPA's intent to apply WQS to municipal storm water discharges can also be inferred by the fact that the 1988 proposal did not propose to alter 40 CFR 122.44(d), which provides that all NPDES permits must contain water quality-based requirements more stringent than technology-based requirements, where necessary to achieve WQS.

First, to support the opposite reading (i.e., that WQ-based requirements do not apply to municipal storm water permits), one would have to assert that Congress implicitly waived section 301(b)(1)(C) requirements for municipal storm water. One would further have to assume that Congress impliedly exempted municipal storm water permits from the Section 401 certification requirements. Implied repeals of statutory provisions are generally disfavored. Morton v. Mancari, 417 U.S. 535, 549 (1974). A court generally will find a statute impliedly repealed only if the later enacted provision is in "irreconcilable conflict" with the earlier provision. Kremer v. Chemical Construction Corp., 456 U.S. 461, 468 (1982) (citations omitted). In this case, the statutory provisions are not in irreconcilable conflict; rather, as discussed above, one may read Section 301(b)(1)(C) as requiring "any more stringent limitation" necessary to meet a WQS in every NPDES permit, including permits for discharges from municipal separate storm sewers which are subject to the MEP standard. Such a reading would harmonize the two provisions and give effect to the policy behind Sections 301(b)(1)(C) and 401, i.e., to ensure that WQS are met regardless of practical considerations (such as the availability of treatment technology or the "practicability" of MS4 permit requirements).

To read Section 402(p)(3)(B) as overriding 301(b)(1)(C) requirements would also cause a conflict between Section 402(p) and the general focus of the provisions in the 1987 Amendments, many of which reflect a Congressional desire to improve compliance with the WQ-based requirements of the Act. The amendments to/additions of sections 303(c)(2)(B), 304(l), 319, 320, 402(o) all reflect Congressional concern with the improvement of water quality through the NPDES and other CWA programs. It would be particularly difficult to argue that the storm water provisions, a major part of the 1987 Amendments, were intended to create an exemption from the general rule regarding WQ-based requirements without an explicit acknowledgment of that result. We think the approach taken in the proposed rule is preferable.

B. Compliance Date for WQ-Based Limits in Municipal Storm Water Permits

In contrast to the issue of whether WQ-based requirements apply at all to MS4s, Congress had indeed spoken to the compliance date issue. Section 402(p)(4) requires compliance with all permit conditions no later than three years from the date of issuance. In light of the express language, we believe the Agency may reasonably interpret the three-year compliance provisions in Section 402(p)(4) to apply to all permit conditions, including those imposed under 301(b)(1)(C).[2]

There are arguments which support the reasonableness of this interpretation. First, EPA has issued few, if any storm water permits to MS4s to date. Many of these systems will face NPDES permit conditions for the first time, and I understand immediate compliance for these systems is likely to be unrealistic. The compliance date in Section 402(p)(4) apparently reflects a Congressional realization of that reality. Second, EPA has already construed another very similar provision of the 1987 Amendments in the same manner. Section 304(1) establishes an identical three-year compliance date for achieving water quality standards in Individual Control Strategies issued under that section. EPA has interpreted that provision, while not repealing Section 301(b)(1)(C), to allow for three-year compliance with new effluent limits established to meet WQS on 304(1)-identified streams. 54 Fed. Reg. 23,889 (Jun. 2, 1989). Given that 304(1) deals directly with WQ-based standards and permit requirements, a consistent interpretation with respect to 402(p)(3) and (p)(4) (which, as we have seen, is silent on the role of WQ-based requirements for MS4s) is certainly reasonable.[3]

If you have any questions regarding this memorandum, please contact Randy Hill of my staff, FTS 382-7700.

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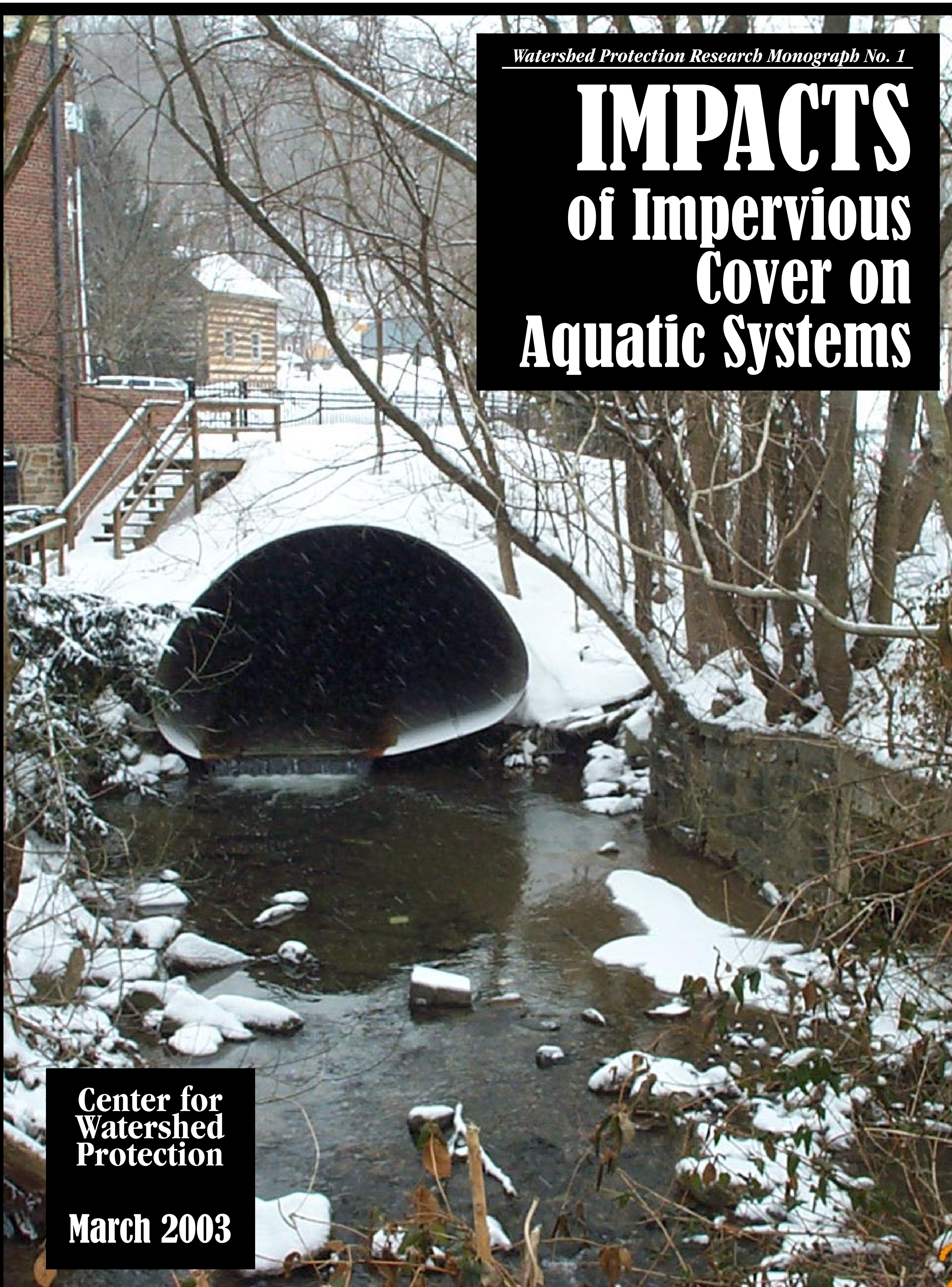
2. There may be some municipal separate storm sewer systems which are unable to meet even the three-year compliance date in their permits. The Agency retains the discretion to issue an administrative order fixing a schedule for compliance if compliance is not achieved in that three-year period.

3 The decision of the Administrator in the Star-Kist permit appeal does not affect this analysis. Indeed, the decision itself supports the reading that compliance schedules under Section 304(1) (and, by extension, schedules under Section 402(p)(4)) are unaffected by the holding in that decision. Cf. Order on Petition for Reconsideration, In the Matter of Star-Kist Caribe, Inc., NPDES Appeal No. 88-5, (Apr. 17, 1990), at 6 n.5 (because decision does not prevent all post-1977 compliance schedules, arguments regarding 304(1) are not pertinent); (order stayed Sept. 4 1990).

Watershed Protection Research Monograph No. 1

IMPACTS of Impervious Cover on Aquatic Systems



Center for Watershed Protection

March 2003

Cover photograph Ellicott City, Maryland 2003.
Courtesy Anne Kitchell, Center for Watershed Protection.

Watershed Protection Research Monograph No. 1

Impacts of Impervious Cover on Aquatic Systems

March 2003

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Foreword

We are extremely pleased to launch the first edition of a new series called *Watershed Protection Research Monographs*. Each monograph will synthesize emerging research within a major topical area in the practice of watershed protection. The series of periodic monographs will replace our journal *Watershed Protection Techniques,* which lapsed in 2002. We hope this new format will provide watershed managers with the science and perspectives they need to better protect and restore their local watersheds.

This monograph was written to respond to many inquiries from watershed managers and policy makers seeking to understand the scientific basis behind the relationship between impervious cover and the health of aquatic ecosystems. It reviews more than 225 research studies that have explored the impact of impervious cover and other indicators of urbanization on aquatic systems. This report comprehensively reviews the available scientific data on how urbanization influences hydrologic, physical, water quality, and biological indicators of aquatic health, as of late 2002.

Our intention was to organize the available scientific data in a manner that was accessible to watershed leaders, policy-makers and agency staff. In addition, the research itself, which spans dozens of different academic departments and disciplines, was conducted in many different eco-regions, climatic zones, and stream types. In order to communicate across such a wide audience, we have resorted to some simplifications, avoided some important particulars, refrained from some jargon, and tried, wherever possible, to use consistent terminology. Thus, the interpretations and conclusions contained in this document are ours alone, and our readers are encouraged to consult the original sources when in doubt.

We would also like to note that the Center for Watershed Protection and the University of Alabama are currently developing a major national database on stormwater quality. The database will contain nearly 4,000 station-storm events collected by municipalities as part of the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) Phase I Stormwater Permit Program. We anticipate releasing a data report in late 2003 that will provide a much needed update of stormwater event mean concentrations (EMCs).

As of this writing, many research efforts are underway that will further test and refine these relationships (most notably, the U.S. Geological Survey gradients initiative, but also many other local, state and academic efforts). We hope that this report provides a useful summary of the existing science, suggests some directions for new research, and stimulates greater discussion of this important topic in watershed management. We also feel it is time for a major conference or symposium, where this diverse community can join together to discuss methods, findings and the important policy implications of their research.

Acknowledgments

Putting this first research monograph together took a lot of energy, editing and analysis, and many Center staff devoted their time and energy over the last two years to get it done. The project team consisted of Karen Cappiella, Deb Caraco, Samantha Corbin, Heather Holland, Anne Kitchell, Stephanie Linebaugh, Paul Sturm, and Chris Swann. Special thanks are extended to Tiffany Wright, who worked tirelessly to assemble, edit and otherwise polish the final draft.

I am also grateful to Michael Paul of Tetratech, Inc., who graciously provided us with an extensive literature review from his PhD days at the University of Georgia that contained many obscure and hard to find citations. Portions of this monograph were developed as part of a literature review conducted as part of a work assignment for the U.S. EPA Office of Wastewater Management in 2001, which proved indispensable in our efforts. Lastly, I would like to thank the hundreds of scientists who have contributed their time and data to explore and test the relationships between urbanization and aquatic health.

Tom Schueler
Center for Watershed Protection

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Acronyms and Abbreviations

B-IBI	Benthic Index of Biotic Integrity
BOD	Biological Oxygen Demand
BSD	Better Site Design
C-IBI	Combined Index of Biotic Integrity
cfs	cubic feet per second
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
Cu	Copper
DOC	Dissolved Organic Carbon
du/ac	dwelling units per acre
EMC	Event Mean Concentration
EPT	Ephemeroptera, Plecoptera and Trichoptera
FC	Forest Cover
GIS	Geographic Information Systems
IBI	Index of Biotic Integrity
IC	Impervious Cover
ICM	Impervious Cover Model
lbs/ac	pounds per acre
LWD	Large Woody Debris
mg/kg	milligrams per kilogram
mg/l	milligrams per liter (equal to ppm)
MPN	Most Probable Number
MTBE	Methyl Tertiary-Butyl Ether
N	Number of Studies
N/R	data not reported
NO_2	Nitrite
NO_3	Nitrate
NO_x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Unit
NURP	National Urban Runoff Program
PAH	Polycylic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
ppb	Parts per billion (equal to ug/l)
ppm	Parts per million (equal to mg/l)
RBP	Rapid Bioassessment Protocol
SLAMM	Source Loading Assessment/ Management Model
SPMD	Semi-Permeable Membrane Device
SSO	Sanitary Sewer Overflow
STP	Stormwater Treatment Practice
TC	Turf Cover
TDS	Total Dissolved Solids
TKN	Total Kjeldhal Nitrogen
TMDL	Total Maximum Daily Load
Total N	Total Nitrogen
Total P	Total Phosphorous
TOC	Total Organic Carbon
TSS	Total Suspended Solids
ug/l	micrograms per liter (equal to ppb)
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
WLF	Water Level Fluctuation
WTP	Wastewater Treatment Plant

Chapter 1: Introduction

This research monograph comprehensively reviews the available scientific data on the impacts of urbanization on small streams and receiving waters. These impacts are generally classified according to one of four broad categories: changes in hydrologic, physical, water quality or biological indicators. More than 225 research studies have documented the adverse impact of urbanization on one or more of these key indicators. In general, most research has focused on smaller watersheds, with drainage areas ranging from a few hundred acres up to ten square miles.

Streams vs. Downstream Receiving Waters

Urban watershed research has traditionally pursued two core themes. One theme has evaluated the direct impact of urbanization on small streams, whereas the second theme has explored the more indirect impact of urbanization on downstream receiving waters, such as rivers, lakes, reservoirs, estuaries and coastal areas. This report is organized to profile recent research progress in both thematic areas and to discuss the implications each poses for urban watershed managers.

When evaluating the direct impact of urbanization on streams, researchers have emphasized hydrologic, physical and biological indicators to define urban stream quality. In recent years, impervious cover (IC) has emerged as a key paradigm to explain and sometimes predict how severely these stream quality indicators change in response to different levels of watershed development. The Center for Watershed Protection has integrated these research findings into a general watershed planning model, known as the impervious cover model (ICM). The ICM predicts that most stream quality indicators decline when watershed IC exceeds 10%, with severe degradation expected beyond 25% IC. In the first part of this review, we critically analyze the scientific basis for the ICM and explore some of its more interesting technical implications.

While many researchers have monitored the quality of stormwater runoff from small watersheds, few have directly linked these pollutants to specific water quality problems within streams (e.g., toxicity, biofouling, eutrophication). Instead, the prevailing view is that stormwater pollutants are a downstream export. That is, they primarily influence downstream receiving water quality. Therefore, researchers have focused on how to estimate stormwater pollutant loads and then determine the water quality response of the rivers, lakes and estuaries that receive them. To be sure, there is an increasing recognition that runoff volume can influence physical and biological indicators within some receiving waters, but only a handful of studies have explored this area. In the second part of this review, we review the impacts of urbanization on downstream receiving waters, primarily from the standpoint of stormwater quality. We also evaluate whether the ICM can be extended to predict water quality in rivers, lakes and estuaries.

This chapter is organized as follows:

1.1 A Review of Recent Urban Stream Research and the ICM
1.2 Impacts of Urbanization on Downstream Receiving Waters
1.3 Implications of the ICM for Watershed Managers

1.1 A Review of Recent Urban Stream Research and the ICM

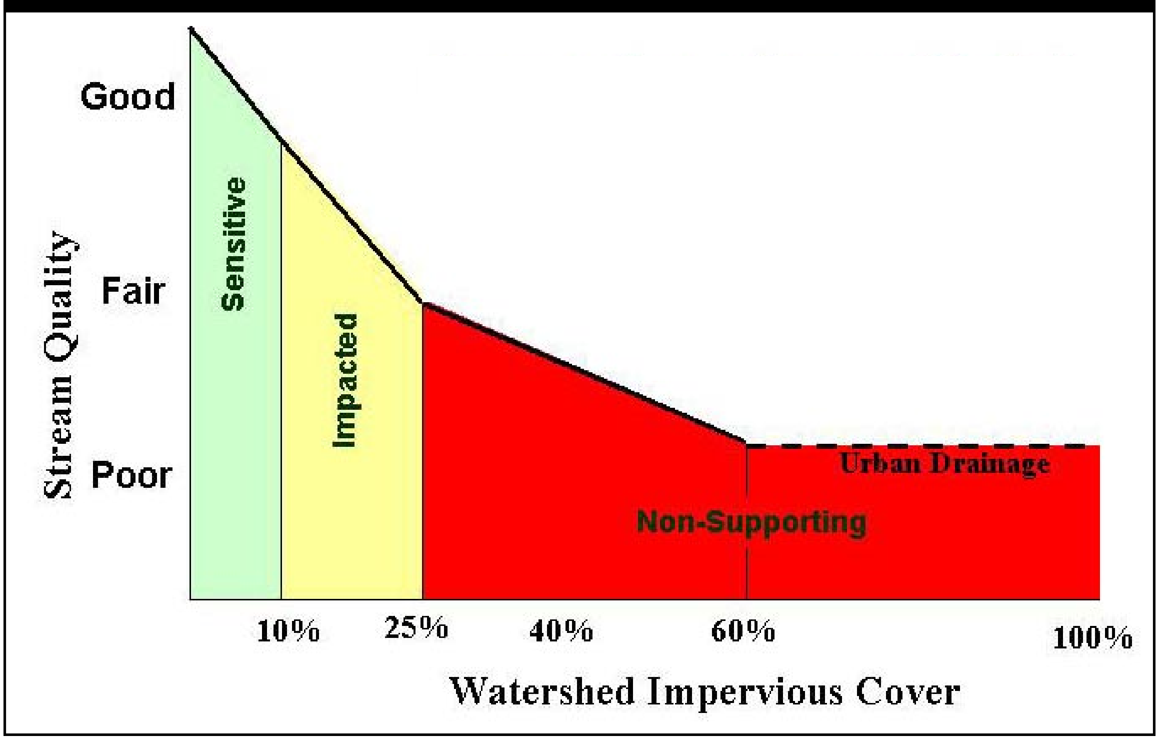
In 1994, the Center published "The Importance of Imperviousness," which outlined the scientific evidence for the relationship between IC and stream quality. At that time, about two dozen research studies documented a reasonably strong relationship between watershed IC and various indicators of stream quality. The research findings were subsequently integrated into the ICM (Schueler, 1994a and CWP, 1998). A brief summary of the basic assumptions of the ICM can be found in Figure 1. The ICM has had a major influence in watershed planning, stream classification and land use regulation in many communities. The ICM is a deceptively simple model that raises extremely complex and profound policy implications for watershed managers.

The ICM has been widely applied in many urban watershed settings for the purposes of small watershed planning, stream classification, and supporting restrictive development regulations and watershed zoning. As such, the ICM has stimulated intense debate among the planning, engineering and scientific communities. This debate is likely to soon spill over into the realm of politics and the courtroom, given its potential implications for local land use and environmental regulation. It is no wonder that the specter of scientific uncertainty is frequently invoked in the ICM debate, given the land use policy issues at stake. In this light, it is helpful to review the current strength of the evidence for and against the ICM.

The ICM is based on the following assumptions and caveats:

- Applies only to 1st, 2nd and 3rd order streams.
- Requires accurate estimates of percent IC, which is defined as the total amount of impervious cover over a subwatershed area.
- Predicts <u>potential</u> rather than <u>actual</u> stream quality. It can and should be expected that some streams will depart from the predictions of the model. For example, monitoring indicators may reveal poor water quality in a stream classified as "sensitive" or a surprisingly high biological diversity

Figure 1: Impervious Cover Model



score in a "non-supporting" one. Consequently, while IC can be used to initially diagnose stream quality, supplemental field monitoring is recommended to actually confirm it.

- Does not predict the precise score of an individual stream quality indicator but rather predicts the average behavior of a group of indicators over a range of IC. Extreme care should be exercised if the ICM is used to predict the fate of individual species (e.g., trout, salmon, mussels).

- "Thresholds" defined as 10 and 25% IC are not sharp "breakpoints," but instead reflect the expected transition of a composite of individual indicators in that range of IC. Thus, it is virtually impossible to distinguish real differences in stream quality indicators within a few percentage points of watershed IC (e.g., 9.9 vs. 10.1%).

- Should only be applied within the ecoregions where it has been tested, including the mid-Atlantic, Northeast, Southeast, Upper Midwest, and Pacific Northwest.

- Has not yet been validated for non-stream conditions (e.g., lakes, reservoirs, aquifers and estuaries).

- Does not currently predict the impact of watershed treatment.

In this section, we review available stream research to answer four questions about the ICM:

1. Does recent stream research still support the basic ICM?
2. What, if any, modifications need to be made to the ICM?
3. To what extent can watershed practices shift the predictions of the ICM?
4. What additional research is needed to test the ICM?

1.1.1 Strength of the Evidence for the ICM

Many researchers have investigated the IC/stream quality relationship in recent years. The Center recently undertook a comprehensive analysis of the literature to assess the scientific basis for the ICM. As of the end of 2002, we discovered more than 225 research studies that measured 26 different urban stream indicators within many regions of North America. We classified the research studies into three basic groups.

The first and most important group consists of studies that directly test the IC/stream quality indicator relationship by monitoring a large population of small watersheds. The second and largest group encompasses secondary studies that indirectly support the ICM by showing significant differences in stream quality indicators between urban and non-urban watersheds. The third and last group of studies includes widely accepted engineering models that explicitly use IC to directly predict stream quality indicators. Examples include engineering models that predict peak discharge or stormwater pollutant loads as a direct function of IC. In most cases, these relationships were derived from prior empirical research.

Table 1 provides a condensed summary of recent urban stream research, which shows the impressive growth in our understanding of urban streams and the watershed factors that influence them. A negative relationship between watershed development and nearly all of the 26 stream quality indicators has been established over many regions and scientific disciplines. About 50 primary studies have tested the IC/stream quality indicator relationship, with the largest number looking at biological indicators of stream health, such as the diversity of aquatic insects or fish. Another 150 or so secondary studies provide evidence that stream quality indicators are significantly different between urban and non-urban watersheds, which lends at least indirect support for the ICM and suggests that additional research to directly test the IC/stream quality indicator

**Table 1: The Strength of Evidence:
A Review of the Current Research on Urban Stream Indicators**

Stream Quality Indicator	#	IC	UN	EM	RV	Notes
Increased Runoff Volume	2	Y	Y	Y	N	extensive national data
Increased Peak Discharge	7	Y	Y	Y	Y	type of drainage system key
Increased Frequency of Bankfull Flow	2	?	Y	N	N	hard to measure
Diminished Baseflow	8	?	Y	N	Y	inconclusive data
Stream Channel Enlargement	8	Y	Y	N	Y	stream type important
Increased Channel Modification	4	Y	Y	N	?	stream enclosure
Loss of Riparian Continuity	4	Y	Y	N	?	can be affected by buffer
Reduced Large Woody Debris	4	Y	Y	N	?	Pacific NW studies
Decline in Stream Habitat Quality	11	Y	Y	N	?	
Changes in Pool Riffle/Structure	4	Y	Y	N	?	
Reduced Channel Sinuosity	1	?	Y	N	?	straighter channels
Decline in Streambed Quality	2	Y	Y	N	?	embeddedness
Increased Stream Temperature	5	Y	Y	N	?	buffers and ponds also a factor
Increased Road Crossings	3	?	Y	N	?	create fish barriers
Increased Nutrient Load	30+	?	Y	Y	N	higher stormwater EMCs
Increased Sediment Load	30+	?	Y	N	Y	higher EMCs in arid regions
Increased Metals & Hydrocarbons	20+	?	Y	Y	N	related to traffic/VMT
Increased Pesticide Levels	7	?	Y	N	Y	may be related to turf cover
Increased Chloride Levels	5	?	Y	N	Y	related to road density
Violations of Bacteria Standards	9	Y	Y	N	Y	indirect association
Decline in Aquatic Insect Diversity	33	Y	Y	N	N	IBI and EPT
Decline in Fish Diversity	19	Y	Y	N	N	regional IBI differences
Loss of Coldwater Fish Species	6	Y	Y	N	N	trout and salmon
Reduced Fish Spawning	3	Y	Y	N	?	
Decline in Wetland Plant Diversity	2	N	Y	N	?	water level fluctuation
Decline in Amphibian Community	5	Y	Y	N	?	few studies

***#**: total number of all studies that evaluated the indicator for urban watersheds*
***IC**: does balance of studies indicate a progressive change in the indicator as IC increases? Answers: Yes, No or No data (?)*
***UN**: If the answer to IC is no, does the balance of the studies show a change in the indicator from non-urban to urban watersheds? Yes or No*
***EM** Is the IC/stream quality indicator relationship implicitly assumed within the framework of widely accepted engineering models? Yes, No or No models yet exist (?)*
***RV**: If the relationship has been tested in more than one eco-region, does it generally show major differences between ecoregions? Answers: Yes, No, or insufficient data (?)*

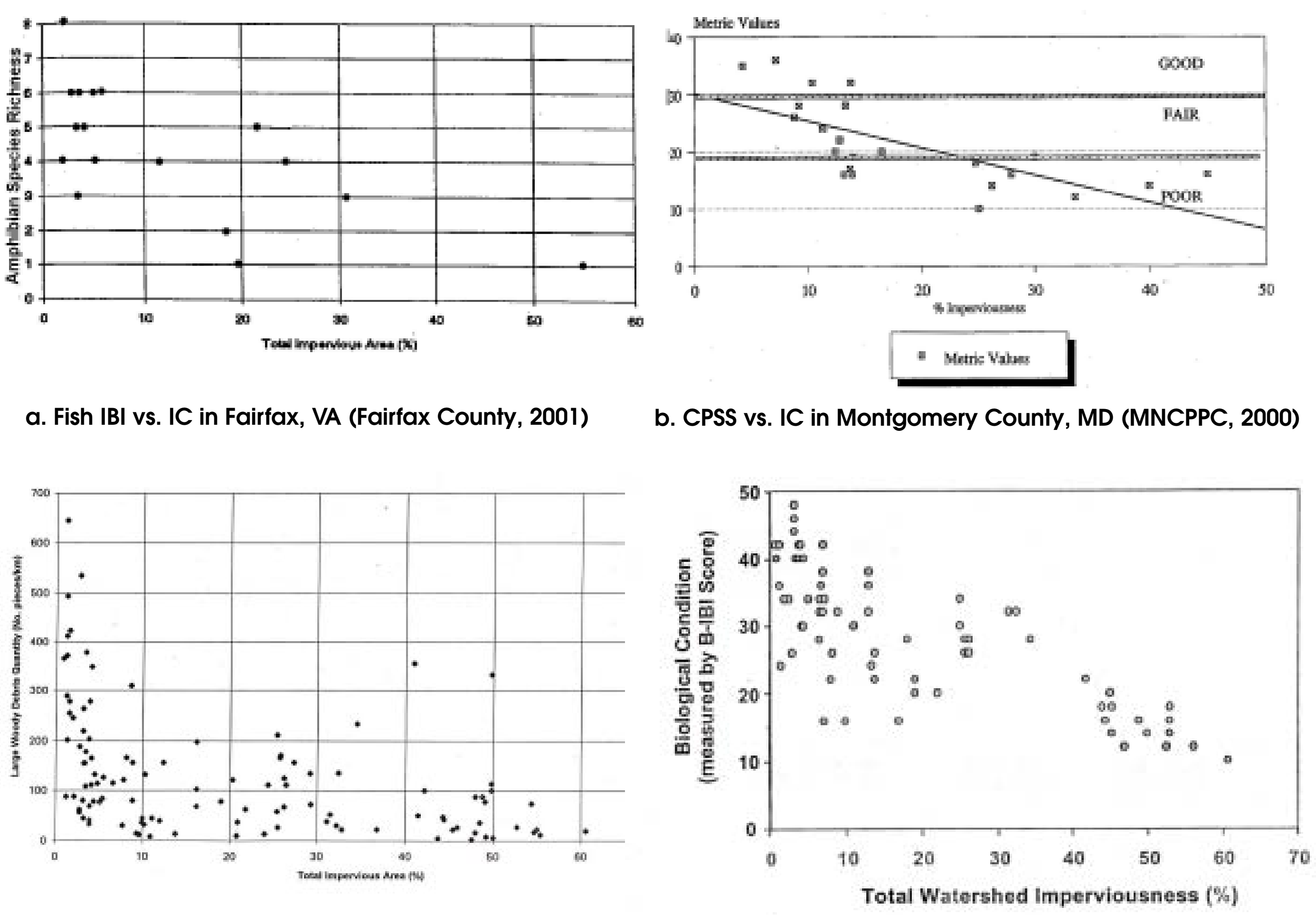
relationship is warranted. In some cases, the IC/stream quality indicator relationship is considered so strongly established by historical research that it has been directly incorporated into accepted engineering models. This has been particularly true for hydrological and water quality indicators.

1.1.2 Reinterpretation of the ICM

Although the balance of recent stream research generally supports the ICM, it also offers several important insights for interpreting and applying the ICM, which are discussed next.

Statistical Variability
Scatter is a common characteristic of most IC/stream quality indicator relationships. In most cases, the overall trend for the indicator is down, but considerable variation exists along the trend line. Often, linear regression equations between IC and individual stream quality indicators produce relatively modest correlation coefficients (reported r^2 of 0.3 to 0.7 are often considered quite strong).

Figure 2 shows typical examples of the IC/stream quality indicator relationship that illustrate the pattern of statistical variability. Variation is always encountered when dealing with urban stream data (particularly so for biological indicators), but several patterns exist that have important implications for watershed managers.



a. Fish IBI vs. IC in Fairfax, VA (Fairfax County, 2001)

b. CPSS vs. IC in Montgomery County, MD (MNCPPC, 2000)

c. Large Woody Debris vs. IC (Booth *et al.*, 1997)

d. Biological Condition vs. Total Watershed IC (Booth, 2000)

Figure 2: Typical Scatter Found in IC/Stream Quality Indicator Research

The first pattern to note is that the greatest scatter in stream quality indicator scores is frequently seen in the range of one to 10% IC. These streams, which are classified as "sensitive" according to the ICM, often exhibit low, moderate or high stream quality indicator scores, as shown in Figure 2. The key interpretation is that sensitive streams have the potential to attain high stream quality indicator scores, but may not always realize this potential.

Quite simply, the influence of IC in the one to 10% range is relatively weak compared to other potential watershed factors, such as percent forest cover, riparian continuity, historical land use, soils, agriculture, acid mine drainage or a host of other stressors. Consequently, watershed managers should never rely on IC alone to classify and manage streams in watersheds with less than 10% IC. Rather, they should evaluate a range of supplemental watershed variables to measure or predict actual stream quality within these lightly developed watersheds.

The second important pattern is that variability in stream quality indicator data is usually dampened when IC exceeds 10%, which presumably reflects the stronger influence of stormwater runoff on stream quality indicators. In particular, the chance that a stream quality indicator will attain a high quality score is sharply diminished at higher IC levels. This trend becomes pronounced within the 10 to 25% IC range and almost inevitable when watershed IC exceeds 25%. Once again, this pattern suggests that IC is a more robust and reliable indicator of overall stream quality beyond the 10% IC threshold.

Other Watershed Variables and the ICM

Several other watershed variables can potentially be included in the ICM. They include forest cover, riparian forest continuity and turf cover.

Forest cover (FC) is clearly the main rival to IC as a useful predictor of stream quality in urban watersheds, at least for humid regions of North America. In some regions, FC is simply the reciprocal of IC. For example, Horner and May (1999) have demonstrated a strong interrelationship between IC and FC for subwatersheds in the Puget Sound region (Figure 3). In other regions, however, "pre-

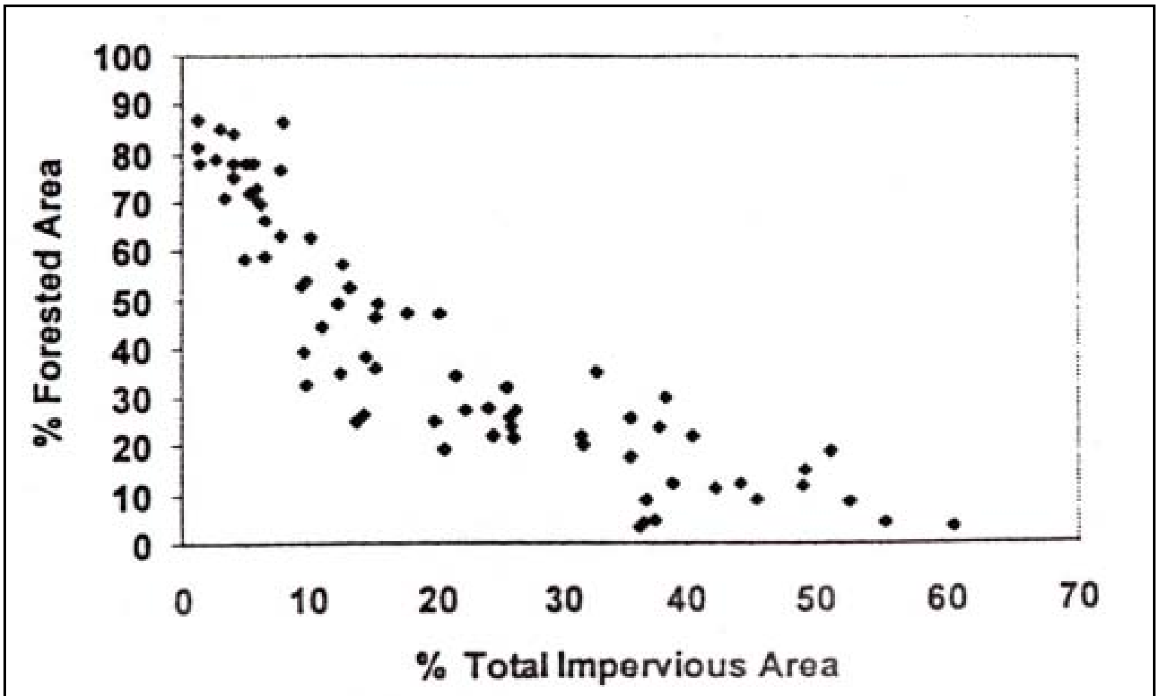


Figure 3: Relationship of IC and FC in Puget Sound Subwatersheds (Horner and May, 1999)

development" land use represents a complex mosaic of crop land, pasture and forest. Therefore, an inverse relationship between FC and IC may not be universal for subwatersheds that have witnessed many cycles of deforestation and cultivation.

It should come as little surprise that the progressive loss of FC has been linked to declining stream quality indicators, given that forested watersheds are often routinely used to define natural reference conditions for streams (Booth, 2000 and Horner *et al.*, 2001). Mature forest is considered to be the main benchmark for defining pre-development hydrology within a subwatershed, as well. Consequently, FC is perhaps the most powerful indicator to predict the quality of streams within the "sensitive" category (zero to 10% IC).

To use an extreme example, one would expect that stream quality indicators would respond quite differently in a subwatershed that had 90% FC compared to one that had 90% crop cover. Indeed, Booth (1991) suggests that stream quality can only be maintained when IC is limited to less than 10% <u>and</u> at least 65% FC is retained within a subwatershed. The key management implication then is that stream health is best managed by simultaneously minimizing the creation of IC and maximizing the preservation of native FC.

FC has also been shown to be useful in predicting the quality of terrestrial variables in a subwatershed. For example, the Mid-Atlantic Integrated Assessment (USEPA, 2000) has documented that watershed FC can reliably predict the diversity of bird, reptile and amphibian communities in the mid-Atlantic region. Moreover, the emerging discipline of landscape ecology provides watershed managers with a strong scientific foundation for deciding where FC should be conserved in a watershed. Conservation plans that protect and connect large forest fragments have been shown to be effective in conserving terrestrial species.

Riparian forest continuity has also shown considerable promise in predicting at least some indicators of stream quality for urban watersheds. Researchers have yet to come up with a standard definition of riparian continuity, but it is usually defined as the proportion of the perennial stream network in a subwatershed that has a fixed width of mature streamside forest. A series of studies indicates that aquatic insect and fish diversity are associated with high levels of riparian continuity (Horner *et al.,* 2001; May *et al.*, 1997; MNCPPC, 2000; Roth *et al.,* 1998). On the other hand, not much evidence has been presented to support the notion that riparian continuity has a strong influence on hydrology or water quality indicators.

One watershed variable that received little attention is the fraction of watershed area maintained in turf cover (TC). Grass often comprises the largest fraction of land area within low-density residential development and could play a significant role in streams that fall within the "impacted" category (10 to 25% IC). Although lawns are pervious, they have sharply different properties than the forests and farmlands they replace (i.e., irrigation, compacted soils, greater runoff, and much higher input of fertilizers and pesticides, etc.). It is interesting to speculate whether the combined area of IC and TC might provide better predictions about stream health than IC area alone, particularly within impacted subwatersheds.

Several other watershed variables might have at least supplemental value in predicting stream quality. They include the presence of extensive wetlands and/or beaverdam complexes in a subwatershed; the dominant form of drainage present in the watershed (tile drains, ditches, swales, curb and gutters, storm drain pipes); the average age of development; and the proximity of sewer lines to the stream. As far as we could discover, none of these variables has been systematically tested in a controlled population of small watersheds. We have observed that these factors could be important in our field investigations and often measure them to provide greater insight into subwatershed behavior.

Lastly, several watershed variables that are closely related to IC have been proposed to predict stream quality. These include population, percent urban land, housing density, road density and other indices of watershed development. As might be expected, they generally track the same trend as IC, but each has some significant technical limitations and/or difficulties in actual planning applications (Brown, 2000).

Individual vs. Multiple Indicators

The ICM does not predict the precise score of individual stream quality indicators, but rather predicts the average behavior of a group of indicators over a range of IC. Extreme care should be exercised if the ICM is used to predict the fate of individual indicators and/or species. This is particularly true for sensitive aquatic species, such as trout, salmon, and freshwater mussels. When researchers have examined the relationship between IC and individual species, they have often discovered lower thresholds for harm. For example, Boward *et al.* (1999) found that brook trout were not found in subwatersheds that had more than 4% IC in Maryland, whereas Horner and May (1999) asserted an 8% threshold for sustaining salmon in Puget Sound streams.

The key point is that if watershed managers want to maintain an individual species, they should be very cautious about adopting the 10% IC threshold. The essential habitat requirements for many sensitive or endangered species are probably determined by the *most sensitive* stream quality indicators, rather than the *average behavior* of all stream quality indicators.

Direct Causality vs. Association

A strong relationship between IC and declining stream quality indicators does not always mean that the IC is directly responsible for the decline. In some cases, however, causality can be demonstrated. For example, increased stormwater runoff volumes are directly caused by the percentage of IC in a subwatershed, although other factors such as conveyance, slope and soils may play a role.

In other cases, the link is much more indirect. For these indicators, IC is merely an index of the cumulative amount of watershed development, and more IC simply means that a greater number of known or unknown pollutant sources or stressors are present. In yet other cases, a causal link appears likely but has not yet been scientifically demonstrated. A good example is the more than 50 studies that have explored how fish or aquatic insect diversity changes in response to IC. While the majority of these studies consistently shows a very strong negative association between IC and biodiversity, they do not really establish which stressor or combination of stressors contributes most to the decline. The widely accepted theory is that IC changes stream hydrology, which degrades stream habitat, and in turn leads to reduced stream biodiversity.

Regional Differences

Currently, the ICM has been largely confirmed within the following regions of North America: the mid-Atlantic, the Northeast, the Southeast, the upper Midwest and the Pacific Northwest. Limited testing in Northern California, the lower Midwest and Central Texas generally agrees with the ICM. The ICM has not been tested in Florida, the Rocky Mountain West, and the Southwest. For a number of reasons, it is not certain if the ICM accurately predicts biological indicators in arid and semiarid climates (Maxted, 1999).

Measuring Impervious Cover

Most researchers have relied on total impervious cover as the basic unit to measure IC at the subwatershed level. The case has repeatedly been made that effective impervious cover is probably a superior metric (e.g., only counting IC that is hydraulically connected to the drainage system). Notwithstanding, most researchers have continued to measure total IC because it is generally quicker and does not require extensive (and often subjective) engineering judgement as to whether it is connected or not. Researchers have used a wide variety of techniques to estimate subwatershed IC, including satellite imagery, analysis of aerial photographs, and derivation from GIS land use layers. Table 2 presents some standard land use/IC relationships that were developed for suburban regions of the Chesapeake Bay.

Table 2: Land Use/IC Relationships for Suburban Areas of the Chesapeake Bay (Cappiella and Brown, 2001)					
Land Use Category	**Sample Number (N)**	**Mean IC (SE)**	**Land Use Category**	**Sample Number (N)**	**Mean IC (SE)**
Agriculture	8	**1.9** – 0.3	Institutional	30	**34.4** – 3.45
Open Urban Land	11	**8.6** – 1.64	Light	20	**53.4** – 2.8
2 Acre Lot Residential	12	**10.6** – 0.65	Commercia	23	**72.2** – 2.0
1 Acre Lot Residential	23	**14.3** – 0.53	Churches	8	**39.9** – 7.8 1
1/2 Acre Lot Residential	20	**21.2** – 0.78	Schools	13	**30.3** – 4.8
1/4 Acre Lot Residential	23	**27.8** – 0.60	Municipals	9	**35.4** – 6.3
1/8 Acre Lot Residential	10	**32.6** – 1.6	Golf	4	**5.0** – 1.7
Townhome Residential	20	**40.9** – 1.39	Cemeteries	3	**8.3** – 3.5
Multifamily Residential	18	**44.4** – 2.0	Parks	4	**12.5** – 0.7

Three points are worth noting. First, it is fair to say that most researchers have spent more quality control effort on their stream quality indicator measurements than on their subwatershed IC estimates. At the current time, no standard protocol exists to estimate subwatershed IC, although Cappiella and Brown (2001) presented a useful method. At best, the different methods used to measure IC make it difficult to compare results from different studies, and at worst, it can introduce an error term of perhaps +/- 10% from the true value within an individual subwatershed. Second, it is important to keep in mind that IC is not constant over time; indeed, major changes in subwatershed IC have been observed within as few as two years. Consequently, it is sound practice to obtain subwatershed IC estimates from the most recent possible mapping data, to ensure that it coincides with stream quality indicator measurements. Lastly, it is important to keep in mind that most suburban and even rural zoning categories exceed 10% IC (see Table 2). Therefore, from a management standpoint, planners should try to project future IC, in order to determine the future stream classification for individual subwatersheds.

1.1.3 Influence of Watershed Treatment Practices on the ICM

The most hotly debated question about the ICM is whether widespread application of watershed practices such as stream buffers or stormwater management can mitigate the impact of IC, thereby allowing greater development density for a given watershed. At this point in time, there are fewer than 10 studies that directly bear on this critical question. Before these are reviewed, it is instructive to look at the difficult technical and scientific issues involved in detecting the effect of watershed treatment, given its enormous implications for land use control and watershed management.

The first tough issue is how to detect the effect of watershed treatment, given the inherent scatter seen in the IC/stream quality indicator relationship. Figure 4 illustrates the “double scatter” problem, based on three different urban stream research studies in Delaware, Maryland and Washington. A quick inspection of the three plots shows how intrinsically hard it is to distinguish the watershed treatment effect. As can be seen, stream quality indicators in subwatersheds with treatment tend to

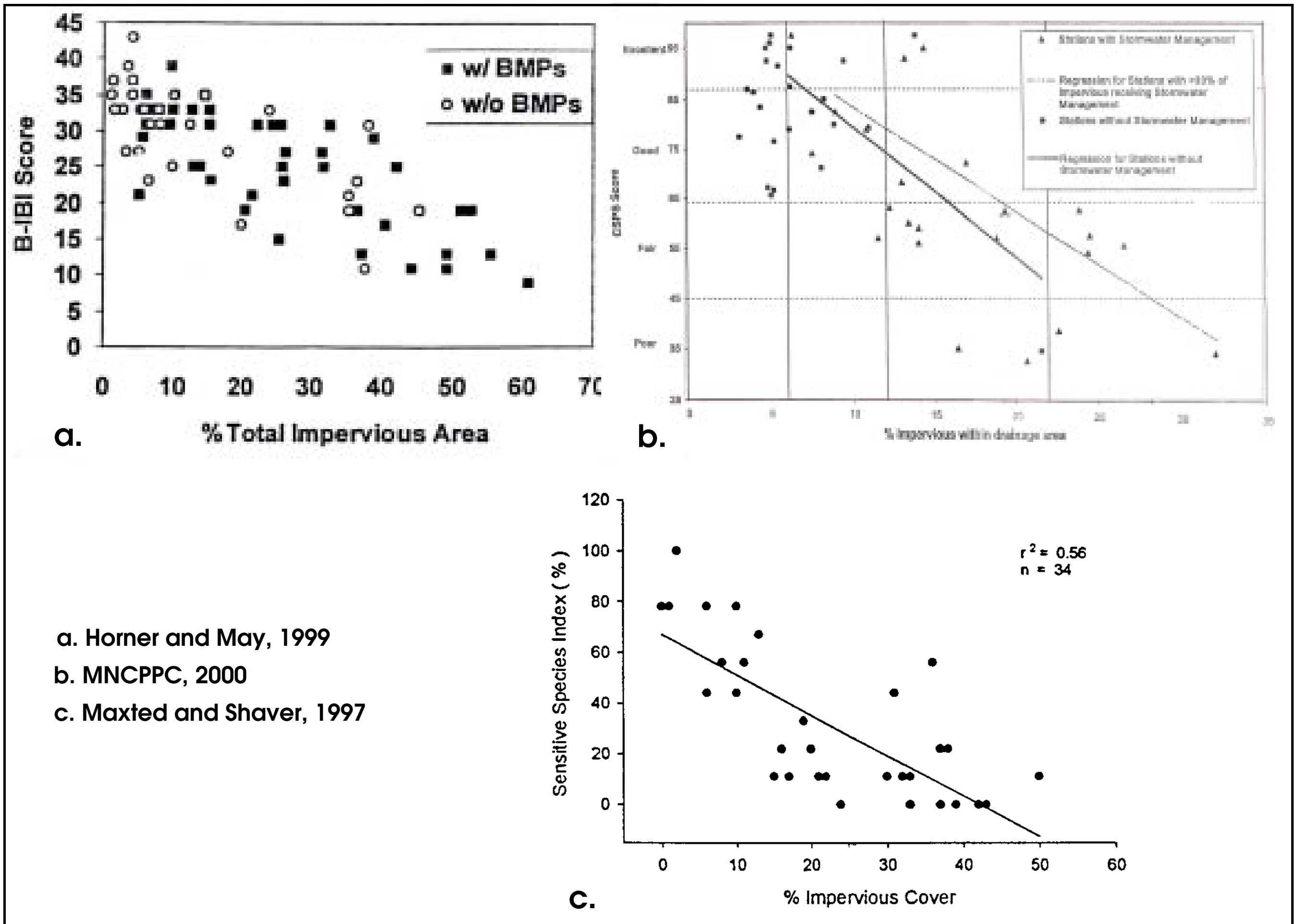


Figure 4: The Double Scatter Problem: Difficulties in Detecting the Effect of Watershed Treatment

overplot those in subwatersheds that lack treatment. While subtle statistical differences may be detected, they are not visibly evident. This suggests that the impact of watershed treatment would need to be extremely dramatic to be detected, given the inherent statistical variability seen in small watersheds (particularly so within the five to 25% IC range where scatter is considerable).

In an ideal world, a watershed study design would look at a controlled population of small urban watersheds that were developed with and without watershed practices to detect the impact of "treatment." In the real world, however, it is impossible to strictly control subwatershed variables. Quite simply, no two subwatersheds are ever alike. Each differs slightly with respect to drainage area, IC, forest cover, riparian continuity, historical land use, and percent watershed treatment. Researchers must also confront other real world issues when designing their watershed treatment experiments.

For example, researchers must carefully choose which indicator or group of indicators will be used to define stream health. IC has a negative influence on 26 stream quality indicators, yet nearly all of the watershed treatment research so far has focused on just a few biological indicators (e.g., aquatic insect or fish diversity) to define stream health. It is conceivable that watershed treatment might have no effect on biological indicators, yet have a positive influence on hydrology, habitat or water quality indicators. At this point, few of these indicators have been systematically tested in the field. It is extremely doubtful that any watershed practice can simultaneously improve or mitigate all 26 stream quality indicators, so researchers must carefully interpret the outcomes of their watershed treatment experiments.

The second issue involves how to quantify watershed treatment. In reality, watershed treatment collectively refers to dozens of practices that are installed at individual development sites in the many years or even decades it takes to fully "build out" a subwatershed. Several researchers have discovered that watershed practices are seldom installed consistently across an entire subwatershed. In some cases, less than a third of the IC in a subwatershed was actually treated by any practice, because development occurred prior to regulations; recent projects were exempted, waived or grandfathered; or practices were inadequately constructed or maintained (Horner and May, 1999 and MNCPPC, 2000).

Even when good coverage is achieved in a watershed, such as the 65 to 90% reported in studies of stormwater ponds (Jones *et al*., 1996; Maxted, 1999; Maxted and Shaver, 1997), it is still quite difficult to quantify the actual quality of treatment. Often, each subwatershed contains its own unique mix of stormwater practices installed over several decades, designed under diverse design criteria, and utilizing widely different stormwater technologies. Given these inconsistencies, researchers will need to develop standard protocols to define the extent and quality of watershed treatment.

Effect of Stormwater Ponds

With this in mind, the effect of stormwater ponds and stream buffers can be discussed. The effect of larger stormwater ponds in mitigating the impacts of IC in small watersheds has received the most scrutiny to date. This is not surprising, since larger ponds often control a large fraction of their contributing subwatershed area (e.g. 100 to 1,000 acres) and are located on the stream itself, therefore lending themselves to easier monitoring. Three studies have evaluated the impact of large stormwater ponds on downstream aquatic insect communities (Jones *et al*., 1996; Maxted and Shaver, 1997; Stribling *et al*., 2001). Each of these studies was conducted in small headwater subwatersheds in the mid-Atlantic Region, and none was able to detect major differences in aquatic insect diversity in streams with or without stormwater ponds.

Four additional studies statistically evaluated the stormwater treatment effect in larger populations of small watersheds with varying degrees of IC (Horner and May, 1999; Horner *et al.,* 2001; Maxted, 1999; MNCPPC, 2000). These studies generally sampled larger watersheds that had many stormwater practices but not necessarily complete watershed coverage. In general, these studies detected a small but positive effect of stormwater treatment relative to aquatic insect diversity. This positive effect was typically seen only in the range of five to 20% IC and was generally undetected beyond about 30% IC. Although each author was hesitant about interpreting his results, all generally agreed that perhaps as much as 5% IC could be added to a subwatershed while maintaining aquatic insect diversity, given effective stormwater treatment. Forest retention and stream buffers were found to be very important, as well. Horner *et al.* (2001) reported a somewhat stronger IC threshold for various species of salmon in Puget Sound streams.

Some might conclude from these initial findings that stormwater ponds have little or no value in maintaining biological diversity in small streams. However, such a conclusion may be premature for several reasons. First, the generation of stormwater ponds that was tested was not explicitly designed to protect stream habitat or to prevent downstream channel erosion, which would presumably promote aquatic diversity. Several states have recently changed their stormwater criteria to require extended detention for the express purpose of preventing downstream channel erosion, and these new criteria may exert a stronger influence on aquatic diversity. Instead, their basic design objective was to maximize pollutant removal, which they did reasonably well.

The second point to stress is that streams with larger stormwater ponds should be considered “regulated streams” (Ward and Stanford, 1979), which have a significantly altered aquatic insect community downstream of the ponds. For example, Galli (1988) has reported that on-stream wet stormwater ponds shift the trophic structure of the aquatic insect community. The insect community above the pond was dominated by shredders, while the insect community below the pond was dominated by scrapers, filterers and collectors. Of particular note, several pollution-sensitive species were eliminated below the pond. Galli reported that changes in stream temperatures, carbon supply and substrate fouling were responsible for the downstream shift in the aquatic insect community. Thus, while it is clear that large stormwater ponds can be expected to have a negative effect on aquatic insect diversity, they could still exert positive influence on other stream quality indicators.

Effect of Stream Buffers

A handful of studies have evaluated biological indicator scores for urban streams that have extensive forest buffers, compared to streams where they were mostly or completely absent (Horner and May, 1999; Horner *et al.,* 2001; May *et al.*, 1997; MNCPPC, 2000; Roth *et al.,* 1998; Steedman, 1988). Biological indicators included various indices of aquatic insect, fish and salmon diversity. Each study sampled a large population of small subwatersheds over a range of IC and derived a quantitative measure to express the continuity, width and forest cover of the riparian buffer network within each subwatershed. Riparian forests were hypothesized to have a positive influence on stream biodiversity, given the direct ways they contribute to stream habitat (e.g., shading, woody debris, leaf litter, bank stability, and organic carbon supply).

All five studies detected a small to moderate positive effect when forested stream buffers were present (frequently defined as at least two-thirds of the stream network with at least 100 feet of stream side forest). The greatest effect was reported by Horner and May (1999) and Horner *et al.* (2001) for salmon streams in the Puget Sound ecoregion. If excellent riparian habitats were preserved, they generally reported that fish diversity could be maintained up to 15% IC, and good aquatic insect diversity could be maintained with as much as 30% IC. Steedman (1988) reported a somewhat smaller effect for Ontario streams. MNCPPC (2000), May *et al.* (1997), and Roth *et al.* (1998) could not find a statistically significant relationship between riparian quality and urban stream quality indicators but did report that most outliers (defined as higher IC subwatersheds with unusually high biological indicator scores) were generally associated with extensive stream side forest.

1.1.4 Recommendations for Further ICM Research

At this point, we recommend three research directions to improve the utility of the ICM for watershed managers. The **first direction** is to expand basic research on the relationship between IC and stream quality indicators that have received little scrutiny. In particular, more work is needed to define the relationship between IC and hydrological and physical indicators such as the following:

- Physical loss or alteration of the stream network
- Stream habitat measures
- Riparian continuity
- Baseflow conditions during dry weather

In addition, more watershed research is needed in ecoregions and physiographic areas where the ICM has not yet been widely tested. Key areas include Florida, arid and semiarid climates, karst areas and mountainous regions. The basic multiple subwatershed monitoring protocol set forth by Schueler (1994a) can be used to investigate IC/stream quality relationships, although it would be wise to measure a wider suite of subwatershed variables beyond IC (e.g., forest cover, turf cover, and riparian continuity).

The **second** research direction is to more clearly define the impact of watershed treatment on stream quality indicators. Based on the insurmountable problems encountered in controlling variation at the subwatershed level, it may be necessary to abandon the multiple watershed or paired watershed sampling approaches that have been used to date. Instead, longitudinal monitoring studies within individual subwatersheds may be a more powerful tool to detect the effect of watershed treatment. These studies could track changes in stream quality indicators in individual subwatersheds over the entire development cycle: pre-development land use, clearing, construction, build out, and post construction. In most cases, longitudinal studies would take five to 10 years to complete, but they would allow watershed managers to measure and control the inherent variability at the subwatershed level and provide a "before and after" test of watershed treatment. Of course, a large population of test subwatersheds would be needed to satisfactorily answer the watershed treatment question.

The **third** research direction is to monitor more non-supporting streams, in order to provide a stronger technical foundation for crafting more realistic urban stream standards and to see how they respond to various watershed restoration treatments. As a general rule, most researchers have been more interested in the behavior of sensitive and impacted streams. The non-supporting stream category spans a wide range of IC, yet we do not really understand how stream quality indicators behave over the entire 25 to 100% IC range.

For example, it would be helpful to establish the IC level at the upper end of the range where streams are essentially transformed into an artificial conveyance system (i.e., become pipes or artificial channels). It would also be interesting to sample more streams near the lower end of the non-supporting category (25 to 35% IC) to detect whether stream quality indicators respond to past watershed treatment or current watershed restoration efforts. For practical reasons, the multiple subwatershed sampling approach is still recommended to characterize indicators in non-supporting streams. However, researchers will need to screen a large number of non-supporting subwatersheds in order to identify a few subwatersheds that are adequate for subsequent sampling (i.e., to control for area, IC, development age, percent watershed treatment, type of conveyance systems, etc.).

1.2 Impacts of Urbanization on Downstream Receiving Waters

In this section, we review the impacts of urbanization on downstream receiving waters, primarily from the standpoint of impacts caused by poor stormwater quality. We begin by looking at the relationship between IC and stormwater pollutant loadings. Next, we discuss the sensitivity of selected downstream receiving waters to stormwater pollutant loads. Lastly, we examine the effect of watershed treatment in reducing stormwater pollutant loads.

1.2.1 Relationship Between Impervious Cover and Stormwater Quality

Urban stormwater runoff contains a wide range of pollutants that can degrade downstream water quality (Table 3). Several generalizations can be supported by the majority of research conducted to date. First, the unit area pollutant load delivered by stormwater runoff to receiving waters increases in direct proportion to watershed IC. This is not altogether surprising, since pollutant load is the product of the average pollutant concentration and stormwater runoff volume. Given that runoff volume increases in direct proportion to IC, pollutant loads must automatically increase when IC increases, as long the average pollutant concentration stays the same (or increases). This relationship is a central assumption in most simple and complex pollutant loading models (Bicknell *et al.*, 1993; Donigian and Huber, 1991; Haith *et al.*, 1992; Novotny and Chester, 1981; NVPDC, 1987; Pitt and Voorhees, 1989).

The second generalization is that stormwater pollutant concentrations are generally similar

Table 3: Summary of Urban Stormwater Pollutant Loads on Quality of Receiving Waters

Pollutants in Urban Stormwater	WQ Impacts To:					Higher Unit Load?	Load a function of IC?	Other Factors Important in Loading
	R	L	E	A	W			
Suspended Sediment	Y	Y	Y	N	Y	Y (ag)	Y	channel erosion
Total Nitrogen	N	N	Y	Y	N	Y (ag)	Y	septic systems
Total Phosphorus	Y	Y	N	N	Y	Y (ag)	Y	tree canopy
Metals	Y	Y	Y	?	N	Y	Y	vehicles
Hydrocarbons	Y	Y	Y	Y	Y	Y	?	related to VMTs and hotspots
Bacteria/Pathogens	Y	Y	Y	N	Y	Y	Y	many sources
Organic Carbon	N	?	?	?	Y	Y	Y	
MTBE	N	N	N	Y	Y	Y	?	roadway, VMTs
Pesticides	?	?	?	?	Y	Y	?	turf/landscaping
Chloride	?	Y	N	Y	Y	Y	?	road density
Trash/Debris	Y	Y	Y	N	?	Y	Y	curb and gutters

Major Water Quality Impacts Reported for:
R = River, L = Lake, E = Estuary, A = Aquifer, W = Surface Water Supply
Higher Unit Area Load? Yes (compared to all land uses) (ag): with exception of cropland
Load a function of IC? Yes, increases proportionally with IC

at the catchment level, regardless of the mix of IC types monitored (e.g., residential, commercial, industrial or highway runoff). Several hundred studies have examined stormwater pollutant concentrations from small urban catchments and have generally found that the variation within a catchment is as great as the variation between catchments. Runoff concentrations tend to be log-normally distributed, and therefore the long term "average" concentration is best expressed by a median value. It should be kept in mind that researchers have discovered sharp differences in pollutant concentrations for smaller, individual components of IC (e.g., rooftops, parking lots, streets, driveways and the like). Since most urban catchments are composed of many kinds of IC, this mosaic quality tempers the variability in long term pollutant concentrations at the catchment or subwatershed scale.

The third generalization is that median concentrations of pollutants in urban runoff are usually higher than in stormwater runoff from most other non-urban land uses. Consequently, the unit area nonpoint pollutant load generated by urban land normally exceeds that of nearly all watershed land uses that it replaces (forest, pasture, cropland, open space — see Table 3). One important exception is cropland, which often produces high unit area sediment and nutrient loads in many regions of the country. In these watersheds, conversion of intensively managed crops to low density residential development may actually result in a slightly decreased sediment or nutrient load. On the other hand, more intensive land development (30% IC or more) will tend to equal or exceed cropland loadings.

The last generalization is that the effect of IC on stormwater pollutant loadings tends to be weakest for subwatersheds in the one to 10% IC range. Numerous studies have suggested that other watershed and regional factors may have a stronger influence, such as the underlying geology, the amount of carbonate rock in the watershed, physiographic region, local soil types, and most important, the relative fraction of forest and crop cover in the subwatershed (Herlihy *et al*., 1998 and Liu *et al.,* 2000). The limited influence of IC on pollutant loads is generally consistent with the finding for hydrologic, habitat and biological indicators over this narrow range of IC. Once again, watershed managers are advised to track other watershed indicators in the sensitive stream category, such as forest or crop cover.

1.2.2 Water Quality Response to Stormwater Pollution

As noted in the previous section, most ICM research has been done on streams, which are directly influenced by increased stormwater. Many managers have wondered whether the ICM also applies to downstream receiving waters, such as lakes, water supply reservoirs and small estuaries. In general, the exact water quality response of downstream receiving waters to increased nonpoint source pollutant loads depends on many factors, including the specific pollutant, the existing loading generated by the converted land use, and the geometry and hydraulics of the receiving water. Table 3 indicates the sensitivity of rivers, lakes, estuaries, aquifers and water supply reservoirs to various stormwater pollutants.

Lakes and the ICM

The water column and sediments of urban lakes are impacted by many stormwater pollutants, including sediment, nutrients, bacteria, metals, hydrocarbons, chlorides, and trash/debris. Of these pollutants, limnologists have always regarded phosphorus as the primary lake management concern, given that more than 80% of urban lakes experience symptoms of eutrophication (CWP, 2001a).

In general, phosphorus export steadily increases as IC is added to a lake watershed, although the precise amount of IC that triggers eutrophication problems is unique to each urban lake. With a little effort, it is possible to calculate the specific IC threshold for an individual lake, given its internal geometry, the size of its contributing watershed, current in-lake phosphorus concentration, degree of watershed treatment, and the desired water quality goals for the lake (CWP, 2001a). As a general rule, most lakes are extremely sensitive to increases in phosphorus loads caused by watershed IC. Exceptions include lakes that are unusually deep and/or have very small drainage area/lake area ratios. In most lakes, however, even a small amount of watershed development will result in an upward shift in trophic status (CWP, 2001a).

Reservoirs and the ICM

While surface water supply reservoirs respond to stormwater pollutant loads in the same general manner as lakes, they are subject to stricter standards because of their uses for drinking water. In particular, water supply reservoirs are particularly sensitive to increased turbidity, pathogens, total organic carbon, chlorides, metals, pesticides and hydrocarbon loads, in addition to phosphorus (Kitchell, 2001). While some pollutants can be removed or reduced through expanded filtering and treatment at drinking water intakes, the most reliable approach is to protect the source waters through watershed protection and treatment.

Consequently, we often recommend that the ICM be used as a "threat index" for most drinking water supplies. Quite simply, if current or future development is expected to exceed 10% IC in the contributing watershed, we recommend that a very aggressive watershed protection strategy be implemented (Kitchell, 2001). In addition, we contend that drinking water quality cannot be sustained once watershed IC exceeds 25% and have yet to find an actual watershed where a drinking water utility has been maintained under these conditions.

Small Tidal Estuaries and Coves and the ICM

The aquatic resources of small tidal estuaries, creeks, and coves are often highly impacted by watershed development and associated activities, such as boating/marinas, wastewater discharge, septic systems, alterations in freshwater flow and wetland degradation and loss. Given the unique impacts of eutrophication on the marine system and stringent water quality standards for shellfish harvesting, the stormwater pollutants of greatest concern in the estuarine water column are nitrogen and fecal coliform bacteria. Metals and hydrocarbons in stormwater runoff can also contaminate bottom sediments, which can prove toxic to local biota (Fortner *et al*., 1996; Fulton *et al*., 1996; Kucklick *et al*., 1997; Lerberg *et al.*, 2000; Sanger *et al.,* 1999; Vernberg *et al.*, 1992).

While numerous studies have demonstrated that physical, hydrologic, water quality and biological indicators differ in urban and non-urban coastal watersheds, only a handful of studies have used watershed IC as an indicator of estuarine health. These studies show significant correlations with IC, although degradation thresholds may not necessarily adhere to the ICM due to tidal dilution and dispersion. Given the limited research, it is not fully clear if the ICM can be applied to coastal systems without modification.

Atmospheric deposition is considered a primary source of nitrogen loading to estuarine watersheds. Consequently, nitrogen loads in urban stormwater are often directly linked to IC. Total nitrogen loads have also been linked to groundwater input, especially from subsurface discharges from septic systems, which are common in low density coastal development (Swann, 2001; Valiela *et al*., 1997; Vernberg *et al*., 1996a). Nitrogen is generally considered to be the limiting nutrient in estuarine systems, and increased loading has been shown to increase algal and phytoplankton biomass and cause shifts in the phytoplankton community and food web structure that may increase the potential for phytoplankton blooms and fish kills (Bowen and Valiela, 2001; Evgenidou *et al*., 1997; Livingston, 1996).

Increased nitrogen loads have been linked to declining seagrass communities, finfish populations, zooplankton reproduction, invertebrate species richness, and shellfish populations (Bowen and Valiela, 2001; Rutkowski *et al*., 1999; Short and Wyllie-Echeverria, 1996; Valiela and Costa, 1988). Multiple studies have shown significant increases in nitrogen loading as watershed land use becomes more urban (Valiela *et al.,* 1997; Vernberg *et al.* 1996a; Wahl *et al.,* 1997). While a few studies link nitrogen loads with building and population density, no study was found that used IC as an indicator of estuarine nitrogen loading.

The second key water quality concern in small estuaries is high fecal coliform levels in stormwater runoff, which can lead to the closure of shellfish beds and swimming beaches. Waterfowl and other wildlife have also been shown to contribute to fecal coliform loading (Wieskel *et al.*, 1996). Recent research has shown that fecal coliform standards are routinely violated during storm events at very low levels of IC in coastal watersheds (Mallin *et al.,* 2001; Vernberg *et al.*, 1996b; Schueler, 1999). Maiolo and Tschetter (1981) found a significant correlation between human population and closed shellfish acreage in North Carolina, and Duda and Cromartie (1982) found greater fecal coliform densities when septic tank density and IC increased, with an approximate threshold at 10% watershed IC.

Recently, Mallin *et al.* (2000) studied five small North Carolina estuaries of different land uses and showed that fecal coliform levels were significantly correlated with watershed population, developed land and IC. Percent IC was the most statistically significant indicator and could explain 95% of the variability in fecal coliform concentrations. They also found that shellfish bed closures were possible in watersheds with less than 10% IC, common in watersheds above 10% IC, and almost certain in watersheds above 20% IC. While higher fecal coliform levels were observed in developed watersheds, salinity, flushing and proximity to pollution sources often resulted in higher concentrations at upstream locations and at high tides (Mallin *et al.*, 1999). While these studies support the ICM, more research is needed to prove the reliability of the ICM in predicting shellfish bed closures based on IC.

Several studies have also investigated the impacts of urbanization on estuarine fish, macrobenthos and shellfish communities. Increased PAH accumulation in oysters, negative effects of growth in juvenile sheepshead minnows, reduced molting efficiency in copepods, and reduced numbers of grass shrimp have all been reported for urban estuaries as compared to forested estuaries (Fulton *et al.,* 1996). Holland *et al. (*1997) reported that the greatest abundance of penaid shrimp and mummichogs was observed in tidal creeks with forested watersheds compared to those with urban cover. Porter *et al.* (1997) found lower grass shrimp abundance in small tidal creeks adjacent to commercial and urban development, as compared to non-urban watersheds.

Lerberg *et al.* (2000) studied small tidal creeks and found that highly urban watersheds (50% IC) had the lowest benthic diversity and abundance as compared to suburban and forested creeks, and benthic communities were numerically dominated by tolerant oligochaetes and polychaetes. Suburban watersheds (15 to 35% IC) also showed signs of degradation and had some pollution tolerant macrobenthos, though not as markedly as urban creeks. Percent abundance of pollution-indicative species showed a marked decline at 30% IC, and the abundance of pollution-sensitive species also significantly correlated with IC (Lerberg *et al*., 2000). Holland *et al*. (1997) reported that the variety and food availability for juvenile fish species was impacted at 15 to 20% IC.

Lastly, a limited amount of research has focused on the direct impact of stormwater runoff on salinity and hypoxia in small tidal creeks. Blood and Smith (1996) compared urban and forested watersheds and found higher salinities in urban watersheds due to the increased number of impoundments. Fluctuations in salinity have been shown to affect shellfish and other aquatic populations (see Vernberg, 1996b). When urban and forested watersheds were compared, Lerberg *et al.* (2000) reported that higher salinity fluctuations occurred most often in developed watersheds; significant correlations with salinity range and IC were also determined. Lerberg *et al.* (2000) also found that the most severe and frequent hypoxia occurred in impacted salt marsh creeks and that dissolved oxygen dynamics in tidal creeks were comparable to dead-end canals common in residential marina-style coastal developments. Suburban watersheds (15 to 35% IC) exhibited signs of degradation and had some pollution-tolerant macrobenthic species, though not to the extent of urban watersheds (50% IC).

In summary, recent research suggests that indicators of coastal watershed health are linked to IC. However, more research is needed to clarify the relationship between IC and estuarine indicators in small tidal estuaries and high salinity creeks.

1.2.3 Effect of Watershed Treatment on Stormwater Quality

Over the past two decades, many communities have invested in watershed protection practices, such as stormwater treatment practices (STPs), stream buffers, and better site design, in order to reduce pollutant loads to receiving waters. In this section, we review the effect of watershed treatment on the quality of stormwater runoff.

Effect of Stormwater Treatment Practices

We cannot directly answer the question as to whether or not stormwater treatment practices can significantly reduce water quality impacts at the watershed level, simply because no controlled monitoring studies have yet been conducted at this scale. Instead, we must rely on more indirect research that has tracked the change in mass or concentration of pollutants as they travel through individual stormwater treatment practices. Thankfully, we have an abundance of these performance studies, with nearly 140 monitoring studies evaluating a diverse range of STPs, including ponds, wetlands, filters, and swales (Winer, 2000).

These studies have generally shown that stormwater practices have at least a moderate ability to remove many pollutants in urban stormwater. Table 4 provides average removal efficiency rates for a range of practices and stormwater pollutants, and Table 5 profiles the mean storm outflow concentrations for various practices. As can be seen, some groups of practices perform better than others in removing certain stormwater pollutants. Consequently, managers need to carefully choose which practices to apply to solve the primary water quality problems within their watersheds.

It is also important to keep in mind that site-based removal rates cannot be extrapolated to the watershed level without significant adjustment. Individual site practices are never implemented perfectly or consistently across a watershed. At least three discount factors need to be considered: bypassed load, treatability and loss of performance over time. For a review on how these discounts are derived, consult Schueler and Caraco (2001). Even under the most optimistic watershed implementation scenarios, overall pollutant reduc-

Table 4: The Effectiveness of Stormwater Treatment Practices in Removing Pollutants - Percent Removal Rate (Winer, 2000)

Practice	N	TSS	TP	OP	TN	NOx	Cu	Zn	Oil/ Grease[1]	Bacteria
Dry Ponds	9	47	19	N/R	25	3.5	26	26	3	44
Wet Ponds	43	80	51	65	33	43	57	66	78	70
Wetlands	36	76	49	48	30	67	40	44	85	78
Filtering Practices[2]	18	86	59	57	38	-14	49	88	84	37
Water Quality Swales	9	81	34	1.0	84	31	51	71	62	-25
Ditches[3]	9	31	-16	N/R	-9.0	24	14	0	N/R	0
Infiltration	6	95	80	85	51	82	N/R	N/R	N/R	N/R

1: Represents data for Oil and Grease and PAH
2: Excludes vertical sand filters
3: Refers to open channel practices not designed for water quality
N/R = Not Reported

Table 5: Median Effluent Concentrations from Stormwater Treatment Practices (mg/l) (Winer, 2000)								
Practice	N	TSS	TP	OP	TN	NOx	Cu[1]	Zn[1]
Dry Ponds[2]	3	28	0.18	N/R	0.86	N/R	9.0	98
Wet Ponds	25	17	0.11	0.03	1.3	0.26	5.0	30
Wetlands	19	22	0.20	0.07	1.7	0.36	7.0	31
Filtering Practices[3]	8	11	0.10	0.07	1.1	0.55	9.7	21
Water Quality Swales	7	14	0.19	0.09	1.1	0.35	10	53
Ditches[4]	3	29	0.31	N/R	2.4	0.72	18	32

1. Units for Zn and Cu are micrograms per liter (Fg/l)
2. Data available for Dry Extended Detention Ponds only
3. Excludes vertical sand filters
4. Refers to open channel practices not designed for water quality
N/R = Not Reported

tions by STPs may need to be discounted by at least 30% to account for partial watershed treatment.

Even with discounting, however, it is evident that STPs can achieve enough pollutant reduction to mimic rural background loads for many pollutants, as long as the watershed IC does not exceed 30 to 35%. This capability is illustrated in Figure 5, which shows phosphorus load as a function of IC, with and without stormwater treatment.

Effect of Stream Buffers/Riparian Areas
Forested stream buffers are thought to have very limited capability to remove stormwater pollutants, although virtually no systematic monitoring data exists to test this hypothesis. The major reason cited for their limited removal capacity is that stormwater generated from upland IC has usually concentrated before it reaches the forest buffer and therefore crosses the buffer in a channel, ditch or storm drain pipe. Consequently, the opportunity to filter runoff is lost in many forest buffers in urban watersheds.

Effect of Better Site Design
Better site design (BSD) is a term for nonstructural practices that minimize IC, conserve natural areas and distribute stormwater treatment across individual development sites. BSD is also known by many other names, including conservation development, low-impact development, green infrastructure, and sustainable urban drainage systems. While

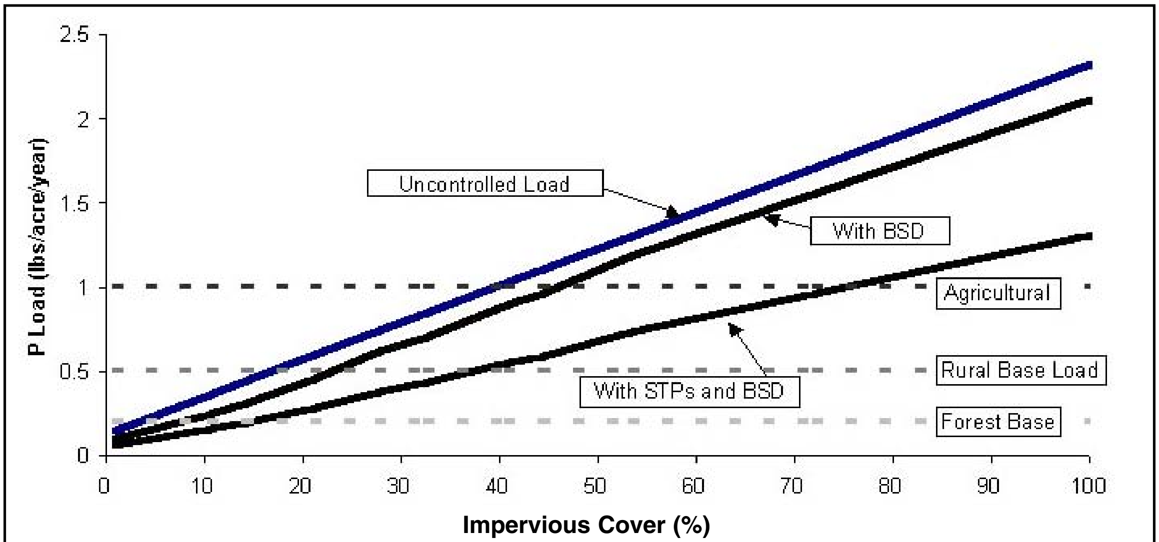


Figure 5: Estimated Phosphorus Load as a Function of Impervious Cover, Discounted Stormwater Treatment and Better Site Design (Schueler and Caraco, 2001)

some maintain that BSD is an alternative to traditional STPs, most consider it to be an important complement to reduce pollutant loads.

While BSD has become popular in recent years, only one controlled research study has evaluated its potential performance, and this is not yet complete (i.e. Jordan Cove, CT).

Indirect estimates of the potential value of BSD to reduce pollutant discharges have been inferred from modeling and redesign analyses (Zielinski, 2000). A typical example is provided in Figure 5, which shows the presumed impact of BSD in reducing phosphorus loadings. As is apparent, BSD appears to be a very effective strategy in the one to 25% IC range, but its benefits diminish beyond that point.

1.3 Implications of the ICM for Watershed Managers

One of the major policy implications of the ICM is that in the absence of watershed treatment, it predicts negative stream impacts at an extremely low intensity of watershed development. To put this in perspective, consider that a watershed zoned for two-acre lot residential development will generally exceed 10% IC, and therefore shift from a sensitive to an impacted stream classification (Cappiella and Brown, 2001). Thus, if a community wants to protect an important water resource or a highly regarded species (such as trout, salmon or an endangered freshwater mussel), the ICM suggests that there is a maximum limit to growth that is not only quite low, but is usually well below the current zoning for many suburban or even rural watersheds. Consequently, the ICM suggests the unpleasant prospect that massive down-zoning, with all of the associated political and legal carnage involving property rights and economic development, may be required to maintain stream quality.

It is not surprising, then, that the ICM debate has quickly shifted to the issue of whether or not watershed treatment practices can provide adequate mitigation for IC. How much relief can be expected from stream buffers, stormwater ponds, and other watershed practices, which might allow greater development density within a given watershed? Only a limited amount of research has addressed this question, and the early results are not reassuring (reviewed in section 1.1.3). At this early stage, researchers are still having trouble detecting the impact of watershed treatment, much less defining it. As noted earlier, both watershed research techniques and practice implementation need to be greatly improved if we ever expect to get a scientifically defensible answer to this crucial question. Until then, managers should be extremely cautious in setting high expectations for how much watershed treatment can mitigate IC.

1.3.1 Management of Non-Supporting Streams

Most researchers acknowledge that streams with more than 25% IC in their watersheds cannot support their designated uses or attain water quality standards and are severely degraded from a physical and biological standpoint. As a consequence, many of these streams are listed for non-attainment under the Clean Water Act and are subject to Total Maximum Daily Load (TMDL) regulations. Communities that have streams within this regulatory class must prepare implementation plans that demonstrate that water quality standards can ultimately be met.

While some communities have started to restore or rehabilitate these streams in recent years, their efforts have yielded only modest improvements in water quality and biological indicators. In particular, no community has yet demonstrated that they can achieve water quality standards in an urban watershed that exceeds 25% IC. Many communities are deeply concerned that non-supporting streams may never achieve water quality standards, despite massive investments in watershed restoration. The ICM suggests that water quality standards may need to be sharply revised for streams with more than 25% IC, if they are ever to come into attainment. While states have authority to create more achievable standards for non-supporting streams within the regulatory framework of the Clean Water Act (Swietlik, 2001), no state has yet exercised this authority. At this time, we are not aware of any water quality standards that are based on the ICM or similar urban stream classification techniques.

Two political perceptions largely explain why states are so reticent about revising water quality standards. The first is a concern that they will run afoul of anti-degradation provisions within the Clean Water Act or be accused of “backsliding” by the environmental community. The second concern relates to the demographics of watershed organizations across the country. According to recent surveys, slightly more than half of all watershed organizations represent moderately to highly developed watersheds (CWP, 2001a). These urban watershed organizations often have a keen interest in keeping the existing regulatory structure intact, since it is perceived to be the only lever to motivate municipalities to implement restoration efforts in non-supporting streams.

However, revised water quality standards are urgently needed to support smart growth efforts. A key premise of smart growth is that it is more desirable to locate new development within a non-supporting subwatershed rather than a sensitive or impacted one (i.e., concentrating density and IC within an existing subwatershed helps prevent sprawl from encroaching on a less developed one). Yet while smart growth is desirable on a regional basis, it will usually contribute to already serious problems in non-supporting watersheds, which makes it even more difficult to meet water quality standards.

This creates a tough choice for regulators: if they adopt stringent development criteria for non-supporting watersheds, their added costs can quickly become a powerful barrier to desired redevelopment. If, on the other hand, they relax or waive environmental criteria, they contribute to the further degradation of the watershed. To address this problem, the Center has developed a "smart watersheds" program to ensure that any localized degradation caused by development within a non-supporting subwatershed is more than compensated for by improvements in stream quality achieved through municipal restoration efforts (CWP, in press). Specifically, the smart watersheds program includes 17 public sector programs to treat stormwater runoff, restore urban stream corridors and reduce pollution discharges in highly urban watersheds. It is hoped that communities that adopt and implement smart watershed programs will be given greater flexibility to meet state and federal water quality regulations and standards within non-supporting watersheds.

1.3.2 Use of the ICM for Urban Stream Classification

The ICM has proven to be a useful tool for classifying and managing the large inventory of streams that most communities possess. It is not unusual for a typical county to have several thousand miles of headwater streams within its political boundaries, and the ICM provides a unified framework to identify and manage these subwatersheds. In our watershed practice, we use the ICM to make an initial diagnosis rather than a final determination for stream classification. Where possible, we conduct rapid stream and subwatershed assessments as a final check for an individual stream classification, particularly if it borders between the sensitive and impacted category. As noted earlier, the statistical variation in the IC/stream quality indicator makes it difficult to distinguish between a stream with 9% versus 11% IC. Some of the key criteria we use to make a final stream classification are provided in Table 6.

1.3.3 Role of the ICM in Small Watershed Planning

The ICM has also proven to be an extremely important tool for watershed planning, since it can rapidly project how streams will change in response to future land use. We routinely estimate existing and future IC in our watershed planning practice and find that it is an excellent indicator of change for subwatersheds in the zero to 30% IC range. In particular, the ICM often forces watershed planners to directly confront land use planning and land conservation issues early in the planning process.

On the other hand, we often find that the ICM has limited planning value when subwatersheds exceed 30% IC for two practical reasons. First, the ICM does not differentiate stream conditions within this very large span of IC (i.e., there is no difference in the stream quality prediction for a subwatershed that has 39.6% IC versus one that has 58.4% IC). Second, the key management question for non-supporting watersheds is whether or not they are potentially restorable. More detailed analysis and field investigations are needed to determine, in each subwatershed, the answer to this question. While a knowledge of IC is often used in these feasibility assessments, it is but one of many factors that needs to be considered.

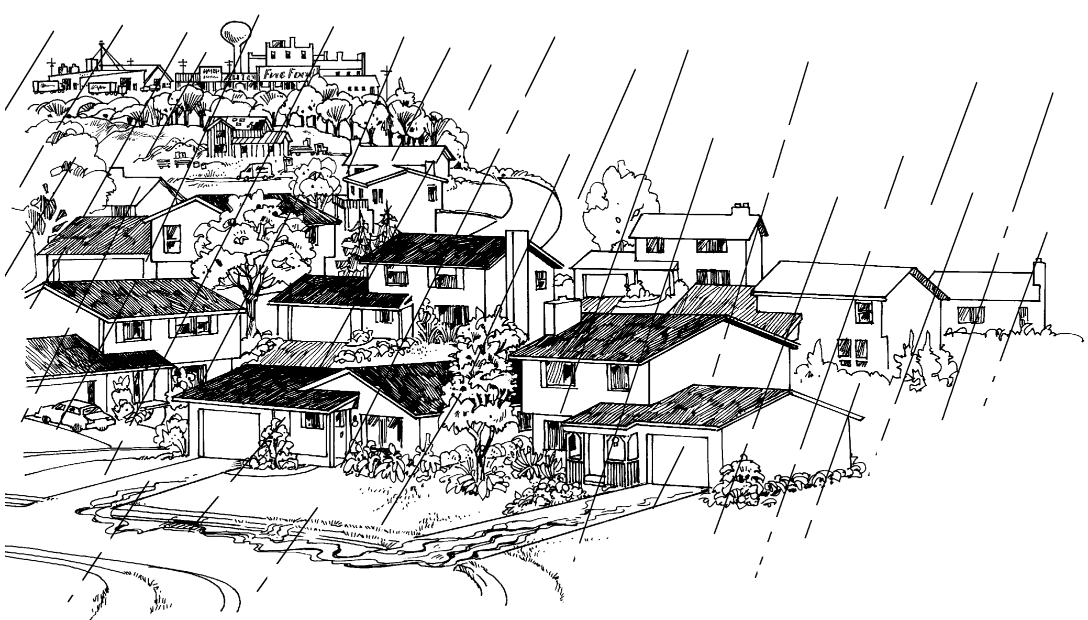
Lastly, we have come to recognize several practical factors when applying the ICM for small watershed planning. These include thoughtful delineation of subwatershed boundaries, the proper accounting of a direct drainage area in larger watersheds, and the critical need for the most recent IC data. More guidance on these factors can be found in Zielinski (2001).

Impervious cover is not a perfect indicator of existing stream quality. A number of stream and subwatershed criteria should be evaluated in the field before a final classification decision is made, particularly when the stream is on the borderline between two classifications. We routinely look at the stream and subwatershed criteria to decide whether a borderline stream should be classified as sensitive or impacted. Table 6 reviews these additional criteria.

Table 6: Additional Considerations for Urban Stream Classification
Stream Criteria
Reported presence of rare, threatened or endangered species in the aquatic community (e.g., freshwater mussels, fish, crayfish or amphibians) Confirmed spawning of cold-water fish species (e.g., trout) Fair/good, good, or good to excellent macro invertebrate scores More than 65% of EPT species present in macro-invertebrate surveys No barriers impede movement of fish between the subwatershed and downstream receiving waters Stream channels show little evidence of ditching, enclosure, tile drainage or channelization Water quality monitoring indicates no standards violations during dry weather Stream and flood plain remain connected and regularly interact Stream drains to a downstream surface water supply Stream channels are generally stable, as determined by the Rosgen level analysis Stream habitat scores are rated at least fair to good
Subwatershed Criteria
Contains terrestrial species that are documented as rare, threatened and endangered Wetlands, flood plains and/or beaver complexes make up more than 10% of subwatershed area Inventoried conservation areas comprise more than 10% of subwatershed area More than 50% of the riparian forest corridor has forest cover and is either publicly owned or regulated Large contiguous forest tracts remain in the subwatershed (more than 40% in forest cover) Significant fraction of subwatershed is in public ownership and management Subwatershed connected to the watershed through a wide corridor Farming, ranching and livestock operations in the subwatershed utilize best management practices Prior development in the subwatershed has utilized stormwater treatment practices

1.4 Summary

The remainder of this report presents greater detail on the individual research studies that bear on the ICM. Chapter 2 profiles research on hydrologic indicators in urban streams, while Chapter 3 summarizes the status of current research on the impact of urbanization on physical habitat indicators. Chapter 4 presents a comprehensive review of the impact of urbanization on ten major stormwater pollutants. Finally, Chapter 5 reviews the growing body of research on the link between IC and biological indicators within urban streams and wetlands.



Chapter 2: Hydrologic Impacts of Impervious Cover

The natural hydrology of streams is fundamentally changed by increased watershed development. This chapter reviews the impacts of watershed development on selected indicators of stream hydrology.

This chapter is organized as follows:

2.1 Introduction

Fundamental changes in urban stream hydrology occur as a result of three changes in the urban landscape that accompany land development. First, large areas of the watershed are paved, rendering them impervious. Second, soils are compacted during construction, which significantly reduces their infiltration capabilities. Lastly, urban stormwater drainage systems are installed that increase the efficiency with which runoff is delivered to the stream (i.e., curbs and gutters, and storm drain pipes). Consequently, a greater fraction of annual rainfall is converted to surface runoff, runoff occurs more quickly, and peak flows become larger. Additionally, dry weather flow in streams may actually decrease because less groundwater recharge is available. Figure 6 illustrates the change in hydrology due to increased urban runoff as compared to pre-development conditions.

Research has demonstrated that the effect of watershed urbanization on peak discharge is more marked for smaller storm events. In particular, the bankfull, or channel forming flow, is increased in magnitude, frequency and duration. Increased bankfull flows have strong ramifications for sediment transport and channel enlargement. All of these changes in the natural water balance have impacts on the physical structure of streams, and ultimately affect water quality and biological diversity.

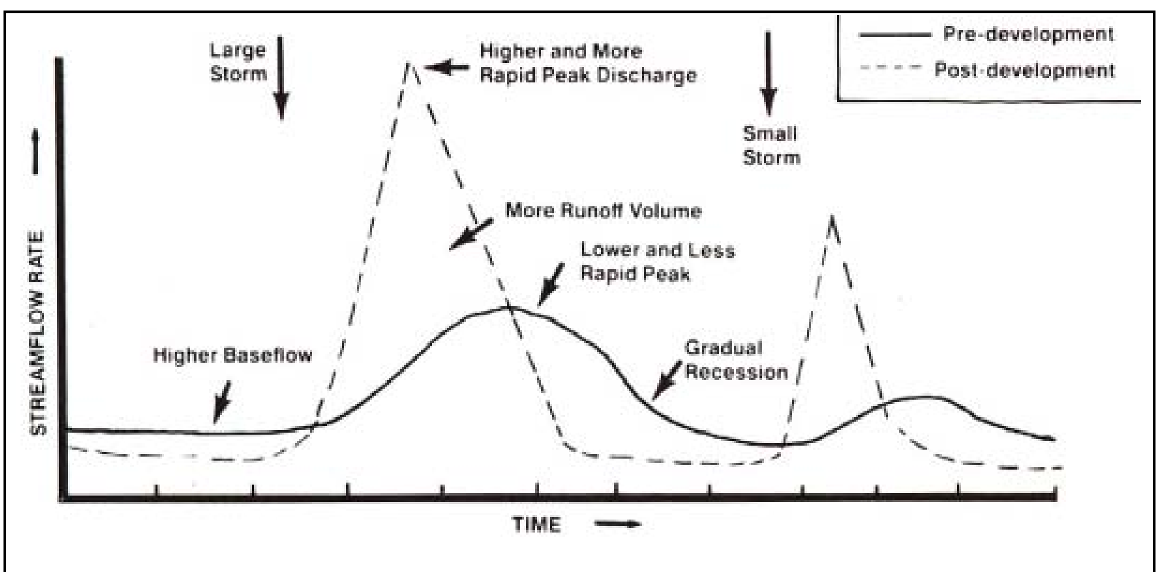
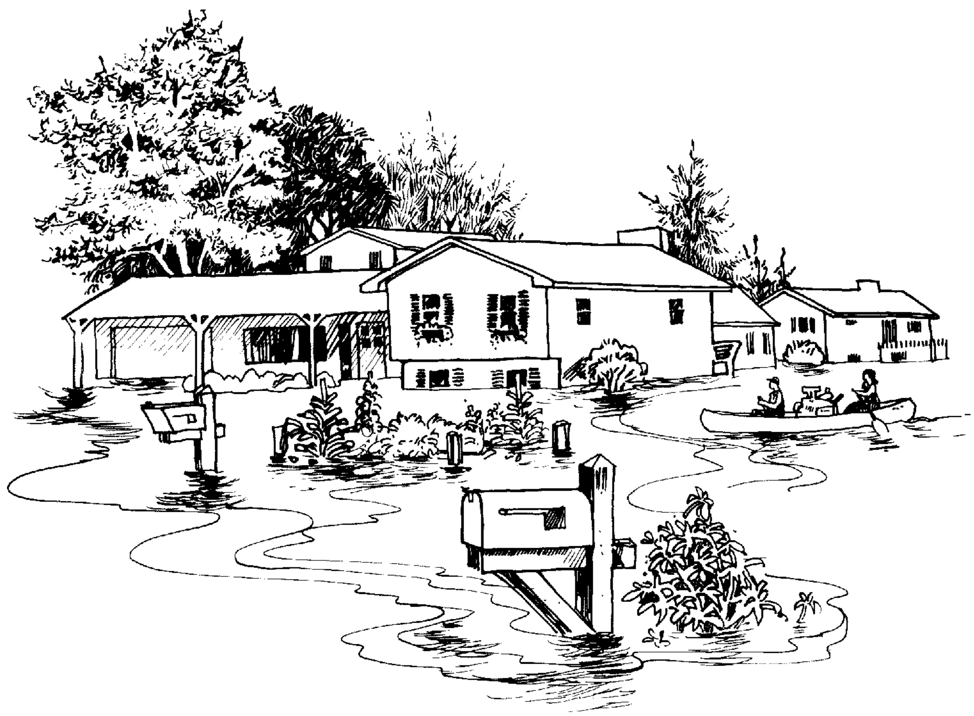


Figure 6: Altered Hydrograph in Response to Urbanization (Schueler, 1987)

The relationship between watershed IC and stream hydrology is widely accepted, and has been incorporated into many hydrologic engineering models over the past three decades. Several articles provide a good summary of these (Bicknell *et al.*, 1993; Hirsch *et al.*, 1990; HEC, 1977; Huber and Dickinson, 1988; McCuen and Moglen, 1988; Overton and Meadows, 1976; Pitt and Voorhees, 1989; Schueler, 1987; USDA, 1992; 1986).

The primary impacts of watershed development on stream hydrology are as follows:

- Increased runoff volume
- Increased peak discharge rates
- Increased magnitude, frequency, and duration of bankfull flows
- Diminished baseflow

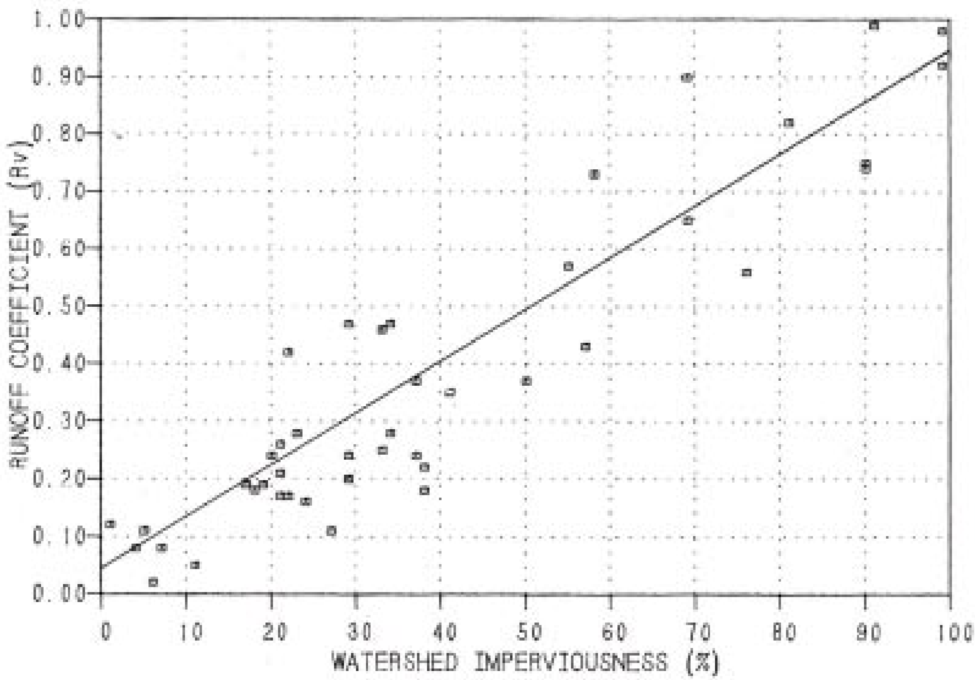


2.2 Increased Runoff Volume

Impervious cover and other urban land use alterations, such as soil compaction and storm drain construction, alter infiltration rates and increase runoff velocities and the efficiency with which water is delivered to streams. This decrease in infiltration and basin lag time can significantly increase runoff volumes. Table 7 reviews research on the impact of IC on runoff volume in urban streams. Schueler (1987) demonstrated that runoff values are directly related to subwatershed IC (Figure 7). Runoff data was derived from 44 small catchment areas across the country for EPA's Nationwide Urban Runoff Program.

Table 8 illustrates the difference in runoff volume between a meadow and a parking lot, as compiled from engineering models. The parking lot produces more than 15 times more runoff than a meadow for the same storm event.

Urban soils are also profoundly modified during the construction process. The compaction of urban soils and the removal of topsoil can decrease the infiltration capacity, causing increases in runoff volumes (Schueler, 2000). Bulk density is often used to measure soil compaction, and Table 9 illustrates how bulk density increases in many urban land uses.



Note: 44 small urban catchments monitored during the national NURP study

Figure 7: Runoff Coefficient vs. IC (Schueler, 1987)

Table 7: Research Review of Increased Runoff Volume and Peak Discharge in Urban Streams		
Reference	**Key Finding**	**Location**
	Increased Runoff Volume	
Schueler, 1987	Runoff coefficients were found to be strongly correlated with IC at 44 sites nationwide.	U.S.
Neller, 1988	Urban watershed produced more than seven times as much runoff as a similar rural watershed. Average time to produce runoff was reduced by 63% in urban watersheds compared to rural watersheds.	Australia
	Increased Peak Discharge	
Hollis, 1975	Review of data from several studies showed that floods with a return period of a year or longer are not affected by a 5% watershed IC; small floods may be increased 10 times by urbanization; flood with a return period of 100 years may be doubled in size by a 30% watershed IC.	N/A
Leopold, 1968	Data from seven nationwide studies showed that 20% IC can cause the mean annual flood to double.	U.S.
Neller, 1988	Average peak discharge from urban watersheds was 3.5 times higher than peak runoff from rural watersheds.	Australia
Doll *et al.*, 2000	Peak discharge was greater for 18 urban streams versus 11 rural Piedmont streams.	NC
Sauer *et al.*, 1983	Estimates of flood discharge for various recurrence intervals showed that less than 50% watershed IC can result in a doubling of the 2-year, 10-year, and 100-year floods.	U.S.
Leopold, 1994	Watershed development over a 29-year period caused the peak discharge of the 10-year storm to more than double.	MD
Kibler *et al.*, 1981	Rainfall/runoff model for two watersheds showed that an increase in IC caused a significant increase in mean annual flood.	PA
Konrad and Booth, 2002	Evaluated streamflow data at 11 streams and found that the fraction of annual mean discharges was exceeded and maximum annual instantaneous discharges were related to watershed development and road density for moderately and highly developed watersheds.	WA

Table 8: Hydrologic Differences Between a Parking Lot and a Meadow (Schueler, 1994a)		
Hydrologic or Water Quality Parameter	**Parking Lot**	**Meadow**
Runoff Coefficient	0.95	0.06
Time of Concentration (minutes)	4.8	14.4
Peak Discharge, two-year, 24-hour storm (cfs)	4.3	0.4
Peak Discharge Rate, 100-year storm (cfs)	12.6	3.1
Runoff Volume from one-inch storm (cu. ft)	3,450	218
Runoff Velocity @ two-year storm (ft/sec)	8	1.8

Key Assumptions:
2-yr, 24-hr storm = 3.1 in; 100-yr storm = 8.9 in.
Parking Lot: 100% imperviousness; 3% slope; 200ft flow length; hydraulic radius =.03; concrete channel; suburban Washington C values
Meadow: 1% impervious; 3% slope; 200 ft flow length; good vegetative condition; B soils; earthen channel
Source: Schueler, 1994a

Table 9: Comparison of Bulk Density for Undisturbed Soils and Common Urban Conditions (Schueler, 2000)			
Undisturbed Soil Type or Urban Condition	**Surface Bulk Density (grams/cubic centimeter)**	**Urban Condition**	**Surface Bulk Density (grams/cubic centimeter)**
Peat	0.2 to 0.3	Urban Lawns	1.5 to 1.9
Compost	1.0	Crushed Rock Parking Lot	1.5 to 1.9
Sandy Soils	1.1 to 1.3	Urban Fill Soils	1.8 to 2.0
Silty Sands	1.4	Athletic Fields	1.8 to 2.0
Silt	1.3 to 1.4	Rights-of-Way and Building Pads (85%)	1.5 to 1.8
Silt Loams	1.2 to 1.5	Rights-of-Way and Building Pads (95%)	1.6 to 2.1
Organic Silts/Clays	1.0 to 1.2	Concrete Pavement	2.2
Glacial Till	1.6 to 2.0	Rock	2.65

2.3 Increased Peak Discharge Rate

Watershed development has a strong influence on the magnitude and frequency of flooding in urban streams. Peak discharge rates are often used to define flooding risk. Doll *et al.* (2000) compared 18 urban streams with 11 rural streams in the North Carolina Piedmont and found that unit area peak discharge was always greater in urban streams (Figure 8). Data from Seneca Creek, Maryland also suggest a similar increase in peak discharge. The watershed experienced significant growth during the 1950s and 1960s. Comparison of pre- and post-development gage records suggests that the peak 10-year flow event more than doubled over that time (Leopold, 1994).

Hollis (1975) reviewed numerous studies on the effects of urbanization on floods of different recurrence intervals and found that the effect of urbanization diminishes when flood recurrence gets longer (i.e., 50 and 100 years). Figure 9 shows the effect on flood magnitude in urban watersheds with 30% IC, and shows the one-year peak discharge rate increasing by a factor of 10, compared to an undeveloped watershed. In contrast, floods with a 100-year recurrence interval only double in size under the same watershed conditions.

Sauer *et al.* (1983) evaluated the magnitude of flooding in urban watersheds throughout the United States. An equation was developed for estimating discharge for floods of two-year, 10-year, and 100-year recurrence intervals. The equations used IC to account for increased runoff volume and a basin development factor to account for sewers, curbs and gutters, channel improvements and drainage development. Sauer noted that IC is not the dominant factor in determining peak discharge rates for extreme floods because these storm events saturate the soils of undeveloped watersheds and produce high peak discharge rates. Sauer found that watersheds with 50% IC can increase peak discharge for the two-year flood by a factor of four, the 10-year flood by a factor of three, and the 100-year flood by a factor of 2.5, depending on the basin development factor (Figure 10).

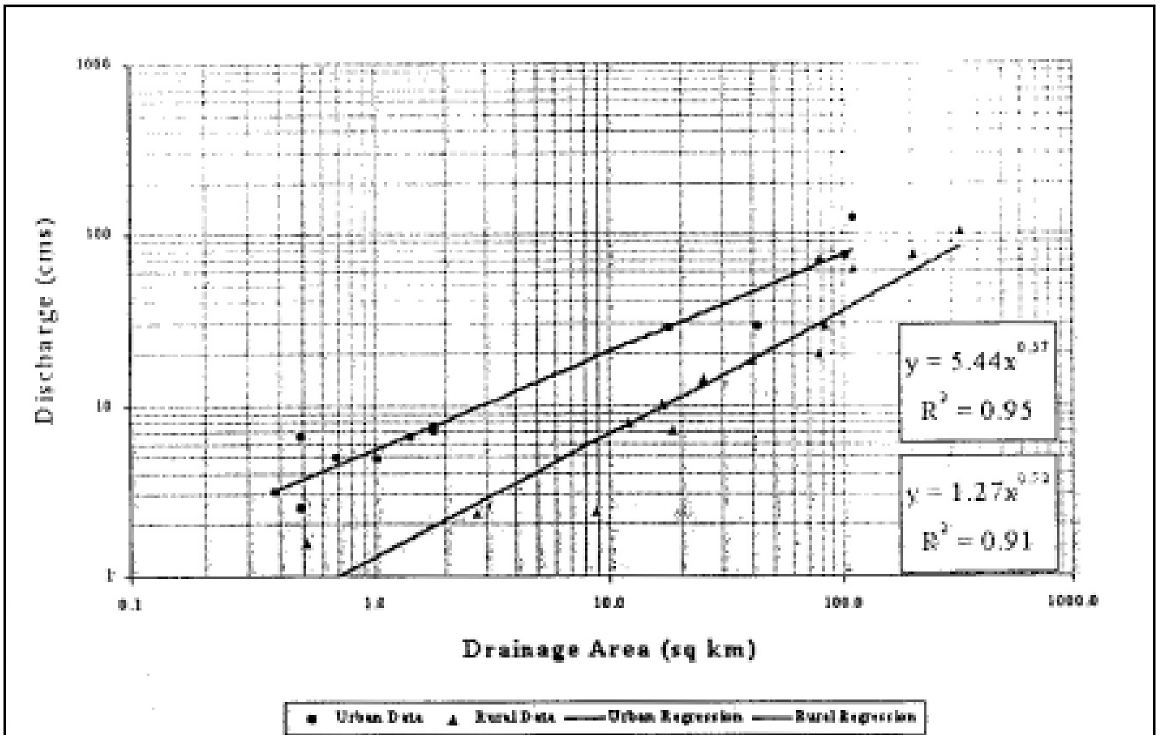


Figure 8: Peak Discharge for Urban and Rural Streams in North Carolina (Doll *et al.*, 2000)

2.4 Increased Bankfull Flow

Urbanization also increases the frequency and duration of peak discharge associated with smaller flood events (i.e., one- to two-year return storms). In terms of stream channel morphology, these more frequent bankfull flows are actually much more important than large flood events in forming the channel. In fact, Hollis (1975) demonstrated that urbanization increased the frequency and magnitude of bankfull flow events to a greater degree than the larger flood events.

An example of the increase in bankfull flow in arid regions is presented by the U.S. Geological Survey (1996), which compared the peak discharge rate from two-year storm events before and after watersheds urbanized in Parris Valley, California. Over an approximately 20-year period, watershed IC increased by 13.5%, which caused the two-year peak flow to more than double. Table 10 reviews other research studies on the relationship between watershed IC and bankfull flows in urban streams.

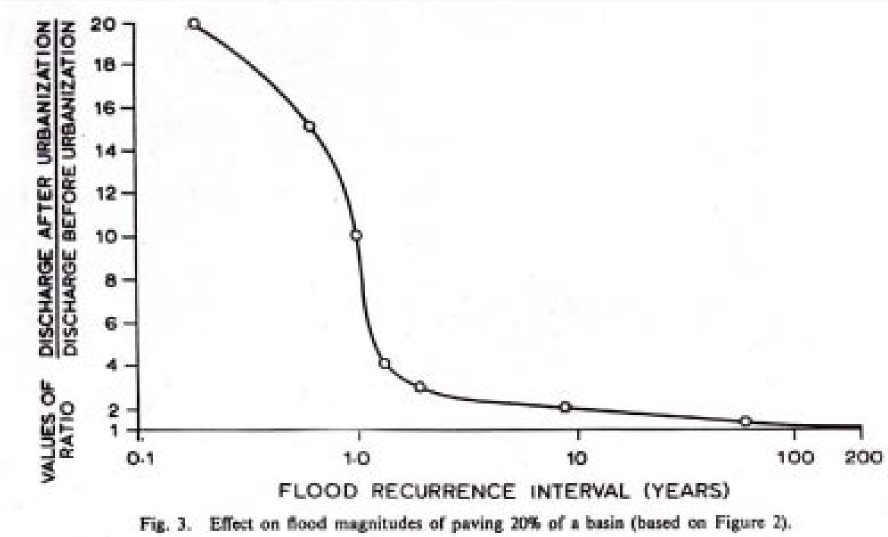


Figure 9: Effect on Flood Magnitudes of 30% Basin IC (Hollis, 1975)

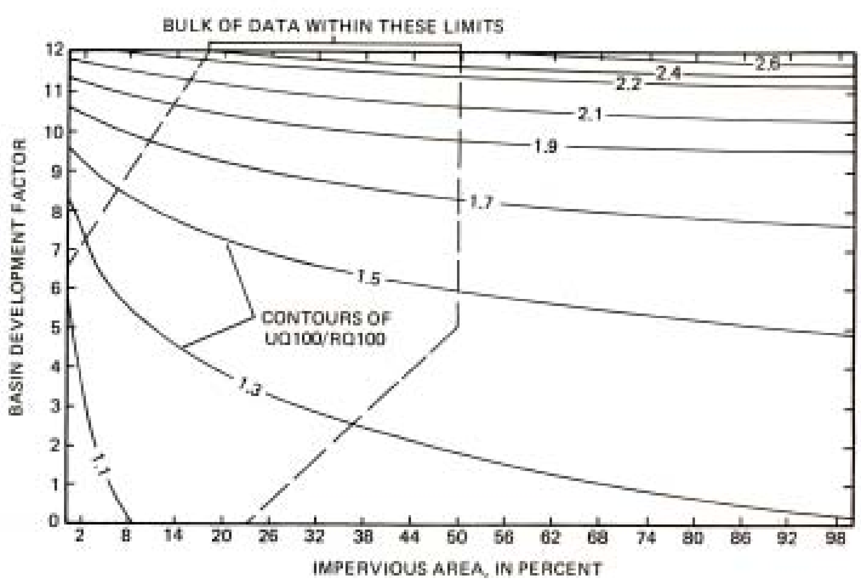


Figure 10: Relationship of Urban/Rural 100-Year Peak Flow Ratio to Basin Development Factor and IC (Sauer *et al.*, 1983)

Table 10: Research Review of Increased Bankfull Discharge in Urban Streams		
Reference	**Key Finding**	**Location**
Booth and Reinelt, 1993	Using a simulation model and hydrologic data from four watersheds, it was estimated that more than 10% watershed IC may cause discharge from the two-year storm under current conditions to equal or exceed discharge from the 10-year storm under forested conditions.	WA
Fongers and Fulcher, 2001	Bankfull flow of 1200 cfs was exceeded more frequently over time with urbanization, and exceedence was three times as frequent from 1930s to 1990s.	MI
USGS, 1996	Over a 20-year period, IC increased 13.5%, and the two-year peak flow more than doubled in a semi-arid watershed.	CA
Henshaw and Booth, 2000	Two of three watersheds in the Puget Sound lowlands showed increasing flashiness over 50 years with urbanization.	WA
Leopold, 1968	Using hydrologic data from a nine-year period for North Branch Brandywine Creek, it was estimated that for a 50% IC watershed, bankfull frequency would be increased fourfold.	PA
Leopold, 1994	Bankfull frequency increased two to seven times after urbanization in Watts Branch.	MD
MacRae, 1996	For a site downstream of a stormwater pond in Markham, Ontario hours of exceedence of bankfull flows increased by 4.2 times after the watershed urbanized (34% IC)	Ontario

Leopold (1968) evaluated data from seven nationwide studies and extrapolated this data to illustrate the increase in bankfull flows due to urbanization. Figure 11 summarizes the relationship between bankfull flows over a range of watershed IC. For example, watersheds that have 20% IC increase the number of flows equal to or greater than bankfull flow by a factor of two. Leopold (1994) also observed a dramatic increase in the frequency of the bankfull event in Watts Branch, an urban subwatershed in Rockville, Maryland. This watershed experienced significant urban development during the 1950s and 1960s. Leopold compared gage records and found that the bankfull storm event frequency increased from two to seven times per year from 1958 to 1987.

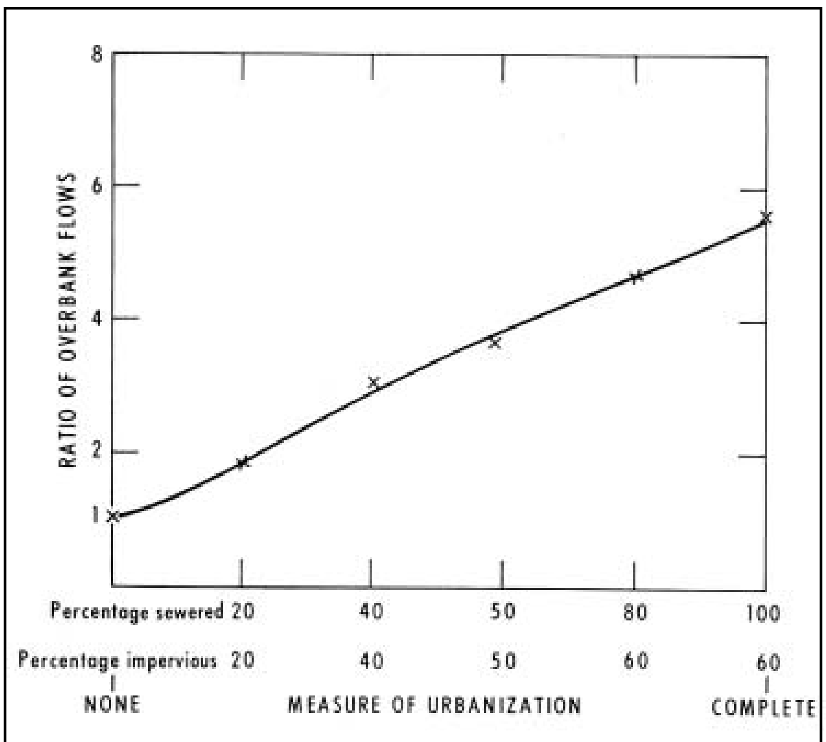


Figure 11: Increase in Bankfull Flows Due to Urbanization (Leopold, 1968)

More recent data on bankfull flow frequency was reported for the Rouge River near Detroit, Michigan by Fongers and Fulcher (2001). They noted that channel-forming flow (1200 cfs) was exceeded more frequently as urbanization increased in the watershed and had become three times more frequent between 1930 and 1990 (Figure 12).

McCuen and Moglen (1988) have documented the increase in duration of bankfull flows in response to urbanization using hydrology models. MacRae (1996), monitored a stream in Markham, Ontario downstream of a stormwater pond and found that the hours of

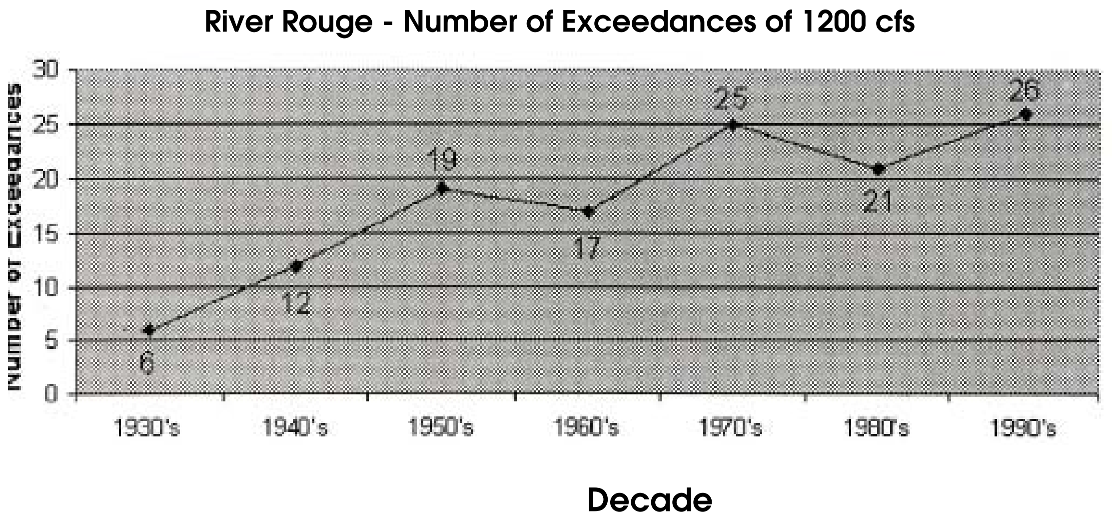


Figure 12: Increase in Number of Exceedences of Bankfull Flow Over Time With Urbanization in the Rouge River, MT (Fongers and Fulcher, 2001)

exceedence of bankfull flows increased by a factor of 4.2 once watershed IC exceeded 30%. Modeling for seven streams also downstream of stormwater ponds in Surrey, British Columbia also indicated an increase in bankfull flooding in response to watershed development (MacRae, 1996).

Watershed IC also increases the "flashiness" of stream hydrographs. Flashiness is defined here as the percent of daily flows each year that exceeds the mean annual flow. Henshaw and Booth (2000) evaluated seven urbanized watersheds in the Puget Sound lowland streams and tracked changes in flashiness over 50 years (Figure 13). The most urbanized watersheds experienced flashy discharges. Henshaw and Booth concluded that increased runoff in urban watersheds leads to higher but shorter-duration peak discharges.

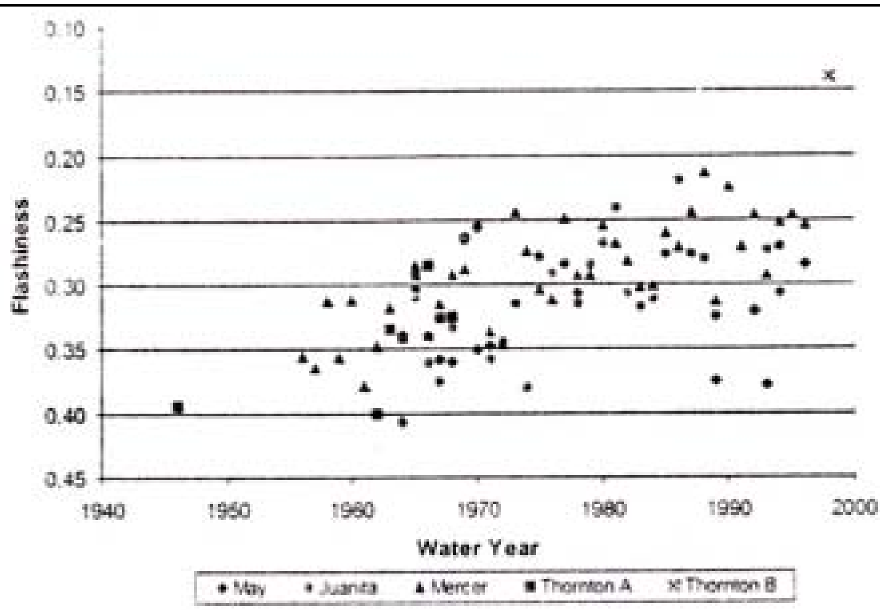


Figure 13: Percent of Gage Reading Above Mean Annual Flow for Puget Sound Lowland Streams (Henshaw and Booth, 2000)

2.5 Decreased Baseflow

As IC increases in a watershed, less groundwater infiltration is expected, which can potentially decrease stream flow during dry periods, (i.e. baseflow). Several East Coast studies provide support for a decrease in baseflow as a result of watershed development. Table 11 reviews eight research studies on baseflow in urban streams.

Klein (1979) measured baseflow in 27 small watersheds in the Maryland Piedmont and reported an inverse relationship between IC and baseflow (Figure 14). Spinello and Simmons (1992) demonstrated that baseflow in two urban Long Island streams declined seasonally as a result of urbanization (Figure 15). Saravanapavan (2002) also found that percentage of baseflow decreased in direct proportion to percent IC for 13 subwatersheds of the Shawsheen River watershed in Massachusetts (Figure 16).

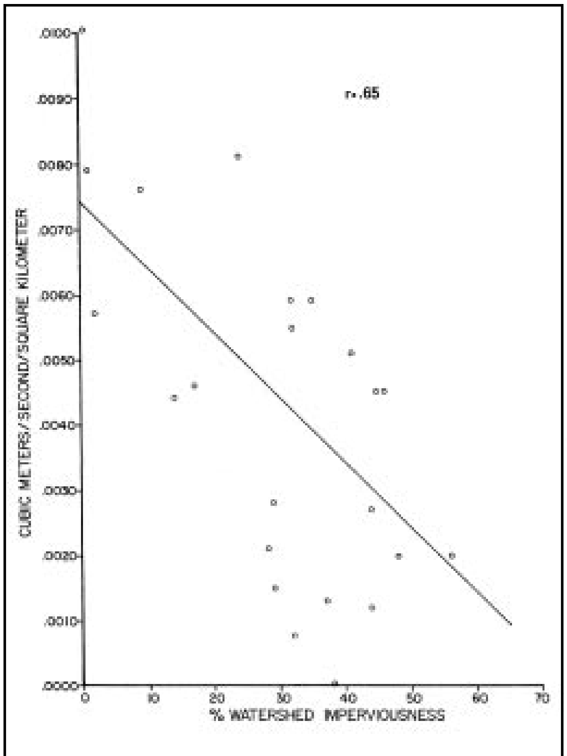
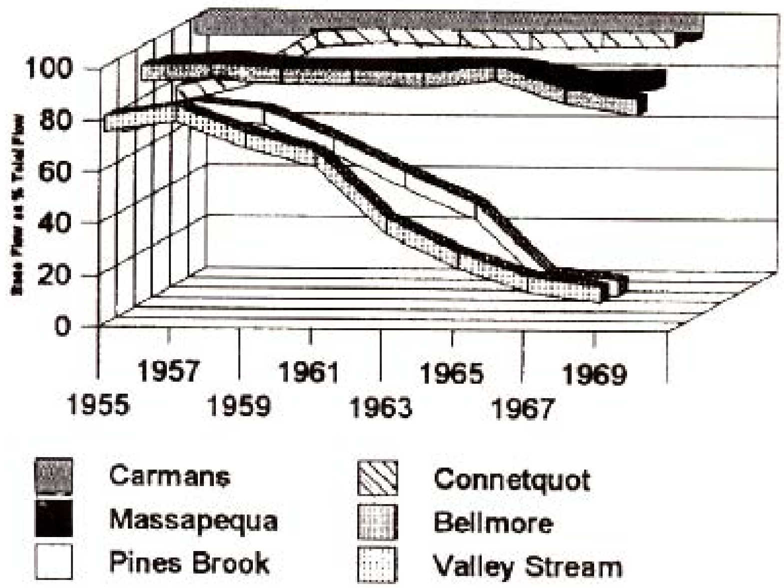


Figure 14: Relationship Between Baseflow and Watershed IC in the Streams on Maryland Piedmont (Klein, 1979)

Table 11: Research Review of Decreased Baseflow in Urban Streams		
Reference	**Key Finding**	**Location**
Finkenbine *et al.*, 2000	Summer base flow was uniformly low in 11 streams when IC reached 40% or greater.	Vancouver
Klein, 1979	Baseflow decreased as IC increased in Piedmont streams.	MD
Saravanapavan, 2002	Percentage of baseflow decreased linearly as IC increased for 13 subwatersheds of Shawsheen River watershed.	MA
Simmons and Reynolds, 1982	Dry weather flow dropped 20 to 85% after development in several urban watersheds on Long Island.	NY
Spinello and Simmons, 1992	Baseflow in two Long Island streams went dry as a result of urbanization.	NY
Konrad and Booth, 2002	No discernable trend over many decades in the annual seven day low flow discharge for 11 Washington streams.	WA
Wang *et al.*, 2001	Stream baseflow was negatively correlated with watershed IC in 47 small streams, with an apparent breakpoint at 8 to 12% IC.	WI
Evett *et al.*, 1994	No clear relationship between dry weather flow and urban and rural streams in 21 larger watersheds.	NC



Notes:

Carmans and Connetquot: Rural/suburban, watersheds are unsewered

Bellmore and Massapequa: Moderately urbanized, not sewered until 1989

Valley Stream and Pine Brook: Urbanized and densely populated watersheds, sewer systems completed in 1960s

1953-1964: Period of sanitary sewer construction in eastern Nassau County

1962-1966: Drought years

Figure 15: Baseflow Response to Urbanization in Long Island Streams (Spinello and Simmons, 1992)

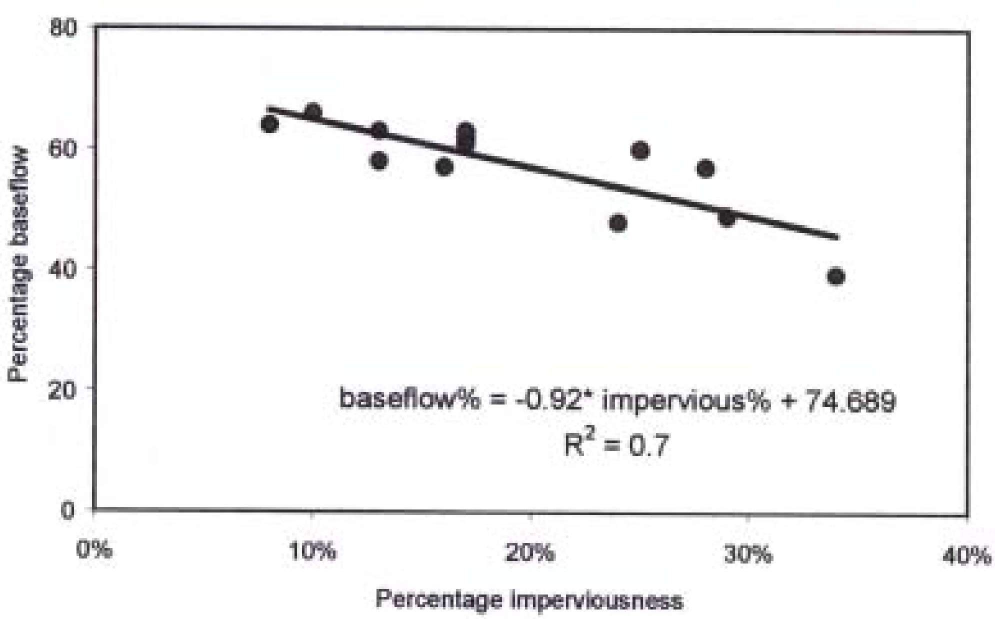


Figure 16: Relationship Between Percentage Baseflow and Percent IC in Massachusetts Streams (Saravanapan, 2002)

Finkebine *et al.* (2000) monitored summer baseflow in 11 streams near Vancouver, British Columbia and found that stream base flow was uniformly low due to decreased groundwater recharge in watersheds with more than 40% IC (Figure 17). Baseflow velocity also consistently decreased when IC increased (Figure 18). The study cautioned that other factors can affect stream baseflow, such as watershed geology and age of development.

Other studies, however, have not been able to establish a relationship between IC and declining baseflow. For example, a study in North Carolina could not conclusively determine that urbanization reduced baseflow in larger urban and suburban watersheds in that area (Evett *et al.*, 1994). In some cases, stream baseflow is supported by deeper aquifers or originate in areas outside the surface watershed boundary. In others, baseflow is augmented by leaking sewers, water pipes and irrigation return flows.

This appears to be particularly true in arid and semi-arid areas, where baseflow can actually increase in response to greater IC (Hollis, 1975). For instance, Crippen and Waananen (1969) found that Sharon Creek near San Francisco changed from an ephemeral stream into a perennial stream after urban development. Increased infiltration from lawn watering and return flow from sewage treatment plants are two common sources of augmented baseflows in these regions (Caraco, 2000a).

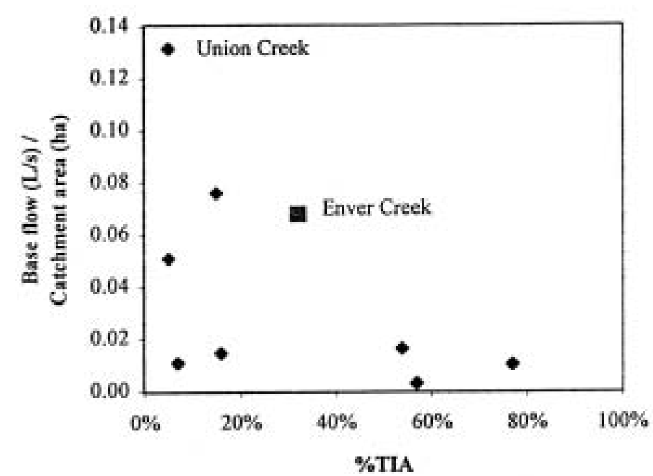


Figure 17: Effect of IC on Summer Baseflow in Vancouver Streams (Finkerbine *et al.*, 2000)

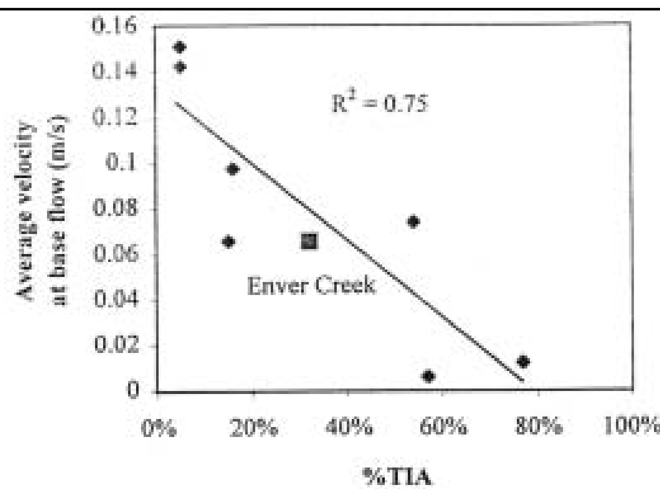


Figure 18: Effect of Watershed IC on Summer Stream Velocity in Vancouver Streams (Finkerbine *et al.*, 2000)

2.6 Conclusions

The changes in hydrology indicators caused by watershed urbanization include increased runoff volume; increased peak discharge; increased magnitude, frequency and duration of bankfull flows; flashier/less predictable flows; and decreased baseflow. Many studies support the direct relationship between IC and these indicators. However, at low levels of watershed IC, site-specific factors such as slope, soils, types of conveyance systems, age of development, and watershed dimensions often play a stronger role in determining a watershed's hydrologic response.

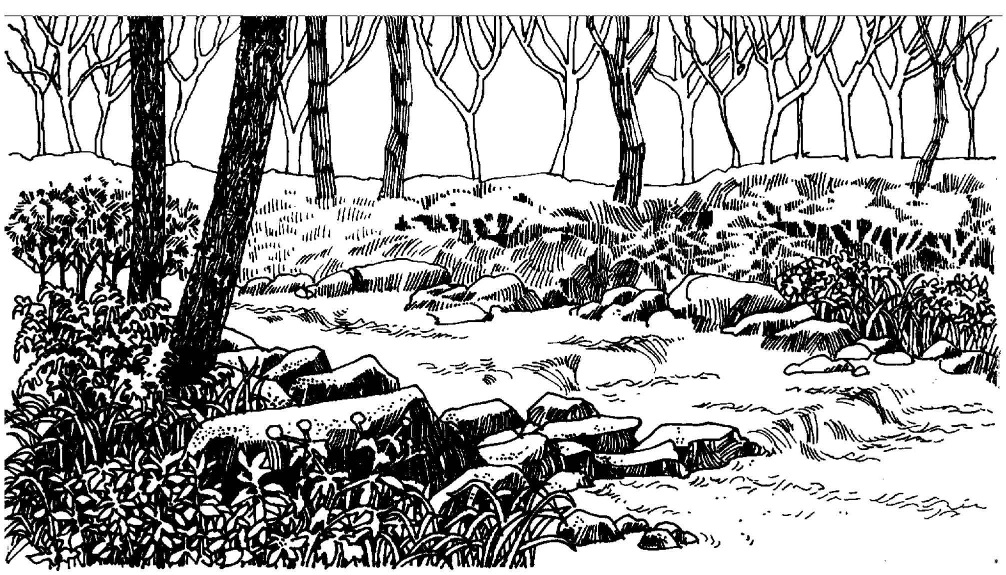
Overall, the following conclusions can be drawn from the relationship between watershed IC and hydrology indicators:

- Strong evidence exists for the direct relationship between watershed IC and increased stormwater runoff volume and peak discharge. These relationships are considered so strong that they have been incorporated into widely accepted engineering models.

- The relationship between IC and bankfull flow frequency has not been extensively documented, although abundant data exists for differences between urban and non-urban watersheds.

- The relationship between IC and declining stream flow is more ambiguous and appears to vary regionally in response to climate and geologic factors, as well as water and sewer infrastructure.

The changes in hydrology indicators caused by watershed urbanization directly influence physical and habitat characteristics of streams. The next chapter reviews how urban streams physically respond to the major changes to their hydrology.



Chapter 3: Physical Impacts of Impervious Cover

A growing body of scientific literature documents the physical changes that occur in streams undergoing watershed urbanization. This chapter discusses the impact of watershed development on various measures of physical habitat in urban stream channels and is organized as follows:

3.1 Difficulty in Measuring Habitat
3.2 Changes in Channel Geometry
3.3 Effect on Composite Indexes of Stream Habitat
3.4 Effect on Individual Elements of Stream Habitat
3.5 Increased Stream Warming
3.6 Alteration of Stream Channel Network
3.7 Conclusion

This chapter reviews the available evidence on stream habitat. We begin by looking at geomorphological research that has examined how the geometry of streams changes in response to altered urban hydrology. The typical response is an enlargement of the cross-sectional area of the stream channel through a process of channel incision, widening, or a combination of both. This process triggers an increase in bank and/or bed erosion that increases sediment transport from the stream, possibly for several decades or more.

Next, we examine the handful of studies that have evaluated the relationship between watershed development and composite indicators of stream habitat (such as the habitat Rapid Bioassessment Protocol, or RBP). In the fourth section, we examine the dozen studies that have evaluated how individual habitat elements respond to watershed development. These studies show a consistent picture. Generally, streams with low levels of IC have stable banks, contain considerable large woody debris (LWD) and possess complex habitat structure. As watershed IC increases, however, urban streambanks become increasingly unstable, streams lose LWD, and they develop a more simple and uniform habitat structure. This is typified by reduced pool depths, loss of pool and riffle sequences, reduced channel roughness and less channel sinuosity.

Water temperature is often regarded as a key habitat element, and the fifth section describes the stream warming effect observed in urban streams in six studies. The last section looks at the effect of watershed development on the stream channel network as a whole, in regard to headwater stream loss and the creation of fish barriers.

3.1 Difficulty in Measuring Habitat

The physical transformation of urban streams is perhaps the most conspicuous impact of watershed development. These dramatic physical changes are easily documented in sequences of stream photos with progressively greater watershed IC (see Figure 19). Indeed, the network of headwater stream channels generally disappears when watershed IC exceeds 60% (CWP).

3.1.1 The Habitat Problem

It is interesting to note that while the physical impacts of urbanization on streams are widely accepted, they have rarely been documented by the research community. As a consequence, no predictive models exist to quantify how physical indicators of stream habitat will decline in response to watershed IC, despite the fact that most would agree that some kind of decline is expected (see Table 12).

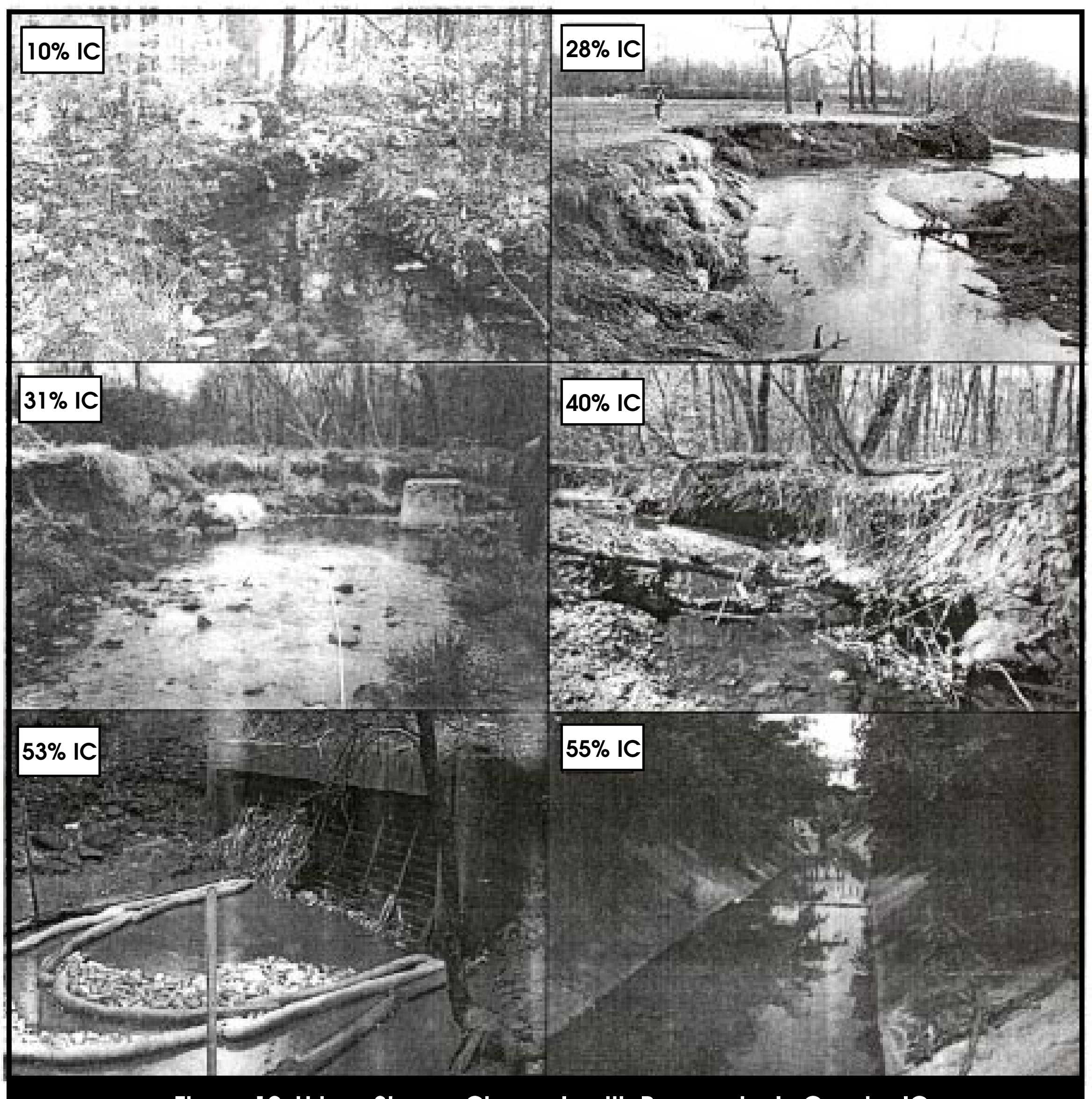


Figure 19: Urban Stream Channels with Progressively Greater IC

The main reason for this gap is that "habitat" is extremely hard to define, and even more difficult to measure in the field. Most indices of physical habitat involve a visual and qualitative assessment of 10 or more individual habitat elements that are perceived by fishery and stream biologists to contribute to quality stream habitat. Since these indices include many different habitat elements, each of which is given equal weight, they have not been very useful in discriminating watershed effects (Wang *et al.*, 2001).

Researchers have had greater success in relating individual habitat elements to watershed conditions, such as large woody debris (LWD), embeddedness, or bank stability. Even so, direct testing has been limited, partly because individual habitat elements are hard to measure and are notoriously variable in both space and time. Consider bank stability for a moment. It would be quite surprising to see a highly urban stream that did not have unstable banks. Yet, the hard question is exactly how would bank instability be quantitatively measured? Where would it be measured — at a point, a cross-section, along a reach, on the left bank or the right?

Geomorphologists stress that no two stream reaches are exactly alike, due to differences in gradient, bed material, sediment transport, hydrology, watershed history and many other factors. Consequently, it is difficult to make controlled comparisons among different streams. Indeed, geomorphic theory stresses that individual stream reaches respond in a highly dynamic way to changes in watershed hydrology and sediment transport, and can take several decades to fully adjust to a new equilibrium.

Returning to our example of defining bank stability, how might our measure of bank instability change over time as its watershed gradually urbanizes, is built out, and possibly reaches a new equilibrium over several decades? It is not very surprising that the effect of watershed development on stream habitat is widely observed, yet rarely measured.

Table 12: Physical Impacts of Urbanization on Streams

Specific Impacts
Sediment transport modified
Channel enlargement
Channel incision
Stream embeddedness
Loss of large woody debris
Changes in pool/riffle structure
Loss of riparian cover
Reduced channel sinuosity
Warmer in-stream temperatures
Loss of cold water species and diversity
Channel hardening
Fish blockages
Loss of 1st and 2nd order streams through storm drain enclosure

3.2 Changes in Stream Geometry

As noted in the last chapter, urbanization causes an increase in the frequency and duration of bankfull and sub-bankfull flow events in streams. These flow events perform more "effective work" on the stream channel, as defined by Leopold (1994). The net effect is that an urban stream channel is exposed to more shear stress above the critical threshold needed to move bank and bed sediments (Figure 20). This usually triggers a cycle of active bank erosion and greater sediment transport in urban streams. As a consequence, the stream channel adjusts by expanding its cross-sectional area, in order to effectively accommodate greater flows and sediment supply. The stream channel can expand by incision, widening, or both. Incision refers to stream down-cutting through the streambed, whereas widening refers to lateral erosion of the stream bank and its flood plain (Allen and Narramore, 1985; Booth, 1990; Morisawa and LaFlure, 1979).

3.2.1 Channel Enlargement

A handful of research studies have specifically examined the relationship between watershed development and stream channel enlargement (Table 13). These studies indicate that stream cross-sectional areas can enlarge by as much as two to eight times in response to urbanization, although the process is complex and may take several decades to complete (Pizzuto *et al.*, 2000; Caraco, 2000b; Hammer, 1972). An example of channel enlargement is provided in Figure 21, which shows how a stream cross-section in Watts Branch near Rockville, Maryland has expanded in response to nearly five decades of urbanization (i.e., watershed IC increased from two to 27%).

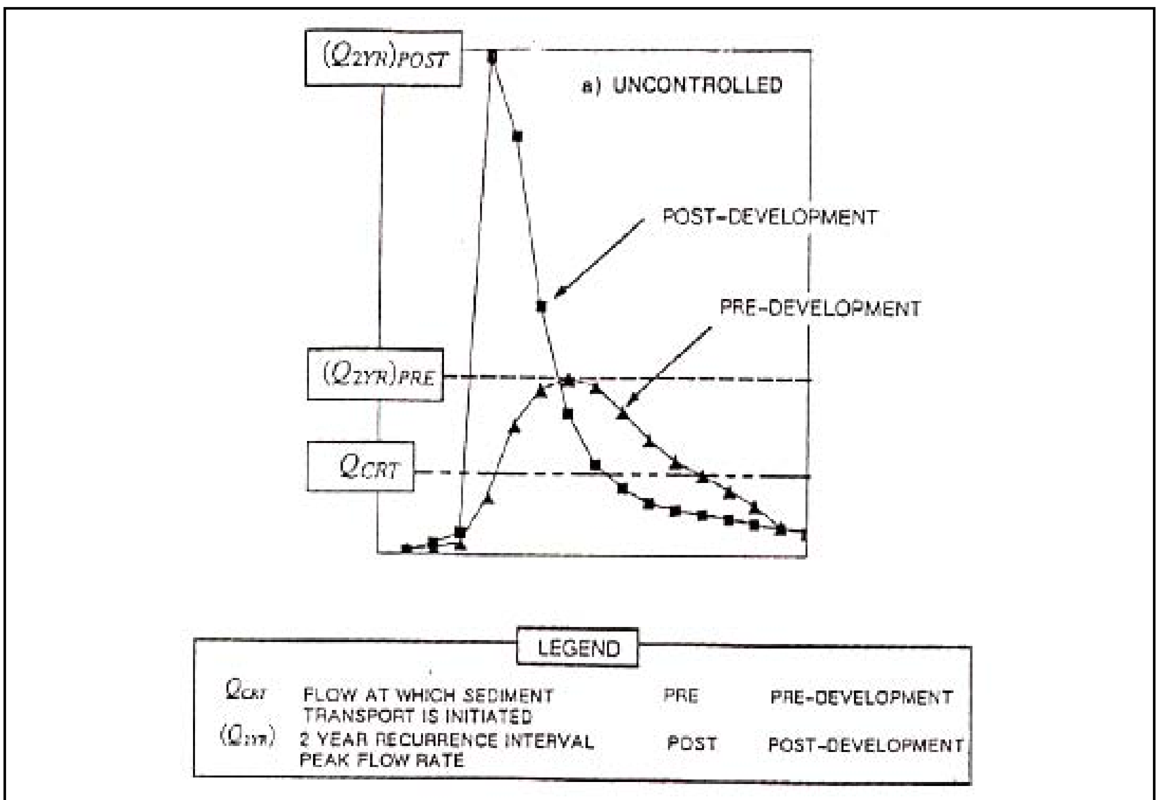


Figure 20: Increased Shear Stress from a Hydrograph (MacRae and Rowney, 1992)

Table 13: Research Review of Channel Enlargement and Sediment Transport in Urban Streams		
Reference	**Key Finding**	**Location**
	% IC used as Indicator	
Caraco, 2000b	Reported enlargement in ratios of 1.5 to 2.2 for 10 stream reaches in Watts Branch and computed ultimate enlargement ratios of 2.0	MD
MacCrae and De Andrea, 1999	Introduced the concept of ultimate channel enlargement based on watershed IC and channel characteristics.	Ontario, TX
Morse, 2001	Demonstrated increased erosion rates with increases in IC (channels were generally of the same geomorphic type).	ME
	Urbanization Used as Indicator	
Allen and Narramore, 1985	Enlargement ratios in two urban streams ranged from 1.7 to 2.4.	TX
Bledsoe, 2001	Reported that channel response to urbanization depends on other factors in addition to watershed IC including geology, vegetation, sediment and flow regimes.	N/A
Booth and Henshaw, 2001	Evaluated channel cross section erosion rates and determined that these rates vary based on additional factors including the underlying geology, age of development and gradient.	WA
Hammer, 1972	Enlargement ratios ranged from 0.7 to 3.8 in urban watersheds.	PA
Neller, 1989	Enlargement ratios in small urban catchments ranged from two to 7.19, the higher enlargement ratios were primarily from incision occurring in small channels.	Australia
Pizzuto *et al.*, 2000	Evaluated channel characteristics of paired urban and rural streams and demonstrated median bankfull cross sectional increase of 180%. Median values for channel sinuosity were 8% lower in urban streams; Mannings N values were found to be 10% lower in urban streams.	PA
Hession *et al.*, *in press*	Bankfull widths for urban streams were significantly wider than non-urban streams in 26 paired streams. Forested reaches were consistently wider than non-forested reaches in urban streams.	MD, DE, PA
Dartiguenave *et al.*, 1997	Bank erosion accounted for up to 75% of the sediment transport in urban watersheds.	TX
Trimble, 1997	Demonstrated channel enlargement over time in an urbanizing San Diego Creek; Bank erosion accounted for over 66% of the sediment transport.	CA

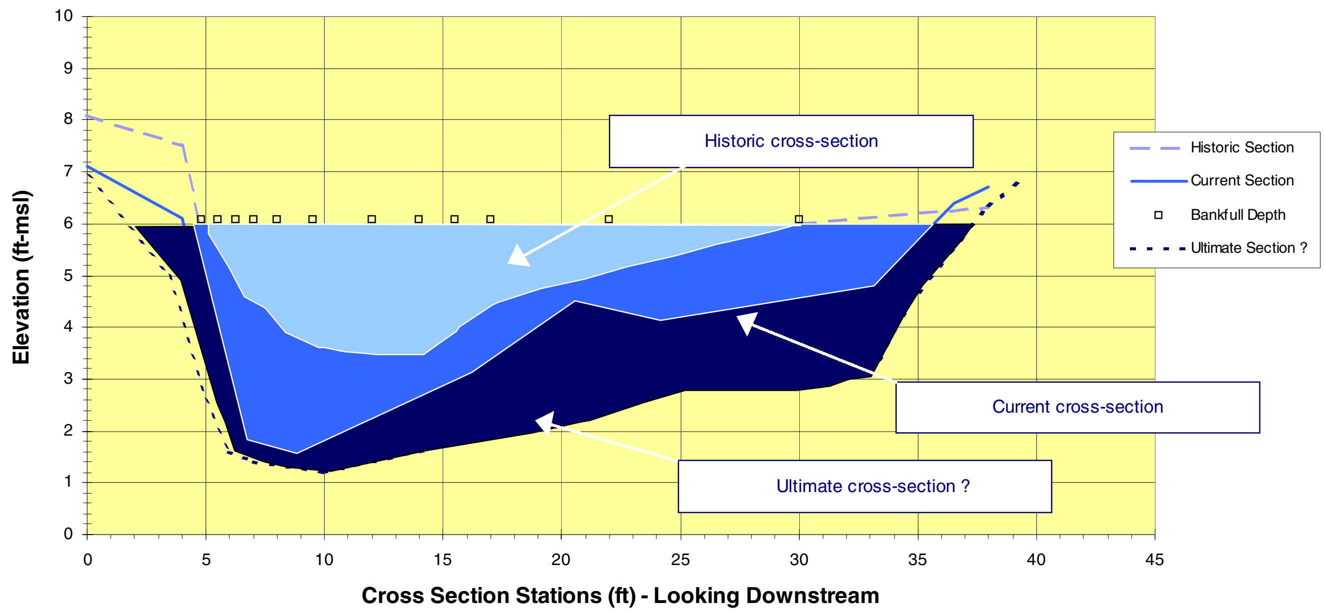


Figure 21: Stream Channel Enlargement in Watts Branch, MD 1950-2000 (Caraco, 2000b)

Some geomorphologists suggest that urban stream channels will reach an "ultimate enlargement" relative to pre-developed channels (MacRae and DeAndrea, 1999) and that this can be predicted based on watershed IC, age of development, and the resistance of the channel bed and banks. A relationship between ultimate stream channel enlargement and watershed IC has been developed for alluvial streams in Texas, Vermont and Maryland (Figure 22). Other geomorphologists such as Bledsoe (2001) and Booth and Henshaw (2001) contend that channel response to urbanization is more complex, and also depends on geology, grade control, stream gradient and other factors.

Channel incision is often limited by grade control caused by bedrock, cobbles, armored substrates, bridges, culverts and pipelines. These features can impede the downward erosion of the stream channel and thereby limit the incision process. Stream incision can become severe in streams that have softer substrates such as sand, gravel and clay (Booth, 1990). For example, Allen and Narramore (1985) showed that channel enlargement in chalk channels was 12 to 67% greater than in shale channels near Dallas, Texas. They attributed the differences to the softer substrate, greater velocities and higher shear stress in the chalk channels.

Neller (1989) and Booth and Henshaw (2001) also report that incised urban stream channels possess cross-sectional areas that are larger than would be predicted based on watershed area or discharge alone. This is due to the fact that larger floods are often contained within the stream channel rather than the floodplain. Thus, incised channels often result in greater erosion and geomorphic change. In general, stream conditions that can foster incision include erodible substrates, moderate to high stream gradients, and an absence of grade control features.

Channel widening occurs more frequently when streams have grade control and the stream has cut into its bank, thereby expanding its cross-sectional area. Urban stream channels often have artificial grade controls caused by frequent culverts and road crossings. These grade controls often cause localized sediment deposition that can reduce the capacity of culverts and bridge crossings to pass flood waters.

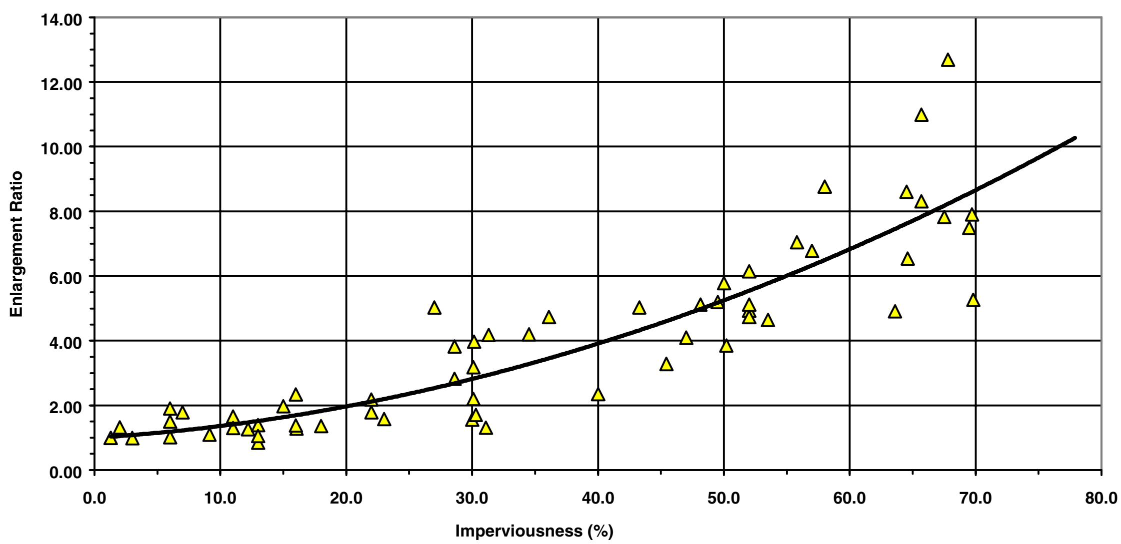


Figure 22: Ultimate Channel Enlargement in MD, UT and TX Alluvial Streams (MacRae and DeAndrea, 1999 and CWP, 2001b)

The loss of flood plain and riparian vegetation has been strongly associated with watershed urbanization (May *et al.*, 1997). A few studies have shown that the loss of riparian trees can result in increased erosion and channel migration rates (Beeson and Doyle, 1995 and Allmendinger *et al.*, 1999). For example, Beeson and Doyle (1995) found that meander bends with vegetation were five times less likely to experience significant erosion from a major flood than non-vegetated meander bends.Hession *et al.* (in press) observed that forested reaches consistently had greater bankfull widths than non-forested reaches in a series of urban streams in Pennsylvania, Maryland and Delaware.

3.2.2 Effect of Channel Enlargement on Sediment Yield

Regardless of whether a stream incises, widens, or does both, it will greatly increase sediment transport from the watershed due to erosion. Urban stream research conducted in California and Texas suggests that 60 to 75% of the sediment yield of urban watersheds can be derived from channel erosion (Trimble, 1997 and Dartingunave *et al.*, 1997) This can be compared to estimates for rural streams where channel erosion accounts for only five to 20% of the annual sediment yield (Collins *et al.*, 1997 and Walling and Woodward, 1995).

Some geomorphologists speculate that urban stream channels will ultimately adjust to their post-development flow regime and sediment supply. Finkenbine *et al.* (2000) observed these conditions in Vancouver streams, where study streams eventually stabilized two decades after the watersheds were fully developed. In older urban streams, reduced sediment transport can be expected when urbanization has been completed. At this point, headwater stream channels are replaced by storm drains and pipes, which can transport less sediment. The lack of available sediment may cause downstream channel erosion, due to the diminished sediment supply found in the stream.

3.3 Effect on Composite Measures of Stream Habitat

Composite measures of stream habitat refer to assessments such as EPA's Habitat Rapid Bioassessment Protocol (RBP) that combine multiple habitat elements into a single score or index (Barbour *et al*., 1999). For example, the RBP requires visual assessment of 10 stream habitat elements, including embeddedness, epifaunal substrate quality, velocity/depth regime, sediment deposition, channel flow status, riffle frequency, bank stabilization, streambank vegetation and riparian vegetation width. Each habitat element is qualitatively scored on a 20 point scale, and each element is weighted equally to derive a composite score for the stream reach.

To date, several studies have found a relationship between declining composite habitat indicator scores and increasing watershed IC in different eco-regions of the United States. A typical pattern in the composite habitat scores is provided for headwater streams in Maine (Morse, 2001; Figure 23). This general finding has been reported in the mid-Atlantic, Northeast and the Northwest (Black and Veatch, 1994; Booth and Jackson, 1997; Hicks and Larson, 1997; Maxted and Shaver, 1997; Morse, 2001; Stranko and Rodney, 2001).

However, other researchers have found a much weaker relationship between composite habitat scores and watershed IC. Wang and his colleagues (2001) found that composite habitat scores were not correlated with watershed IC in Wisconsin streams, although it was correlated with individual habitat elements, such as streambank erosion. They noted that many agricultural and rural streams had fair to poor composite habitat scores, due to poor riparian management and sediment deposition. The same basic conclusion was also reported for streams of the Maryland Piedmont (MNCPPC, 2000).

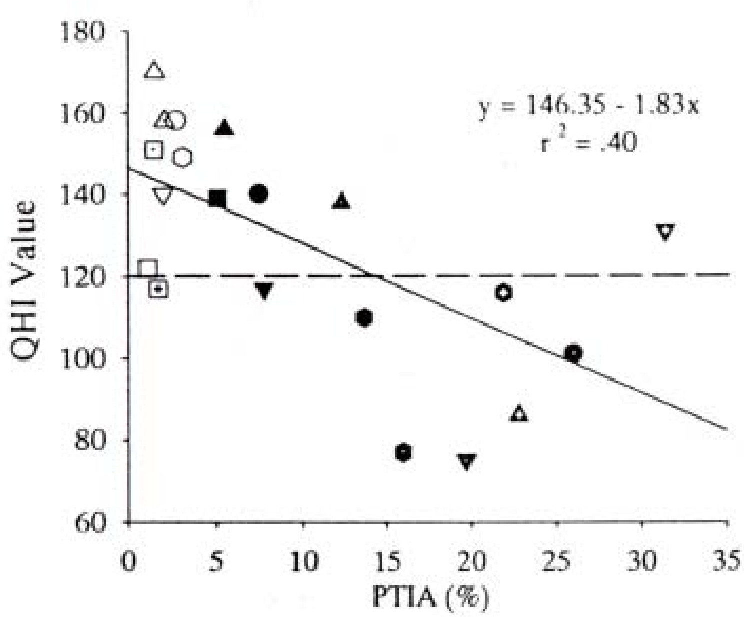


Figure 23: Relationship Between Habitat Quality and IC in Maine Streams (Morse, 2001)

3.4 Effect on Individual Elements of Stream Habitat

Roughly a dozen studies have examined the effect of watershed development on the degradation of individual stream habitat features such as bank stability, embeddedness, riffle/pool quality, and loss of LWD (Table 14). Much of this data has been acquired from the Pacific Northwest, where the importance of such habitat for migrating salmon has been a persistent management concern.

3.4.1 Bank Erosion and Bank Stability

It is somewhat surprising that we could only find one study that related bank stability or bank erosion to watershed IC. Conducted by Booth (1991) in the streams of the Puget Sound lowlands, the study reported that stream banks were consistently rated as stable in watersheds with less than 10% IC, but became progressively more unstable above this threshold. Dozens of stream assessments have found high rates of bank erosion in urban streams, but none, to our knowledge, has systematically related the prevalence or severity of bank erosion to watershed IC. As noted earlier, this may reflect the lack of a universally recognized method to measure comparative bank erosion in the field.

3.4.2 Embeddedness

Embeddedness is a term that describes the extent to which the rock surfaces found on the stream bottom are filled in with sand, silts and clay. In a healthy stream, the interstitial pores between cobbles, rock and gravel generally lack fine sediments, and are an active habitat zone and detrital processing area. The increased sediment transport in urban streams can rapidly fill up these pores in a process known as embedding. Normally, embeddedness is visually measured in riffle zones of streams. Riffles tend to be an important habitat for aquatic insects and fish (such as darters and sculpins). Clean stream substrates are also critical to trout and salmon egg incubation and embryo development. May *et al.* (1997) demonstrated that the percent of fine sediment particles in riffles generally increased with watershed IC (Figure 24). However, Finkenbine *et al.* (2000) reported that embeddedness eventually decreased slightly after watershed land use and sediment transport had stabilized for 20 years.

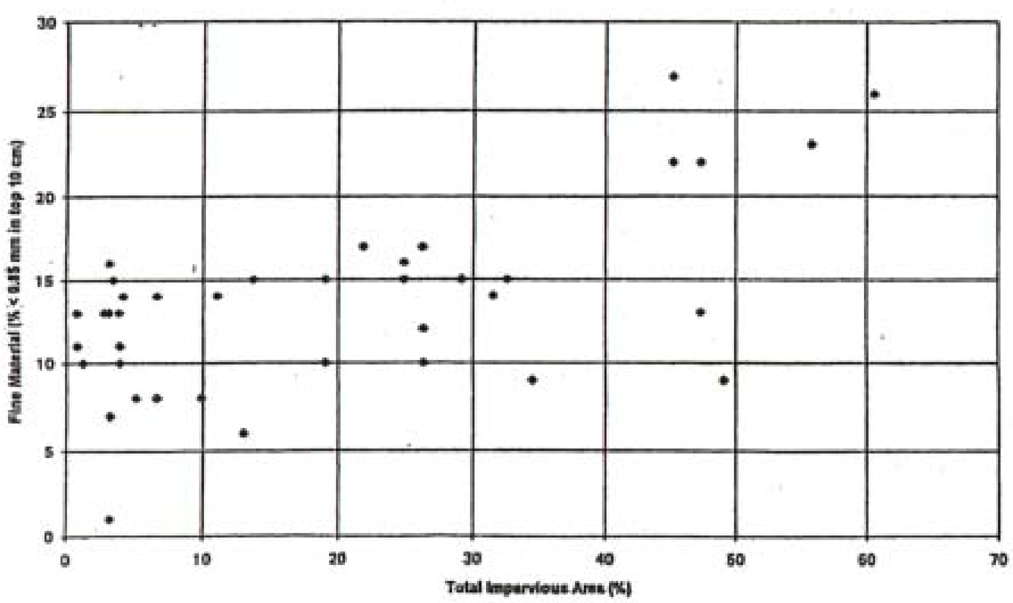


Figure 24: Fine Material Sediment Deposition as a Function of IC in Pacific Northwest Streams (Horner *et al.*, 1997)

Table 14: Research Review of Changes in Urban Stream Habitat		
Reference	**Key Finding**	**Location**
% IC Used as Indicator		
Black & Veatch, 1994	Habitat scores were ranked as poor in five subwatersheds that had greater than 30% IC.	MD
Booth and Jackson, 1997	Increase in degraded habitat conditions with increases in watershed IC.	WA
Hicks and Larson, 1997	Reported a reduction in composite stream habitat indices with increasing watershed IC.	MA
May *et al.*, 1997	Composite stream habitat declined most rapidly during the initial phase of the watershed urbanization, when percent IC exceeded the 5-10% range.	WA
Stranko and Rodney, 2001	Composite index of stream habitat declined with increasing watershed IC in coastal plain streams.	MD
Wang *et al.*, 2001	Composite stream habitat scores were not correlated with watershed IC in 47 small watersheds, although channel erosion was. Non-urban watersheds were highly agricultural and often lacked riparian forest buffers.	WI
MNCPPC, 2000	Reported that stream habitat scores were not correlated with IC in suburban watersheds.	MD
Morse, 2001	Composite habitat values tended to decline with increases in watershed IC.	ME
Booth, 1991	Channel stability and fish habitat quality declined rapidly after 10% watershed IC.	WA
Booth *et al.*, 1997	Decreased LWD with increased IC.	PNW
Finkenbine *et al.*, 2000	LWD was scarce in streams with greater than 20% IC in Vancouver.	B.C.
Horner & May, 1999	When IC levels were >5%, average LWD densities fell below 300 pieces/kilometer.	PNW
Horner *et al.*, 1997	Interstitial spaces in streambed sediments begin to fill with increasing watershed IC.	PNW
Urbanization Used as Indicator		
Dunne and Leopold, 1978	Natural channels replaced by storm drains and pipes; increased erosion rates observed downstream.	MD
May *et al.*, 1997	Forested riparian corridor width declines with increased watershed IC.	PNW
MWCOG, 1992	Fish blockages caused by bridges and culverts noted in urban watersheds.	D.C.
Pizzuto *et al.*, 2000	Urban streams had reduced pool depth, roughness, and sinuosity, compared to rural streams; Pools were 31% shallower in urban streams compared to non-urban ones.	PA
Richey, 1982	Altered pool/riffle sequence observed in urban streams.	WA
Scott *et al.*, 1986	Loss of habitat diversity noted in urban watersheds.	PNW
Spence *et al.*, 1996	Large woody debris is important for habitat diversity and anadromous fish.	PNW

3.4.3 Large Woody Debris (LWD)

LWD is a habitat element that describes the approximate volume of large woody material (< four inches in diameter) found in contact with the stream. The presence and stability of LWD is an important habitat parameter in streams. LWD can form dams and pools, trap sediment and detritus, stabilize stream channels, dissipate flow energy, and promote habitat complexity (Booth *et al.,* 1997). LWD creates a variety of pool features (plunge, lateral, scour and backwater); short riffles; undercut banks; side channels; and a range of water depths (Spence *et al.*, 1996). Urban streams tend to have a low supply of LWD, as increased stormwater flows transport LWD and clears riparian areas. Horner *et al.* (1997) presents evidence from Pacific Northwest streams that LWD decreases in response to increasing watershed IC (Figure 25).

3.4.4 Changes in Other Individual Stream Parameters

One of the notable changes in urban stream habitat is a decrease in pool depth and a general simplification of habitat features such as pools, riffles and runs. For example, Richey (1982) and Scott *et al.* (1986) reported an increase in the prevalence of glides and a corresponding altered riffle/pool sequence due to urbanization. Pizzuto *et al.* (2000) reported a median 31% decrease in pool depth in urban streams when compared to forested streams. Pizzuto *et al.* also reported a modest decrease in channel sinuosity and channel roughness in the same urban streams in Pennsylvania.

Several individual stream habitat parameters appear to have received no attention in urban stream research to date. These parameters include riparian shading, wetted perimeter, various measures of velocity/depth regimes, riffle frequency, and sediment deposition in pools. More systematic monitoring of these individual stream habitat parameters may be warranted.

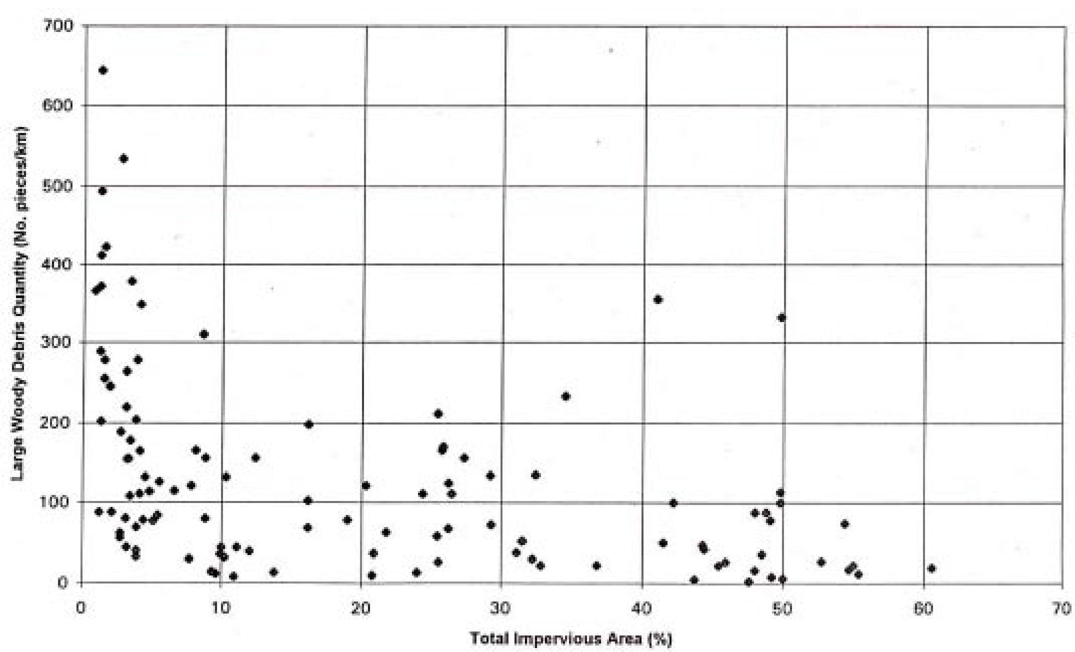


Figure 25: LWD as a Function of IC in Puget Sound Streams (Horner *et al.*, 1997)

3.5 Increased Stream Warming

IC directly influences our local weather in urban areas. This effect is obvious to anyone walking across a parking lot on a hot summer day, when temperatures often reach a scorching 110 to 120 degrees F. Parking lots and other hard surfaces tend to absorb solar energy and release it slowly. Furthermore, they lack the normal cooling properties of trees and vegetation, which act as natural air conditioners. Finally, urban areas release excess heat as a result of the combustion of fossil fuels for heating, cooling and transportation. As a result, highly urban areas tend to be much warmer than their rural counterparts and are known as urban heat islands. Researchers have found that summer temperatures tend to be six to eight degrees F warmer in the summer and two to four degrees F warmer during the winter months.

Water temperature in headwater streams is strongly influenced by local air temperatures. Summer temperatures in urban streams have been shown to increase by as much as five to 12 degrees F in response to watershed development (Table 15). Increased water temperatures can preclude temperature-sensitive species from being able to survive in urban streams.

Figure 26 shows the stream warming phenomenon in small headwater streams in the Maryland Piedmont.

Galli (1990) reported that stream temperatures throughout the summer increased in urban watersheds. He monitored five headwater streams in the Maryland Piedmont with different levels of IC. Each urban stream had mean temperatures that were consistently warmer than a forested reference stream, and stream warming appeared to be a direct function of watershed IC. Other factors, such as lack of riparian cover and the presence of ponds, were also demonstrated to amplify stream warming, but the primary contributing factor appeared to be watershed IC.

Johnson (1995) studied how stormwater influenced an urban trout stream in Minnesota and reported up to a 10 degree F increase in stream water temperatures after summer storm events. Paul *et al.* (2001) evaluated stream temperatures for 30 subwatersheds to the Etowah River in Georgia, which ranged from five to 61% urban land. They found a correlation between summer daily mean water temperatures and the percentage of urban land in a subwatershed.

Table 15: Research Review of Thermal Impacts in Urban Streams

Reference	Key Finding	Location
%IC Used as Indicator		
Galli, 1990	Increase in stream temperatures of five to 12 degrees Fahrenheit in urban watersheds; stream warming linked to IC.	MD
Urbanization Used as Indicator		
Johnson, 1995	Up to 10 degrees Fahrenheit increases in stream temperatures after summer storm events in an urban area	MN
LeBlanc *et al.*, 1997	Calibrated a model predicting stream temperature increase as a result of urbanization	Ontario
MCDEP, 2000	Monitoring effect of urbanization and stormwater ponds on stream temperatures revealed stream warming associated with urbanization and stormwater ponds	MD
Paul *et al.*, 2001	Daily mean stream temperatures in summer increased with urban land use	GA

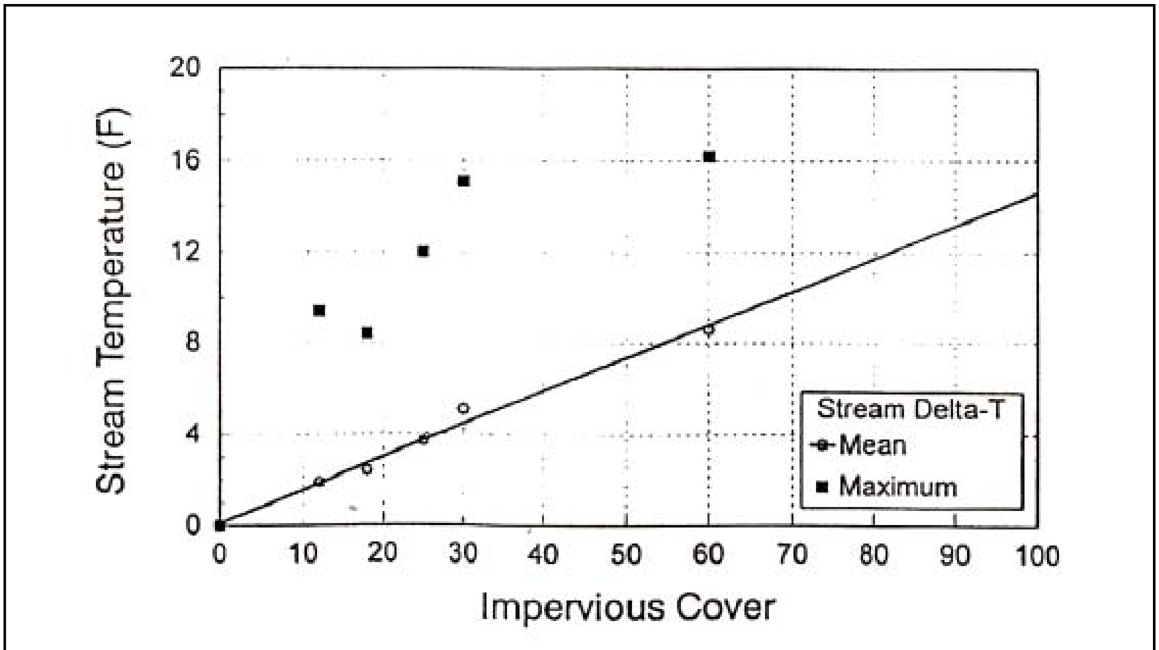


Figure 26: Stream Temperature Increase in Response to IC in Maryland Piedmont Streams (Galli, 1990)

Discharges from stormwater ponds can also contribute to stream warming in urban watersheds. Three studies highlight the temperature increase that can result from stormwater ponds. A study in Ontario found that baseflow temperatures below wet stormwater ponds increased by nine to 18 degrees F in the summer (SWAMP, 2000a, b). Oberts (1997) also measured change in the baseflow temperature as it flowed through a wetland/wet pond system in Minnesota. He concluded that the temperature had increased by an average of nine degrees F during the summer months. Galli (1988) also observed a mean increase of two to 10 degrees F in four stormwater ponds located in Maryland.

3.6 Alteration of Stream Channel Networks

Urban stream channels are often severely altered by man. Channels are lined with rip rap or concrete, natural channels are straightened, and first order and ephemeral streams are enclosed in storm drain pipes. From an engineering standpoint, these modifications rapidly convey flood waters downstream and locally stabilize stream banks. Cumulatively, however, these modifications can have a dramatic effect on the length and habitat quality of headwater stream networks.

3.6.1 Channel Modification

Over time, watershed development can alter or eliminate a significant percentage of the perennial stream network. In general, the loss of stream network becomes quite extensive when watershed IC exceeds 50%. This loss is striking when pre- and post-development stream networks are compared (Figure 27). The first panel illustrates the loss of stream network over time in a highly urban Northern Virginia watershed; the second panel shows how the drainage network of Rock Creek has changed in response to watershed development.

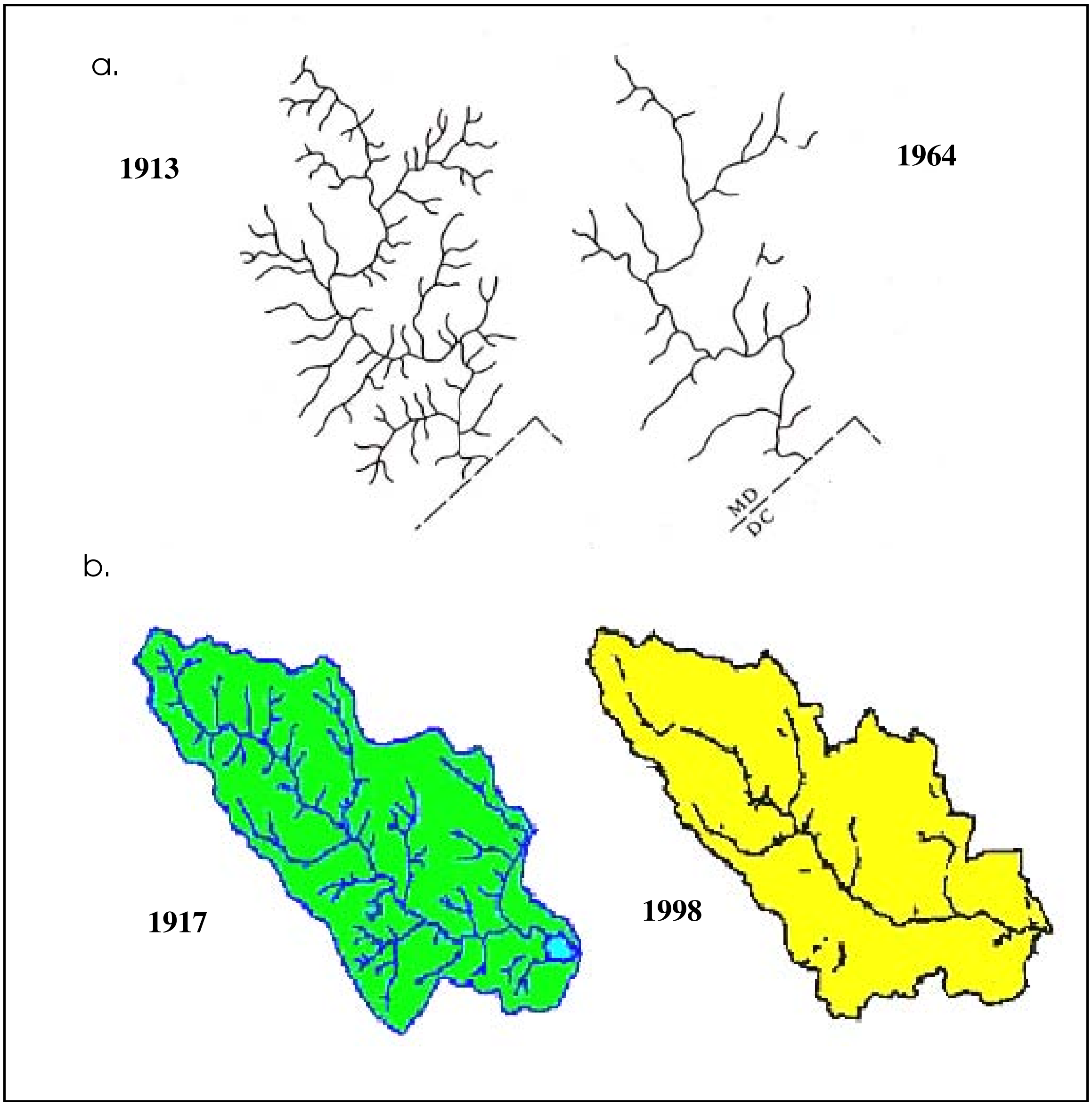


Figure 27: a. Drainage Network of Rock Creek, D.C. (Dunne and Leopold, 1978) and b. Drainage Network of Four Mile Run, VA Before and After Urbanization (NVRC, 2001)

In a national study of 269 gaged urban watersheds, Sauer *et al.* (1983) observed that channelization and channel hardening were important watershed variables that control peak discharge rates. The channel modifications increase the efficiency with which runoff is transported through the stream channel, increasing critical shear stress velocities and causing downstream channel erosion.

3.6.2 Barriers to Fish Migration

Infrastructure such as bridges, dams, pipelines and culverts can create partial or total barriers to fish migration and impair the ability of fish to move freely in a watershed. Blockages can have localized effects on small streams where non-migratory fish species can be prevented from re-colonizing upstream areas after acutely toxic events. The upstream movement of anadromous fish species such as shad, herring, salmon and steelhead can also be blocked by these barriers. Figure 28 depicts the prevalence of fish barriers in the Anacostia Watershed (MWCOG, 1992).

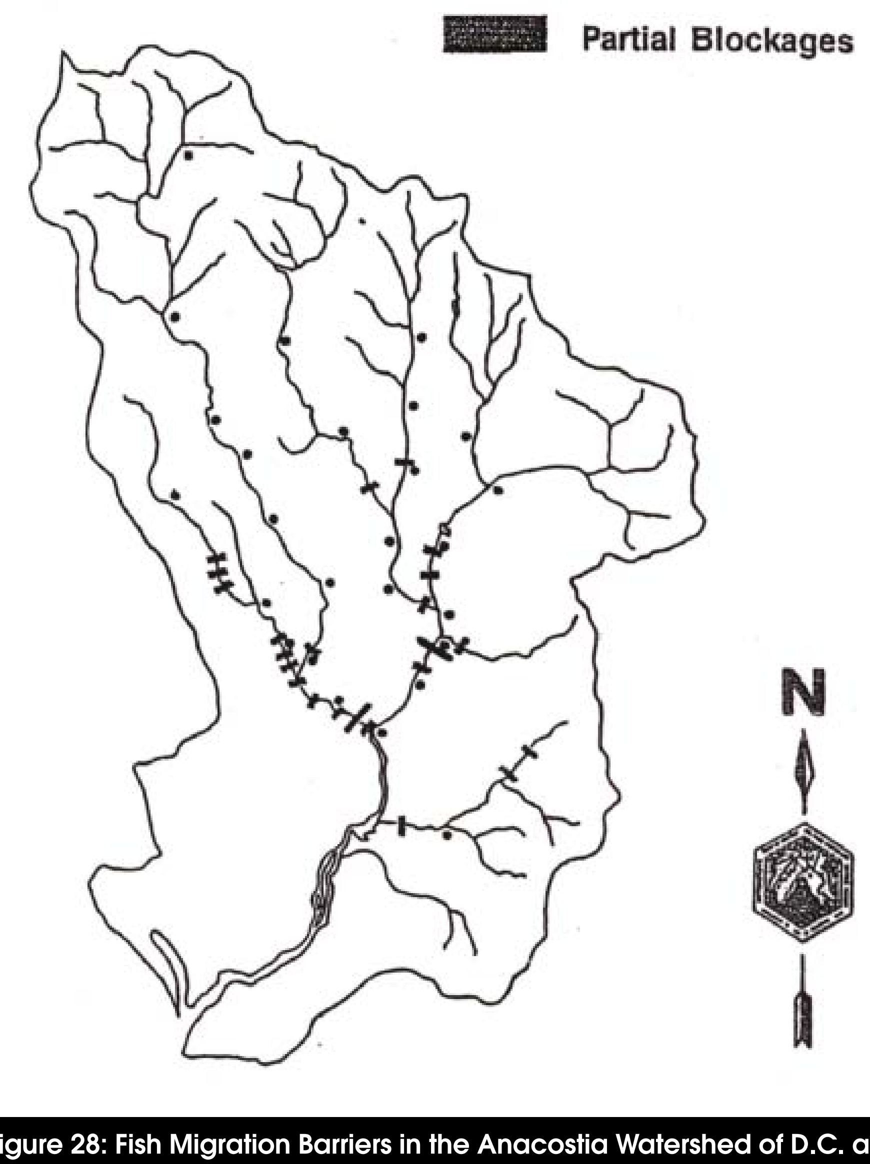


Figure 28: Fish Migration Barriers in the Anacostia Watershed of D.C. and MD (MWCOG, 1992)

3.7 Conclusion

Watershed development and the associated increase in IC have been found to significantly degrade the physical habitat of urban streams. In alluvial streams, the effects of channel enlargement and sediment transport can be severe at relatively low levels of IC (10 to 20%). However, the exact response of any stream is also contingent upon a combination of other physical factors such as geology, vegetation, gradient, the age of development, sediment supply, the use and design of storm-water treatment practices, and the extent of riparian buffers (Bledsoe, 2001).

Despite the uncertainty introduced by these factors, the limited geomorphic research to date suggests that physical habitat quality is almost always degraded by higher levels of watershed IC. Even in bedrock-controlled channels, where sediment transport and channel enlargement may not be as dramatic, researchers have noted changes in stream habitat features, such as embeddedness, loss of LWD, and stream warming.

Overall, the following conclusions can be made about the influence of watershed development on the physical habitat of urban streams:

- The major changes in physical habitat in urban streams are caused by the increased frequency and duration of bankfull and sub-bankfull discharges, and the attendant changes in sediment supply and transport. As a consequence, many urban streams experience significant channel enlargement. Generally, channel enlargement is most evident in alluvial streams.

- Typical habitat changes observed in urban streams include increased embeddedness, reduced supply of LWD, and simplification of stream habitat features such as pools, riffles and runs, as well as reduced channel sinuosity.

- Stream warming is often directly linked to watershed development, although more systematic subwatershed sampling is needed to precisely predict the extent of warming.

- Channel straightening, hardening and enclosure and the creation of fish barriers are all associated with watershed development. More systematic research is needed to establish whether these variables can be predicted based on watershed IC.

- In general, stream habitat diminishes at about 10% watershed IC, and becomes severely degraded beyond 25% watershed IC.

While our understanding of the relationship between stream habitat features and watershed development has improved in recent years, the topic deserves greater research in three areas. First, more systematic monitoring of composite habitat variables needs to be conducted across the full range of watershed IC. In particular, research is needed to define the approximate degree of watershed IC where urban streams are transformed into urban drainage systems.

Second, additional research is needed to explore the relationship between watershed IC and individual and measurable stream habitat parameters, such as bank erosion, channel sinuosity, pool depth and wetted perimeter. Lastly, more research is needed to determine if watershed treatment such as stormwater practices and stream buffers can mitigate the impacts of watershed IC on stream habitat. Together, these three research efforts could provide a technical foundation to develop a more predictive model of how watershed development influences stream habitat.

Chapter 4: Water Quality Impacts of Impervious Cover

This chapter presents information on pollutant concentrations found in urban stormwater runoff based on a national and regional data assessment for nine categories of pollutants. Included is a description of the Simple Method, which can be used to estimate pollutant loads based on the amount of IC found in a catchment or subwatershed. This chapter also addresses specific water quality impacts of stormwater pollutants and explores research on the sources and source areas of stormwater pollutants.

This chapter is organized as follows:

4.1 Introduction

Streams are usually the first aquatic system to receive stormwater runoff, and their water quality can be compromised by the pollutants it contains. Stormwater runoff typically contains dozens of pollutants that are detectable at some concentration, however small. Simply put, any pollutant deposited or derived from an activity on land will likely end up in stormwater runoff, although certain pollutants are consistently more likely to cause water quality problems in receiving waters. Pollutants that are frequently found in stormwater runoff can be grouped into nine broad categories: sediment, nutrients, metals, hydrocarbons, bacteria and pathogens, organic carbon, MTBE, pesticides, and deicers.

The impact that stormwater pollutants exert on water quality depends on many factors, including concentration, annual pollutant load, and category of pollutant. Based on nationally reported concentration data, there is considerable variation in stormwater pollutant concentrations. This variation has been at least partially attributed to regional differences, including rainfall and snowmelt. The volume and regularity of rainfall, the length of snow accumulation, and the rate of snowmelt can all influence stormwater pollutant concentrations.

The annual pollutant load can have long-term effects on stream water quality, and is particularly important information for stormwater managers to have when dealing with non-point source pollution control. The Simple Method is a model developed to estimate the pollutant load for chemical pollutants, assuming that the annual pollutant load is a function of IC. It is an effective method for determining annual sediment, nutrient, and trace metal loads. It cannot always be applied to other stormwater pollutants, since they are not always correlated with IC.

The direct water quality impact of stormwater pollutants also depends on the type of pollutant, as different pollutants impact streams differently. For example, sediments affect stream habitat and aquatic biodiversity; nutrients cause eutrophication; metals, hydrocarbons, deicers, and MTBE can be toxic to aquatic life; and organic carbon can lower dissolved oxygen levels.

The impact stormwater pollutants have on water quality can also directly influence human uses and activities. Perhaps the pollutants of greatest concern are those with associated public health impacts, such as bacteria and pathogens. These pollutants can affect the availability of clean drinking water and limit consumptive recreational activities, such as swimming or fishing. In extreme situations, these pollutants can even limit contact recreational activities such as boating and wading.

It should be noted that although there is much research available on the effects of urbanization on water quality, the majority has not been focused on the impact on streams, but on the response of lakes, reservoirs, rivers and estuaries. It is also important to note that not all pollutants are equally represented in monitoring conducted to date. While we possess excellent monitoring data for sediment, nutrients and trace metals, we have relatively little monitoring data for pesticides, hydrocarbons, organic carbon, deicers, and MTBE.

4.2 Summary of National and Regional Stormwater Pollutant Concentration Data

4.2.1 National Data

National mean concentrations of typical stormwater pollutants are presented in Table 16. National stormwater data are compiled from the Nationwide Urban Runoff Program (NURP), with additional data obtained from the U.S.Geological Survey (USGS), as well as initial stormwater monitoring conducted for EPA's National Pollutant Discharge Elimination System (NPDES) Phase I stormwater program.

In most cases, stormwater pollutant data is reported as an event mean concentration (EMC), which represents the average concentration of the pollutant during an entire stormwater runoff event.

When evaluating stormwater EMC data, it is important to keep in mind that regional EMCs can differ sharply from the reported national pollutant EMCs. Differences in EMCs between regions are often attributed to the variation in the amount and frequency of rainfall and snowmelt.

4.2.2 Regional Differences Due to Rainfall

The frequency of rainfall is important, since it influences the accumulation of pollutants on IC that are subsequently available for wash-off during storm events. The USGS developed a national stormwater database encompassing 1,123 storms in 20 metropolitan areas and used it as the primary data source to define regional differences in stormwater EMCs. Driver (1988) performed regression analysis to determine which factors had the greatest influence on stormwater EMCs and determined that annual rainfall depth was the best overall predictor. Driver grouped together stormwater EMCs based on the depth of average annual rainfall, and Table 17 depicts the regional rainfall groupings and general trends for each region. Table 18 illustrates the distribution of stormwater EMCs for a range of rainfall regions from 13 local studies, based on other monitoring studies. In general, stormwater EMCs for nutrients, suspended sediment and metals tend to be higher in arid and semi-arid

Table 16: National EMCs for Stormwater Pollutants

Pollutant	Source	EMCs		Number of Events
		Mean	Median	
Sediments (mg/l)				
TSS	(1)	78.4	54.5	3047
Nutrients (mg/l)				
Total P	(1)	0.32	0.26	3094
Soluble P	(1)	0.13	0.10	1091
Total N	(1)	2.39	2.00	2016
TKN	(1)	1.73	1.47	2693
Nitrite & Nitrate	(1)	0.66	0.53	2016
Metals (Fg/l)				
Copper	(1)	13.4	11.1	1657
Lead	(1)	67.5	50.7	2713
Zinc	(1)	162	129	2234
Cadmium	(1)	0.7	N/R	150
Chromium	(4)	4	7	164
Hydrocarbons (mg/l)				
PAH	(5)	3.5	N/R	N/R
Oil and Grease	(6)	3	N/R	N/R
Bacteria and Pathogens (colonies/ 100ml)				
Fecal Coliform	(7)	15,038	N/R	34
Fecal Streptococci	(7)	35,351	N/R	17
Organic Carbon (mg/l)				
TOC	(11)	17	15.2	19 studies
BOD	(1)	14.1	11.5	1035
COD	(1)	52.8	44.7	2639
MTBE	(8)	N/R	1.6	592
Pesticides (Fg/l)				
Diazinon	(10)	N/R	0.025	326
	(2)	N/R	0.55	76
Chlorpyrifos	(10)	N/R	N/R	327
Atrazine	(10)	N/R	0.023	327
Prometon	(10)	N/R	0.031	327
Simazine	(10)	N/R	0.039	327
Chloride (mg/l)				
Chloride	(9)	N/R	397	282

Sources: [1] Smullen and Cave, 1998; [2] Brush et al., 1995; [3] Baird et al., 1996; [4] Bannerman et al., 1996; [5] Rabanal and Grizzard, 1995; [6] Crunkilton et al., 1996; [7] Schueler, 1999; [8] Delzer, 1996; [9] Environment Canada, 2001; [10] USEPA, 1998; [11] CWP, 2001a N/R - Not Reported

Table 17: Regional Groupings by Annual Rainfall Amount (Driver, 1988)

Region	Annual Rainfall	States Monitored	Concentration Data
Region I: Low Rainfall	<20 inches	AK, CA, CO, NM, UT	Highest mean and median values for Total N, Total P, TSS and COD
Region II: Moderate Rainfall	20 40 inches	HA, IL, MI, MN, MI, NY, TX, OR, OH, WA, WI	Higher mean and median values than Region III for TSS, dissolved phosphorus and cadmium
Region III: High Rainfall	>40 inches	FL, MD, MA, NC, NH, NY, TX, TN, AR	Lower values for many parameters likely due to the frequency of storms and the lack of build up in pollutants

regions and tend to decrease slightly when annual rainfall increases (Table 19).

It is also hypothesized that a greater amount of sediment is eroded from pervious surfaces in arid or semi-arid regions than in humid regions due to the sparsity of protective vegetative cover. Table 19 shows that the highest concentrations of total suspended solids were recorded in regions with least rainfall. In addition, the chronic toxicity standards for several metals are most frequently exceeded during low rainfall regions (Table 20).

4.2.3 Cold Region Snowmelt Data

In colder regions, snowmelt can have a significant impact on pollutant concentrations. Snow accumulation in winter coincides with pollutant build-up; therefore, greater concentrations of pollutants are measured during snowmelt events. Sources of snowpack pollution in urban areas include wet and dry atmospheric deposition, traffic emissions, urban litter, deteriorated infrastructure, and deicing chemicals and abrasives (WERF, 1999).

Oberts *et al.* (1989) measured snowmelt pollutants in Minnesota streams and found that as much as 50% of annual sediment, nutrient, hydrocarbon and metal loads could be attributed to snowmelt runoff during late winter and early spring. This trend probably applies to any region where snow cover persists through much of the winter. Pollutants accumulate in the snowpack and then contribute high concentrations during snowmelt runoff. Oberts (1994) described four types of snowmelt runoff events and the resulting pollutant characteristics (Table 21).

A typical hydrograph for winter and early spring snow melts in a northern cold climate is portrayed in Figure 29. The importance of snowpack melt on peak runoff during March 1989 can clearly be seen for an urban watershed located in St. Paul, Minnesota.

Major source areas for snowmelt pollutants include snow dumps and roadside snowpacks. Pollutant concentrations in snow dumps can be as much as five times greater than typical stormwater pollutant concentrations (Environment Canada, 2001). Snow dumps and packs accumulate pollutants over the winter months and can release them during a few rain or snow melt events in the early spring. High levels of chloride, lead, phosphorus, biochemical oxygen demand, and total suspended solids have been reported in snow pack runoff (La Barre *et al*, 1973; Oliver *et al.*, 1974; Pierstorff and Bishop, 1980; Scott and Wylie, 1980; Van Loon, 1972).

Atmospheric deposition can add pollutants to snow piles and snowpacks. Deposited pollutants include trace metals, nutrients and particles that are primarily generated by fossil fuel combustion and industrial emissions (Boom and Marsalek, 1988; Horkeby and Malmqvist, 1977; Malmqvist, 1978; Novotny and Chester, 1981; Schrimpff and Herrman, 1979).

Table 18: Stormwater Pollutant Event Mean Concentration for Different U.S. Regions (Units: mg/l, except for metals which are in *F*g/l)

		Region I - Low Rainfall				Region II - Moderate Rainfall			Region III - High Rainfall				Snow
	National	Phoenix, AZ	San Diego, CA	Boise, ID	Denver, CO	Dallas, TX	Marquette, MI	Austin, TX	MD	Louisville, KY	GA	FL	MN
Reference	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(11)	(12)
Annual Rainfall (in.)	N/A	7.1"	10"	11"	15"	28"	32"	32"	41"	43"	51"	52"	N/R
Number of Events	3000	40	36	15	35	32	12	N/R	107	21	81	N/R	49
Pollutant													
TSS	78.4	227	330	116	242	663	159	190	67	98	258	43	112
Total N	2.39	3.26	4.55	4.13	4.06	2.70	1.87	2.35	N/R	2.37	2.52	1.74	4.30
Total P	0.32	0.41	0.7	0.75	0.65	0.78	0.29	0.32	0.33	0.32	0.33	0.38	0.70
Soluble P	0.13	0.17	0.4	0.47	N/R	N/R	0.04	0.24	N/R	0.21	0.14	0.23	0.18
Copper	14	47	25	34	60	40	22	16	18	15	32	1.4	N/R
Lead	68	72	44	46	250	330	49	38	12.5	60	28	8.5	100
Zinc	162	204	180	342	350	540	111	190	143	190	148	55	N/R
BOD	14.1	109	21	89	N/R	112	15.4	14	14.4	88	14	11	N/R
COD	52.8	239	105	261	227	106	66	98	N/R	38	73	64	112

Sources: Adapted from Caraco, 2000a: [1] Smullen and Cave, 1998; [2] Lopes et al.; 1995; [3] Schiff, 1996; [4] Kjelstrom, 1995 (computed); [5] DRCOG, 1983, [6] Brush et al.*, 1995; [7] Steuer* et al.*, 1997; [8] Barrett* et al.*, 1995; [9] Barr, 1997; [10] Evaldi* et al.*, 1992; [11] Thomas and McClelland, 1995; [12] Oberts, 1994 N/R = Not Reported; N/A = Not Applicable*

Table 19: Mean and Median Nutrient and Sediment Stormwater Concentrations for Residential Land Use Based on Rainfall Regions (Driver, 1988)

Region	Total N (median)	Total P (median)	TSS (mean)
Region I: Low Rainfall	4	0.45	320
Region II: Moderate Rainfall	2.3	0.31	250
Region III: High Rainfall	2.15	0.31	120

Table 20: EPA 1986 Water Quality Standards and Percentage of Metal Concentrations Exceeding Water Quality Standards by Rainfall Region (Driver, 1988)				
	Cadmium	**Copper**	**Lead**	**Zinc**
EPA Standards	10 Fg/l	12 Fg/l	32 Fg/l	47 Fg/l
	Percent Exceedance of EPA Standards			
Region I: Low Rainfall	1.5%	89%	97%	97%
Region II: Moderate Rainfall	0	78%	89%	85%
Region III: High Rainfall	0	75%	91%	84%

Table 21: Runoff and Pollutant Characteristics of Snowmelt Stages (Oberts, 1994)			
Snowmelt Stage	Duration /Frequency	Runoff Volume	Pollutant Characteristics
Pavement	Short, but many times in winter	Low	Acidic, high concentrations of soluble pollutants; Chloride, nitrate, lead; total load is minimal
Roadside	Moderate	Moderate	Moderate concentrations of both soluble and particulate pollutants
Pervious Area	Gradual, often most at end of season	High	Dilute concentrations of soluble pollutants; moderate to high concentrations of particulate pollutants depending on flow
Rain-on-Snow	Short	Extreme	High concentrations of particulate pollutants; moderate to high concentrations of soluble pollutants; high total load

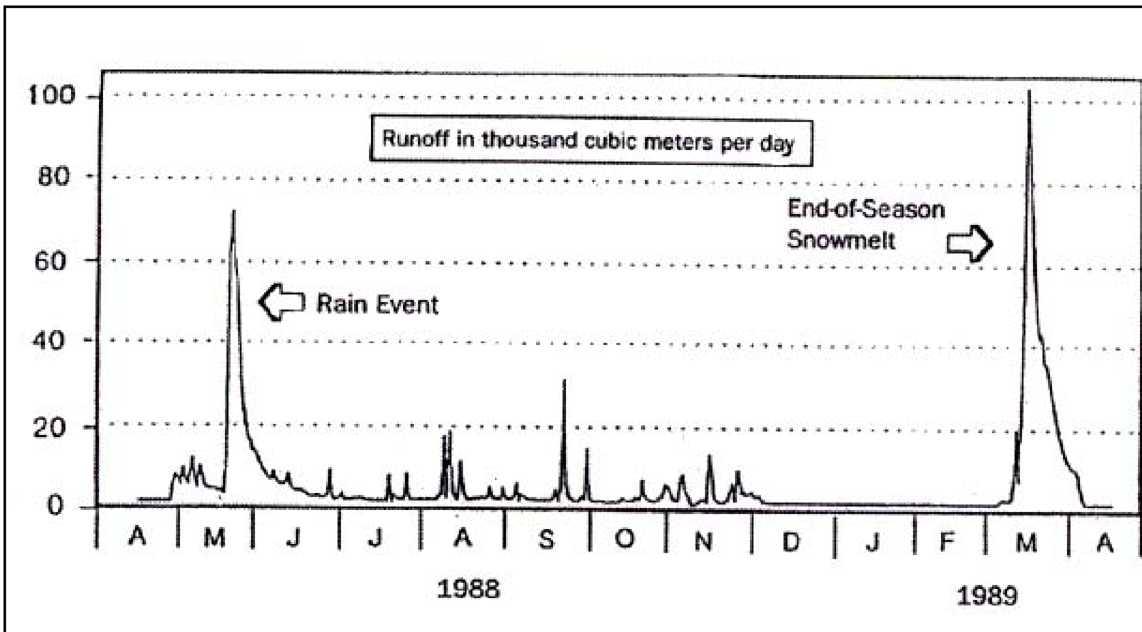


Figure 29: Snowmelt Runoff Hydrograph for Minneapolis Stream (Oberts, 1994)

4.3 Relationship Between Pollutant Loads and IC: The Simple Method

Urban stormwater runoff contains a wide range of pollutants that can degrade downstream water quality. The majority of stormwater monitoring research conducted to date supports several generalizations. First, the unit area pollutant load delivered to receiving waters by stormwater runoff increases in direct proportion to watershed IC. This is not altogether surprising, since pollutant load is the product of the average pollutant concentration and stormwater runoff volume. Given that runoff volume increases in direct proportion to IC, pollutant loads must automatically increase when IC increases, as long the average pollutant concentration stays the same (or increases). This relationship is a central assumption in most simple and complex pollutant loading models (Bicknell *et al.*, 1993; Donigian and Huber, 1991; Haith *et al.*, 1992; Novotny and Chester, 1981; NVPDC, 1987; Pitt and Voorhees, 1989).

Recognizing the relationship between IC and pollutant loads, Schueler (1987) developed the "Simple Method" to quickly and easily estimate stormwater pollutant loads for small urban watersheds (see Figure 30). Estimates of pollutant loads are important to watershed managers as they grapple with costly decisions on non-point source control. The Simple Method is empirical in nature and utilizes the extensive regional and national database (Driscoll, 1983; MWCOG, 1983; USEPA, 1983). Figure 30 provides the basic equations to estimate pollutant loads using the Simple

Figure 30: The Simple Method - Basic Equations

The Simple Method estimates pollutant loads as the product of annual runoff volume and pollutant EMC, as:

$$(1)\ L = 0.226 * R * C * A$$

Where: L = Annual load (lbs), and:
R = Annual runoff (inches)
C = Pollutant concentration in stormwater, EMC (mg/l)
A = Area (acres)
0.226 = Unit conversion factor

For bacteria, the equation is slightly different, to account for the differences in units. The modified equation for bacteria is:

$$(2)\ L = 1.03 * 10^{-3} * R * C * A$$

Where: L = Annual load (Billion Colonies), and:
R = Annual runoff (inches)
C = Bacteria concentration (#/100 ml)
A = Area (acres)
$1.03 * 10^{-3}$ = Unit conversion factor

Annual Runoff

The Simple Method calculates the depth of annual runoff as a product of annual runoff volume and a runoff coefficient (Rv). Runoff volume is calculated as:

$$(3)\ R = P * P_j * Rv$$

Where: R = Annual runoff (inches), and:
P = Annual rainfall (inches)
P_j = Fraction of annual rainfall events that produce runoff (usually 0.9)
Rv = Runoff coefficient

In the Simple Method, the runoff coefficient is calculated based on IC in the subwatershed. The following equation represents the best fit line for the data set (N=47, R^2=0.71).

$$(4)\ Rv=0.05+0.9Ia$$

Where: Rv = runoff coefficient, and:
Ia = Impervious fraction

Method. It assumes that loads of stormwater pollutants are a direct function of watershed IC, as IC is the key independent variable in the equation.

The technique requires a modest amount of information, including the subwatershed drainage area, IC, stormwater runoff pollutant EMCs, and annual precipitation. With the Simple Method, the investigator can either divide up land use into specific areas (i.e. residential, commercial, industrial, and roadway) and calculate annual pollutant loads for each land use, or utilize a generic urban land use. Stormwater pollutant EMC data can be derived from the many summary tables of local, regional, or national monitoring efforts provided in this chapter (e.g., Tables 16, 18, 22, 28, 30, 35, 36, 40, and 44). The model also requires different IC values for separate land uses within a subwatershed. Representative IC data from Cappiella and Brown (2001) were provided in Table 2 (Chapter 1).

Additionally, the Simple Method should not be used to estimate annual pollutant loads of deicers, hydrocarbons and MTBE, because they have not been found to be correlated with IC. These pollutants have been linked to other indicators. Chlorides, hydrocarbons and MTBE are often associated with road density and vehicle miles traveled (VMT). Pesticides are associated with turf area, and traffic patterns and "hotspots" have been noted as potential indicators for hydrocarbons and MTBE.

Limitations of the Simple Method

The Simple Method should provide reasonable estimates of changes in pollutant export resulting from urban development. However, several caveats should be kept in mind when applying this method.

The Simple Method is most appropriate for assessing and comparing the relative stormflow pollutant load changes from different land uses and stormwater treatment scenarios. The Simple Method provides estimates of storm pollutant export that are probably close to the "true" but unknown value for a development site, catchment, or subwatershed. However, it is very important not to overemphasize the precision of the load estimate obtained. For example, it would be inappropriate to use the Simple Method to evaluate relatively similar development scenarios (e.g., 34.3% versus 36.9% IC). The Simple Method provides a general planning estimate of likely storm pollutant export from areas at the scale of a development site, catchment or subwatershed. More sophisticated modeling is needed to analyze larger and more complex watersheds.

In addition, the Simple Method only estimates pollutant loads generated during storm events. It does not consider pollutants associated with baseflow during dry weather. Typically, baseflow is negligible or non-existent at the scale of a single development site and can be safely neglected. However, catchments and subwatersheds do generate significant baseflow volume. Pollutant loads in baseflow are generally low and can seldom be distinguished from natural background levels (NVPDC, 1979).

Consequently, baseflow pollutant loads normally constitute only a small fraction of the total pollutant load delivered from an urban area. Nevertheless, it is important to remember that the load estimates refer only to storm event derived loads and should not be confused with the total pollutant load from an area. This is particularly important when the development density of an area is low. For example, in a low density residential subwatershed (IC < 5%), as much as 75% of the annual runoff volume could occur as baseflow. In such a case, annual baseflow load may be equivalent to the annual stormflow load.

4.4 Sediment

Sediment is an important and ubiquitous pollutant in urban stormwater runoff. Sediment can be measured in three distinct ways: Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and turbidity. TSS is a measure of the total mass suspended sediment particles in water. The measurement of TSS in urban stormwater helps to estimate sediment load transported to local and downstream receiving waters. Table 22 summarizes stormwater EMCs for total suspended solids, as reported by Barrett *et al.* (1995), Smullen and Cave (1998), and USEPA (1983). TDS is a measure of the dissolved solids and minerals present in stormwater runoff and is used as a primary indication of the purity of drinking water. Since few stormwater monitoring efforts have focused on TDS, they are not reported in this document. Turbidity is a measure of how suspended solids present in water reduce the ability of light to penetrate the water column. Turbidity can exert impacts on aquatic biota, such as the ability of submerged aquatic vegetation to receive light and the ability of fish and aquatic insects to use their gills (Table 23).

4.4.1 Concentrations

TSS concentrations in stormwater across the country are well documented. Table 18 reviews mean TSS EMCs from 13 communities across the country and reveals a wide range of recorded concentrations. The lowest concentration of 43 mg/l was reported in Florida, while TSS reached 663 mg/l in Dallas, Texas.

Variation in sediment concentrations has been attributed to regional rainfall differences (Driver, 1988); construction site runoff (Leopold, 1968); and bank erosion (Dartiguenave *et al.*, 1997). National values are provided in Table 22.

Turbidity levels are not as frequently reported in national and regional monitoring summaries. Barrett and Malina (1998) monitored turbidity at two sites in Austin, Texas and reported a mean turbidity of 53 NTU over 34 storm events (Table 22).

4.4.2 Impacts of Sediment on Streams

The impacts of sediment on aquatic biota are well documented and can be divided into impacts caused by suspended sediment and those caused by deposited sediments (Tables 23 and 24).

In general, high levels of TSS and/or turbidity can affect stream habitat and cause sedimentation in downstream receiving waters. Deposited sediment can cover benthic organisms such as aquatic insects and freshwater mussels. Other problems associated with high sediments loads include stream warming by reflecting radiant energy due to increased turbidity (Kundell and Rasmussen, 1995), decreased flow capacity (Leopold, 1973), and increasing overbank flows (Barrett and Malina, 1998). Sediments also transport other pollutants which bind to sediment particles. Significant levels of pollutants can be transported by sediment during stormwater runoff events,

Table 22: EMCs for Total Suspended Solids and Turbidity

Pollutant	EMCs		Number of Events	Source
	Mean	Median		
TSS (mg/l)	78.4	54.5	3047	Smullen and Cave, 1998
	174	113	2000	USEPA, 1983
Turbidity (NTU)	53	N/R	423	Barrett and Malina, 1998

N/R = Not Reported

Table 23: Summary of Impacts of Suspended Sediment on the Aquatic Environment (Schueler and Holland, 2000)
Abrades and damages fish gills, increasing risk of infection and disease
Scouring of periphyton from stream (plants attached to rocks)
Loss of sensitive or threatened fish species when turbidity exceeds 25 NTU
Shifts in fish community toward more sediment-tolerant species
Decline in sunfish, bass, chub and catfish when month turbidity exceeds 100 NTU
Reduces sight distance for trout, with reduction in feeding efficiency
Reduces light penetration causing reduction in plankton and aquatic plant growth
Adversely impacts aquatic insects, which are the base of the food chain
Slightly increases the stream temperature in the summer
Suspended sediments can be a major carrier of nutrients and metals
Reduces anglers chances of catching fish

Table 24: Summary of Impacts of Deposited Sediments on the Aquatic Environment (Schueler and Holland, 2000)
1. Physical smothering of benthic aquatic insect community
2. Reduced survival rates for fish eggs
3. Destruction of fish spawning areas and eggs
4. Embeddedness of stream bottom reduced fish and macroinvertebrate habitat value
5. Loss of trout habitat when fine sediments are deposited in spawning or riffle-runs
6. Sensitive or threatened darters and dace may be eliminated from fish community
7. Increase in sediment oxygen demand can deplete dissolved oxygen in streams
8. Significant contributing factor in the alarming decline of freshwater mussels
9. Reduced channel capacity, exacerbating downstream bank erosion and flooding
10. Reduced flood transport capacity under bridges and through culverts
11. Deposits diminish scenic and recreational values of waterways

including trace metals, hydrocarbons and nutrients (Crunkilton *et al.,* 1996; Dartiguenave *et al*., 1997; Gavin and Moore, 1982; Novotny and Chester, 1989; Schueler 1994b).

4.4.3 Sources and Source Areas of Sediment

Sediment sources in urban watersheds include stream bank erosion; erosion from exposed soils, such as from construction sites; and washoff from impervious areas (Table 25).

As noted in this chapter, streambank erosion is generally considered to be the primary source of sediment to urban streams. Recent studies by Dartiguenave *et al.* (1997) and Trimble (1997) determined that streambank erosion contributes the majority of the annual sediment budget of urban streams. Trimble (1997) directly measured stream cross sections, sediment aggradation and suspended sediment loads and determined that two-thirds of the annual sediment budget of a San Diego, California watershed was supplied by streambank erosion. Dartiguenave *et al.* (1997) developed a GIS based model in Austin, Texas to determine the effects of stream bank erosion on the annual sediment budget. They compared modeled sediment loads from the watershed with the actual sediment loads measured at USGS gaging stations and concluded that more than 75% of the sediment load came from streambank erosion. Dartiguenave *et al.* (1997) reported that sediment load per unit area increases with increasing IC (Figure 31).

Sediment loads are also produced by washoff of sediment particles from impervious areas and their subsequent transport in stormwater runoff sediment. Source areas include parking lots, streets, rooftops, driveways and lawns. Streets and parking lots build up dirt and grime from the wearing of the street surface, exhaust particulates, “blown on” soil and organic matter, and atmospheric deposition. Lawn runoff primarily contains soil and organic matter. Urban source areas that produce the highest TSS concentrations include streets, parking lots and lawns (Table 26).

Parking lots and streets are not only responsible for high concentrations of sediment but also high runoff volumes. The SLAMM source loading model (Pitt and Voorhees, 1989) looks at runoff volume and concentrations of pollutants from different urban land uses and predicts stream loading. When used in the Wisconsin and Michigan subwatersheds, it demonstrated that parking lots and streets were responsible for over 70% of the TSS delivered to the stream. (Steuer *et al*., 1997; Waschbusch *et al*., 2000).

Table 25: Sources and Loading of Suspended Solids Sediment in Urban Areas

Sources	Loading	Source
Bank Erosion	75% of stream sediment budget	Dartinguenave *et al*., 1997
	66% of stream sediment budget	Trimble, 1997
Overland Flow- Lawns	397 mg/l (geometric mean)	Bannerman *et al*., 1993
	262 mg/l	Steuer *et al*., 1997
	11.5% (estimated; 2 sites)	Waschbusch *et al*., 2000
Construction Sites	200 to 1200 mg/l	Table 27
Washoff from Impervious Surfaces	78 mg/l (mean)	Table 16

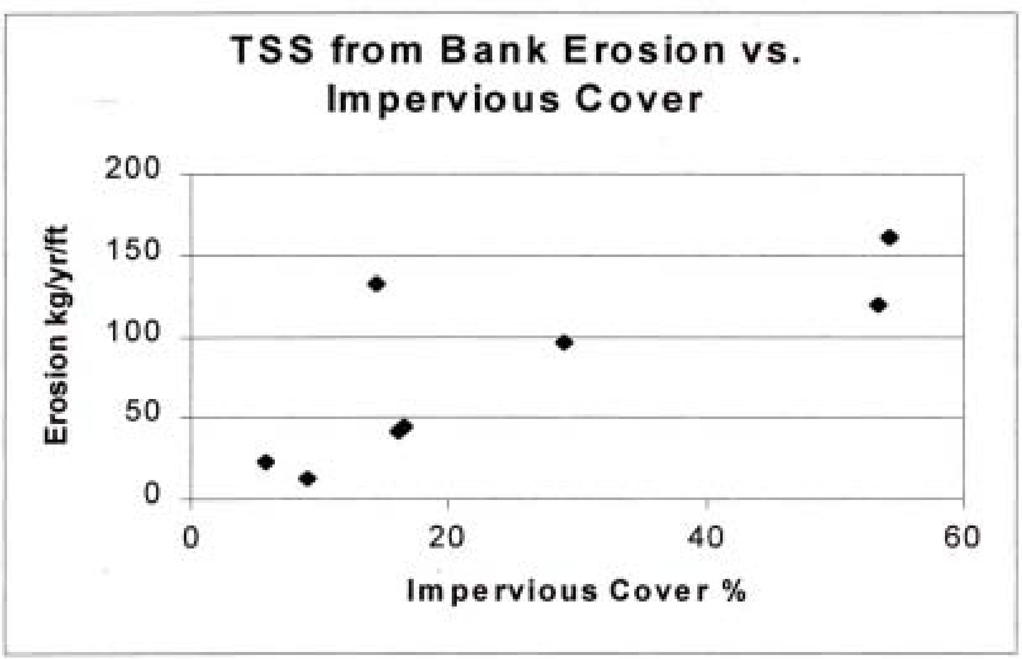


Figure 31: TSS from Bank Erosion vs. IC in Texas Streams (Daringuenave *et al*., 1997)

The third major source of sediment loads is erosion from construction sites. Several studies have reported extremely high TSS concentrations in construction site runoff, and these findings are summarized in Table 27. TSS concentrations from uncontrolled construction sites can be more than 150 times greater than those from undeveloped land (Leopold, 1968) and can be reduced if erosion and sediment control practices are applied to construction sites.

Table 26: Source Area Geometric Mean Concentrations for Suspended Solids in Urban Areas

Source Area	Suspended Solids (mg/l)		
Source	(1)	(2)	(3)
Commercial Parking Lot	110	58	51
High Traffic Street	226	232	65
Medium Traffic Street	305	326	51
Low Traffic Street	175	662	68
Commercial Rooftop	24	15	18
Residential Rooftop	36	27	15
Residential Driveway	157	173	N/R
Residential Lawn	262	397	59

Sources: (1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch et al., 2000; N/R = Not Reported

Table 27: Mean TSS Inflow and Outflow at Uncontrolled, Controlled and Simulated Construction Sites

Source	Mean Inflow TSS Concentration (mg/l)	Mean Outflow TSS Concentration (mg/l)	Location
Uncontrolled Sites			
Horner *et al*., 1990	7,363	281	PNW
Schueler and Lugbill,1990	3,646	501	MD
York and Herb, 1978	4,200	N/R	MD
Islam *et al*., 1988	2,950	N/R	OH
Controlled Sites			
Schueler and Lugbill, 1990	466	212	MD
Simulated Sediment Concentrations			
Jarrett, 1996	9,700	800	PA
Sturm and Kirby, 1991	1,500-4,500	200-1,000	GA
Barfield and Clar, 1985	1,000-5,000	200-1,200	MD
Dartiguenave *et al*., 1997	N/R	600	TX

N/R = Not Reported

4.5 Nutrients

Nitrogen and phosphorus are essential nutrients for aquatic systems. However, when they appear in excess concentrations, they can exert a negative impact on receiving waters. Nutrient concentrations are reported in several ways. Nitrogen is often reported as nitrate (NO_3) and nitrite (NO_2), which are inorganic forms of nitrogen; total nitrogen (Total N), which is the sum of nitrate, nitrite, organic nitrogen and ammonia; and total Kjeldhal nitrogen (TKN), which is organic nitrogen plus ammonia.

Phosphates are frequently reported as soluble phosphorus, which is the dissolved and reactive form of phosphorus that is available for uptake by plants and animals. Total phosphorus (Total P) is also measured, which includes both organic and inorganic forms of phosphorus. Organic phosphorus is derived from living plants and animals, while inorganic phosphate is comprised of phosphate ions that are often bound to sediments.

4.5.1 Concentrations

Many studies have indicated that nutrient concentrations are linked to land use type, with urban and agricultural watersheds producing the highest nutrient loads (Chessman *et al.* 1992; Paul *et al.*, 2001; USGS, 2001b and Wernick *et al.*,1998). Typical nitrogen and phosphorus EMC data in urban stormwater runoff are summarized in Table 28.

Some indication of the typical concentrations of nitrate and phosphorus in stormwater runoff are evident in Figures 32 and 33. These graphs profile average EMCs in stormwater runoff recorded at 37 residential catchments across the U.S. The average nitrate EMC is remarkably consistent among residential neighborhoods, with most clustered around the mean of 0.6 mg/l and a range of 0.25 to 1.4 mg/l. The concentration of phosphorus during storms is also very consistent with a mean of 0.30 mg/l and a rather tight range of 0.1 to 0.66 mg/l (Schueler, 1995).

The amount of annual rainfall can also influence the magnitude of nutrient concentrations in stormwater runoff. For example, both Caraco (2000a) and Driver (1988) reported that the highest nutrient EMCs were found in stormwater from arid or semi-arid regions.

Table 28: EMCs of Phosphorus and Nitrogen Urban Stormwater Pollutants

Pollutant	EMCs (mg/l)		Number of Events	Source
	Mean	Median		
Total P	0.315	0.259	3094	Smullen and Cave, 1998
	0.337	0.266	1902	USEPA, 1983
Soluble P	0.129	0.103	1091	Smullen and Cave, 1998
	0.1	0.078	767	USEPA, 1983
Total N	2.39	2.00	2016	Smullen and Cave, 1998
	2.51	2.08	1234	USEPA, 1983
TKN	1.73	1.47	2693	Smullen and Cave, 1998
	1.67	1.41	1601	USEPA, 1983
Nitrite & Nitrate	0.658	0.533	2016	Smullen and Cave, 1998
	0.837	0.666	1234	USEPA, 1983

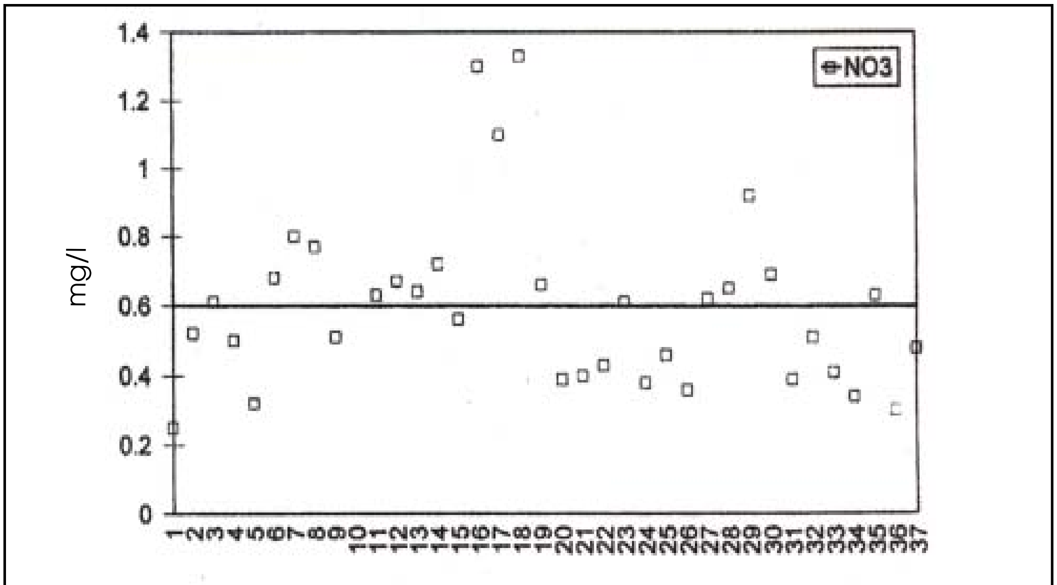


Figure 32: Nitrate-Nitrogen Concentration in Stormwater Runoff at 37 Sites Nationally (Schueler, 1999)

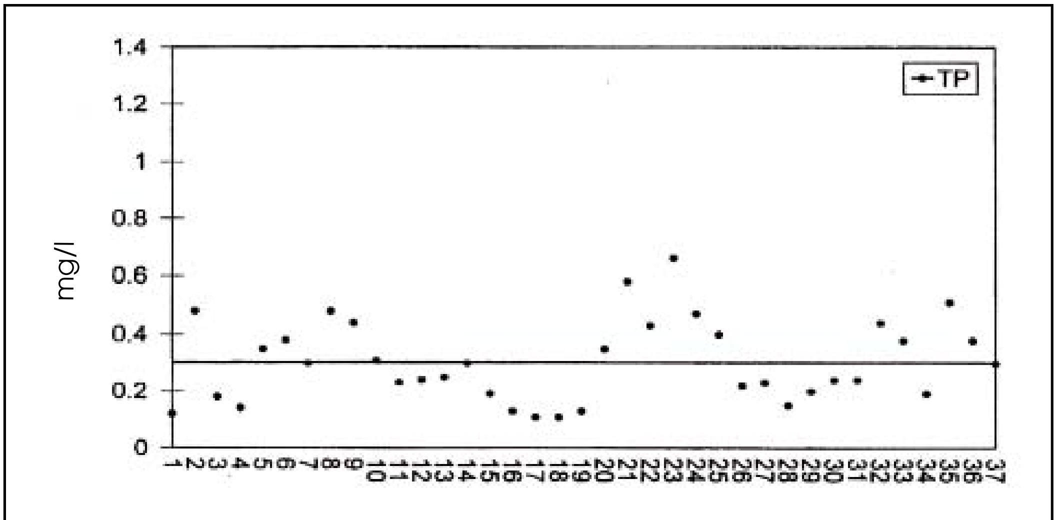


Figure 33: Total Phosphorus Concentration in Stormwater at 37 Sites Nationally (Schueler, 1999)

4.5.2 Impacts of Nutrients on Streams

Much research on the impact of nutrient loads has been focused on lakes, reservoirs and estuaries, which can experience eutrophication. Nitrogen and phosphorus can contribute to algae growth and eutrophic conditions, depending on which nutrient limits growth (USEPA, 1998). Dissolved oxygen is also affected by eutrophication. When algae or aquatic plants that are stimulated by excess nutrients die off, they are broken down by bacteria, which depletes the oxygen in the water. Relatively few studies have specifically explored the impact of nutrient enrichment on urban streams. Chessman *et al*. (1992) studied the limiting nutrients for periphyton growth in a variety of streams and noted that the severity of eutrophication was related to low flow conditions. Higher flow rates in streams may cycle nutrients faster than in slow flow rates, thus diminishing the extent of stream eutrophication.

4.5.3 Sources and Source Areas of Nutrients

Phosphorus is normally transported in surface water attached to sediment particles or in soluble forms. Nitrogen is normally transported by surface water runoff in urban watersheds. Sources for nitrogen and phosphorus in urban stormwater include fertilizer, pet waste, organic matter (such as leaves and detritus), and stream bank erosion. Another significant source of nutrients is atmospheric deposition. Fossil fuel combustion by automobiles, power plants and industry can supply nutrients in both wet fall and dry fall. The Metropolitan Washington Council of Governments (MWCOG, 1983) estimated total annual atmospheric deposition rates of 17 lbs/ac for nitrogen and 0.7 lbs/ac for phosphorus in the Washington, D.C. metro area.

Research from the upper Midwest suggests "hot spot" sources can exist for both nitrogen and phosphorus in urban watersheds. Lawns, in particular, contribute greater concentrations of Total N, Total P and dissolved phosphorus than other urban source areas. Indeed, source research suggests that nutrient concentrations in lawn runoff can be as much as four times greater than other urban sources such as streets, rooftops or driveways (Bannerman *et al.*, 1993; Steuer *et al.*, 1997 and Waschbusch *et al.*, 2000) (Table 29). This finding is significant, since lawns can comprise more than 50% of the total area in suburban watersheds. Lawn care, however, has seldom been directly linked to elevated nutrient concentrations during storms. A very recent lakeshore study noted that phosphorus concentrations were higher in fertilized lawns compared to unfertilized lawns, but no significant difference was noted for nitrogen (Garn, 2002).

Wash-off of deposited nutrients from IC is thought to be a major source of nitrogen and phosphorus during storms (MWCOG, 1983). While the concentration of nitrogen and phosphorus from parking lots and streets is lower than lawns, the volume of runoff is significantly higher. In two studies using the SLAMM source loading model (Pitt and Voorhees, 1989), parking lots and streets were responsible for over 30% of the nitrogen and were second behind lawns in their contributions to the phosphorus load (Steuer *et al.*, 1997; Waschbusch *et al.*, 2000).

Table 29: Source Area Monitoring Data for Total Nitrogen and Total Phosphorous in Urban Areas

Source Area	Total N (mg/l)	Total P (mg/l)		
Source	(1)	(1)	(2)	(3)
Commercial Parking Lot	1.94	0.20	N/R	0.10
High Traffic Street	2.95	0.31	0.47	0.18
Med. Traffic Street	1.62	0.23	1.07	0.22
Low Traffic Street	1.17	0.14	1.31	0.40
Commercial Rooftop	2.09	0.09	0.20	0.13
Residential Rooftop	1.46	0.06	0.15	0.07
Residential Driveway	2.10	0.35	1.16	N/R
Residential Lawn	9.70	2.33	2.67	0.79
Basin Outlet	1.87	0.29	0.66	N/R

(1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch et al., 2000; N/R= Not Reported

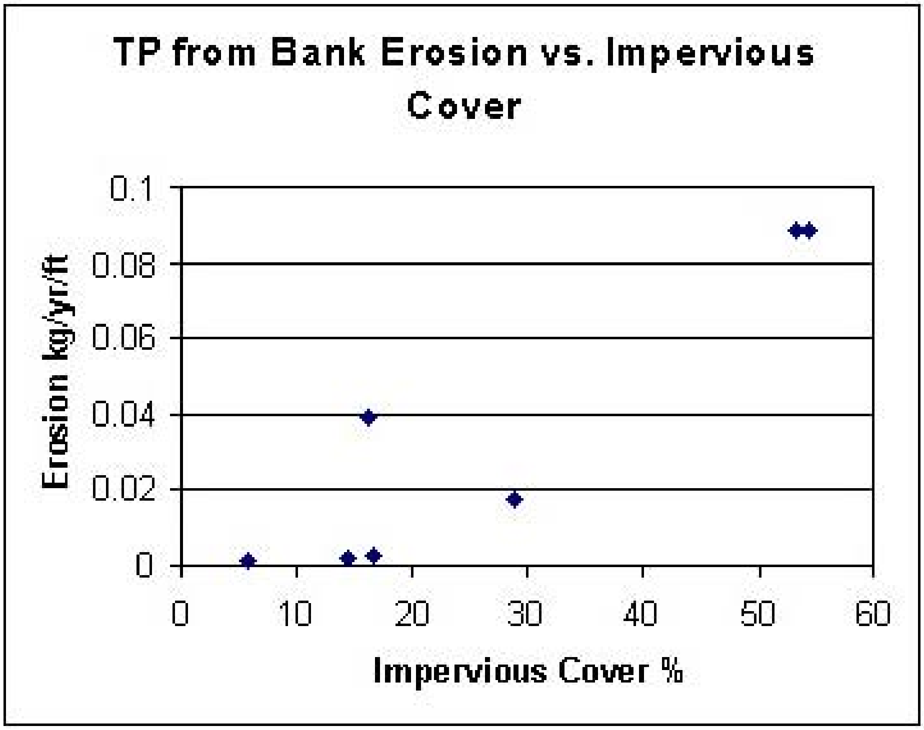


Figure 34: Total Phosphorus from Bank Erosion as a Function of IC in Texas Streams (Dartiguenave *et al.*, 1997)

Streambank erosion also appears to be a major source of nitrogen and phosphorus in urban streams. Both nitrogen and phosphorus are often attached to eroded bank sediment, as indicated in a recent study by Dartiguenave *et al.* (1997) in Austin, Texas. They showed that channel erosion contributed nearly 50% of the Total P load shown for subwatersheds with IC levels between 10 and 60 % (Figure 34). These findings suggest that prevention or reduction of downstream channel erosion may be an important nutrient reduction strategy for urban watersheds.

Snowmelt runoff generally has higher nutrient EMCs, compared to stormwater runoff. Oberts (1994) found that TKN and nitrate EMCs were much higher in snowmelt at all sites. The same pattern has also been observed for phosphorus EMCs during snowmelt and stormwater runoff. Zapf-Gilje *et al*. (1986) found that the first 20% of snowmelt events contained 65% of the phosphorus and 90% of the nitrogen load. Ayers *et al.* (1985) reported that a higher percentage of the annual nitrate, TKN and phosphorus load was derived from snowmelt runoff compared to stormwater runoff in an urban Minnesota watershed, which presumably reflects the accumulation of nutrients in the snowpack during the winter.

4.6 Trace Metals

Many trace metals can be found at potentially harmful concentrations in urban stormwater. Certain metals, such as zinc, copper, lead, cadmium and chromium, are consistently present at concentrations that may be of concern. These metals primarily result from the use of motor vehicles, weathering of metals and paints, burning of fossil fuels and atmospheric deposition.

Metals are routinely reported as the total recoverable form or the dissolved form. The dissolved form refers to the amount of metal dissolved in the water, which excludes metals attached to suspended particles that cannot pass through a 0.45 micron filter. Total recoverable refers to the concentration of an unfiltered sample that is treated with hot dilute mineral acid. In general, the toxicity of metals is related more to the dissolved form than the recoverable form.

4.6.1 Concentrations

Stormwater EMCs for zinc, copper, lead, cadmium and chromium vary regionally and are reviewed in Table 30. Regional differences in trace metal concentrations and water quality standard exceedence appears to be related to climate. In general, drier regions often have a

Table 30: EMCs and Detection Frequency for Metals in Urban Stormwater

Metal	Detection Frequency(1)	EMCs (Fg/l)		Number of Events	Source
		Mean	Median		
Zinc	94%	162	129	2234	Smullen and Cave, 1998
		176	140	1281	USEPA, 1983
Copper	91%	13.5	11.1	1657	Smullen and Cave, 1998
		66.6	54.8	849	USEPA, 1983
Lead	94%	67.5	50.7	2713	Smullen and Cave, 1998
		175(2)	131 (2)	1579	USEPA, 1983
Cadmium	48%	0.7	N/R	150	USEPA, 1983
		0.5	N/R	100	USEPA, 1993
		N/R	0.75 **R** 0.96 **C** 2.1 **I**	30	Baird *et al.*, 1996
		3 **I** 1**U**	N/R	9	Doerfer and Urbonas, 1993
Chromium	58%	4	N/R	32	Baird *et al.*, 1996
		N/R	2.1 **R** 10 **C** 7 **I**	30	Baird *et al.*, 1996
		N/R	7	164	Bannerman *et al.*, 1993

N/R = Not Reported; R- Residential, C- Commercial, I- Industrial; (1) as reprinted in USEPA, 1983; (2) Lead levels have declined over time with the introduction of unleaded gasoline

Table 31: Average Total Recoverable and Dissolved Metals for 13 Stormwater Flows and Nine Baseflow Samples from Lincoln Creek in 1994 (Crunkilton *et al.*, 1996)

	Total Recoverable		Dissolved	
Metal (Fg/l)	Storm Flow	Baseflow	Storm Flow	Baseflow
Lead	35	3	1.7	1.2
Zinc	133	22	13	8
Copper	23	7	5	4
Cadmium	0.6	0.1	0.1	0.1

higher risk of exceeding trace metal concentration standards.

Crunkilton *et al.* (1996) measured recoverable and dissolved metals concentrations in Lincoln Creek, Wisconsin and found higher EMCs during storm events compared to baseflow periods (Table 31). They also found that total recoverable metal concentrations were almost always higher than the dissolved concentration (which is the more available form).

4.6.2 Impacts of Trace Metals on Streams

Although a great deal is known about the concentration of metals in urban stormwater, much less is known about their possible toxicity on aquatic biota. The primary concern related to the presence of trace metals in streams is their potential toxicity to aquatic organisms. High concentrations can lead to bioaccumulation of metals in plants and animals, possible chronic or acute toxicity, and contamination of sediments, which can affect bottom dwelling organisms (Masterson and Bannerman, 1994). Generally, trace metal concentrations found in urban stormwater are not high enough to cause acute toxicity (Field and Pitt, 1990). The cumulative accumulation of trace metal concentrations in bottom sediments and animal tissues are of greater concern. Some evidence exists for trace metal accumulation in bottom sediments of receiving waters and for bioaccumulation in aquatic species (Bay and Brown, 2000 and Livingston, 1996).

Relatively few studies have examined the chronic toxicity issue. Crunkilton *et al.* (1996) found that concentrations of lead, zinc and copper exceeded EPA's Chronic Toxicity Criteria more than 75% of the time in stormflow in stormwater samples for Lincoln Creek in Wisconsin. When exposed to storm and base flows in Lincoln Creek, *Ceriodaphnia dubia*, a common invertebrate test species, demonstrated significant mortality in extended flow-through tests. Around 30% mortality was recorded after seven days of exposure and 70% mortality was recorded after 14 days.

Crunkilton *et al.* (1996) also found that significant mortality in bullhead minnows occurred in only 14% of the tests by the end of 14 days, but mortality increased to 100% during exposures of 17 to 61 days (see Table 32). In a related study in the same watershed, Masterson and Bannerman (1994) determined that crayfish in Lincoln Creek had elevated levels of lead, cadmium, chromium and copper when compared to crayfish from a reference stream. The Lincoln Creek research provides limited evidence that prolonged exposure to trace metals in urban streams may result in significant toxicity.

Most toxicity research conducted on urban stormwater has tested for acute toxicity over a short period of time (two to seven days). Shorter term whole effluent toxicity protocols are generally limited to seven days (Crunkilton *et al.*, 1996). Research by Ellis (1986) reported delayed toxicity in urban streams. Field and Pitt (1990) demonstrated that pollutants deposited to the stream during storm events may take upwards of 10 to 14 days to exert influence. The research suggests that longer term in-situ and flow-through monitoring are needed to definitively answer the question whether metal levels in stormwater can be chronically toxic.

An additional concern is that trace metals co-occur with other pollutants found in urban stormwater, and it is not clear whether they interact to increase or decrease potential toxicity. Hall and Anderson (1988) investigated the toxicity and chemical composition of urban stormwater runoff in British Columbia and found that the interaction of pollutants changed the toxicity of some metals. In laboratory analysis with *Daphnia pulex*, an aquatic invertebrate, they found that the toxicity of iron was low and that its presence reduced the toxicity of other metals. On the other hand, the presence of lead increased the toxicity of copper and zinc.

Interaction with sediment also influences the impact of metals. Often, over half of the trace metals are attached to sediment (MWCOG, 1983). This effectively removes the metals from the water column and reduces the availability for biological uptake and subsequent bioaccumulation (Gavin and Moore, 1982 and OWML, 1983). However, metals accumulated in bottom sediment can then be resuspended during storms (Heaney and Huber, 1978). It is important to note that the toxic effect of metals can be altered when found in conjunction with other substances. For instance, the presence of chlorides can increase the toxicity of some metals. Both metals and chlorides are common pollutants in snowpacks (see section 4.2 for more snow melt information).

4.6.3 Sources and Source Areas of Trace Metals

Research conducted in the Santa Clara Valley of California suggests that cars can be the dominant loading source for many metals of concern, such as cadmium, chromium, copper, lead, mercury and zinc (EOA, Inc., 2001). Other sources are also important and include atmospheric deposition, rooftops and runoff from industrial and residential sites.

The sources and source areas for zinc, copper, lead, chromium and cadmium are listed in Table 33. Source areas for trace metals in the urban environment include streets, parking lots, snowpacks and rooftops. Copper is often found in higher concentrations on urban streets, because some vehicles have brake pads that contain copper. For example, the Santa Clara study estimated that 50% of the total copper load was due to brake pad wear (Woodward-Clyde, 1992). Sources of lead include atmospheric deposition and diesel fuel emissions, which frequently occur along rooftops

Table 32: Percentage of In-situ Flow-through Toxicity Tests Using Daphnia *magna* and Pimephales *promelas* with Significant Toxic Effects from Lincoln Creek (Crunkilton *et al.*, 1996)

Species	Effect	Percent of Tests with Significant ($p<0.05$) Toxic Effects as Compared to Controls According to Exposure				
		48 hours	96 hours	7 days	14 days	17-61 days
D. *magna*	Mortality	0	N/R	36%	93%	N/R
	Reduced Reproduction	0	N/R	36%	93%	N/R
P. *promelas*	Mortality	N/R	0	0	14%	100%
	Reduced Biomass	N/R	N/R	60%	75%	N/R

N/R = Not Reported

and streets. Zinc in urban environments is a result of the wear of automobile tires (estimated 60% in the Santa Clara study), paints, and weathering of galvanized gutters and downspouts. Source area concentrations of trace metals are presented in Table 34. In general, trace metal concentrations vary considerably, but the relative rank among source areas remains relatively constant. For example, a source loading model developed for an urban watershed in Michigan estimated that parking lots, driveways and residential streets were the primary source areas for zinc, copper and cadmium loads (Steuer *et al.*, 1997).

Table 33: Metal Sources and Source Area "Hotspots" in Urban Areas

Metal	Sources	Source Area Hotspots
Zinc	tires, fuel combustion, galvanized pipes, roofs and gutters, road salts **estimate of 60% from tires*	parking lots, commercial and industrial rooftops, and streets
Copper	auto brake linings, pipes and fittings, algacides, and electroplating **estimate of 50% from brake pad wear*	parking lots, commercial roofs and streets
Lead	diesel fuel, paints and stains	parking lots, rooftops, and streets
Cadmium	component of motor oil and corrodes from alloys and plated surfaces	parking lots, rooftops, and streets
Chromium	found in exterior paints and corrodes from alloys and plated surfaces	most frequently found in industrial and commercial runoff

Sources: Bannerman et al., 1993; Barr, 1997; Steuer et al., 1997; Good, 1993; Woodward - Clyde, 1992

Table 34: Metal Source Area Concentrations in the Urban Landscape (Fg/l)

Source Area	Dissolved Zinc	Total Zinc	Dissolved Copper		Total Copper	Dissolved Lead		Total Lead		
Source	(1)	(2)	(1)	(2)	(2)	(1)	(3)	(1)	(3)	(2)
Commercial Parking Lot	64	178	10.7	9	15	N/R	N/R	40	N/R	22
High Traffic Street	73	508	11.2	18	46	2.1	1.7	37	25	50
Medium Traffic Street	44	339	7.3	24	56	1.5	1.9	29	46	55
Low Traffic Street	24	220	7.5	9	24	1.5	.5	21	10	33
Commercial Rooftop	263	330	17.8	6	9	20	N/R	48	N/R	9
Residential Rooftop	188	149	6.6	10	15	4.4	N/R	25	N/R	21
Residential Driveway	27	107	11.8	9	17	2.3	N/R	52	N/R	17
Residential Lawn	N/R	59	N/R	13	13	N/R	N/R	N/R	N/R	N/R
Basin Outlet	23	203	7.0	5	16	2.4	N/R	49	N/R	32

Sources: (1) Steuer et al., 1997; (2) Bannerman et al., 1993; (3) Waschbusch, 2000; N/R = Not Reported

4.7 Hydrocarbons: PAH, Oil and Grease

Hydrocarbons are petroleum-based substances and are found frequently in urban stormwater. The term "hydrocarbons" is used to refer to measurements of oil and grease and polycyclic-aromatic hydrocarbons (PAH). Certain components of hydrocarbons, such as pyrene and benzo[b]fluoranthene, are carcinogens and may be toxic to biota (Menzie-Cura , 1995). Hydrocarbons normally travel attached to sediment or organic carbon. Like many pollutants, hydrocarbons accumulate in bottom sediments of receiving waters, such as urban lakes and estuaries. Relatively few studies have directly researched the impact of hydrocarbons on streams.

4.7.1 Concentrations

Table 35 summarizes reported EMCs of PAH and oil and grease derived from storm event monitoring at three different areas of the U.S. The limited research on oil and grease concentrations in urban runoff indicated that the highest concentrations were consistently found in commercial areas, while the lowest were found in residential areas.

4.7.2 Impacts of Hydrocarbons on Streams

The primary concern of PAH and oil and grease on streams is their potential bioaccumulation and toxicity in aquatic organisms. Bioaccumulation in crayfish, clams and fish has been reported by Masterson and Bannerman (1994); Moring and Rose (1997); and Velinsky and Cummins (1994).

Table 35: Hydrocarbon EMCs in Urban Areas

Hydrocarbon Indicator	EMC Mean	Number of Events	Source	Location
PAH (Fg/l)	3.2*	12	Menzie-Cura, 1995	MA
	7.1	19	Menzie-Cura, 1995	MA
	13.4	N/R	Crunkilton *et al.*, 1996	WI
Oil and Grease (mg/l)	1.7 **R**** 9 **C** 3 **I**	30	Baird *et al.*, 1996	TX
	3	N/R	USEPA, 1983	U.S.
	5.4*	8	Menzie-Cura, 1995	MA
	3.5	10	Menzie-Cura, 1995	MA
	3.89 **R** 13.13 **C** 7.10 **I**	N/R	Silverman *et al.*, 1988	CA
	2.35 **R** 5.63 **C** 4.86 **I**	107	Barr, 1997	MD

*N/R = Not Reported; R = Residential, C = Commercial, I = Industrial; * = geometric mean, ** = median*

Moring and Rose (1997) also showed that not all PAH compounds accumulate equally in urban streams. They detected 24 different PAH compounds in semi-permeable membrane devices (SPMDs), but only three PAH compounds were detected in freshwater clam tissue. In addition, PAH levels in the SPMDs were significantly higher than those reported in the clams.

While acute PAH toxicity has been reported at extremely high concentrations (Ireland *et al.*, 1996), delayed toxicity has also been found (Ellis, 1986). Crayfish from Lincoln Creek had a PAH concentration of 360 Fg/kg, much higher than the concentration thought to be carcinogenic (Masterson and Bannerman, 1994). By comparison, crayfish in a non-urban stream had undetectable PAH levels. Toxic effects from PAH compounds may be limited since many are attached to sediment and may be less available, with further reduction occurring through photodegradation (Ireland *et al.,* 1996).

The metabolic effect of PAH compounds on aquatic life is unclear. Crunkilton *et al.* (1996) found potential metabolic costs to organisms, but Masterson and Bannerman (1994) and MacCoy and Black (1998) did not. The long-term effect of PAH compounds in sediments of receiving waters remains a question for further study.

4.7.3 Sources and Source Areas of Hydrocarbons

In most residential stormwater runoff, hydrocarbon concentrations are generally less than 5mg/l, but the concentrations can increase to five to 10 mg/l within some commercial, industrial and highway areas (See Table 35). Specific "hotspots" for hydrocarbons include gas stations, commuter parking lots, convenience stores, residential parking areas and streets (Schueler and Shepp, 1993). These authors evaluated hydrocarbon concentrations within oil and grease separators in the Washington Metropolitan area and determined that gas stations had significantly higher concentrations of hydrocarbons and trace metals, as compared to other urban source areas. Source area research in an urban catchment in Michigan showed that commercial parking lots contributed 64% of the total hydrocarbon load (Steuer *et al.*, 1997). In addition, highways were found to be a significant contributor of hydrocarbons by Lopes and Dionne (1998).

4.8 Bacteria and Pathogens

Bacteria are single celled organisms that are too small to see with the naked eye. Of particular interest are coliform bacteria, typically found within the digestive system of warm-blooded animals. The coliform family of bacteria includes fecal coliform, fecal streptococci and Escherichia coli, which are consistently found in urban stormwater runoff. Their presence confirms the existence of sewage or animal wastes in the water and indicates that other harmful bacteria, viruses or protozoans may be present, as well. Coliform bacteria are indicators of potential public health risks and not actual causes of disease.

A pathogen is a microbe that is actually known to cause disease under the right conditions. Two of the most common waterborne pathogens in the U.S. are the protozoans *Cryptosporidium parvum* and *Giardia lambia*. *Cryptosporidium* is a waterborne intestinal parasite that infects cattle and domestic animals and can be transmitted to humans, causing life-threatening problems in people with impaired immune systems (Xiao *et al.*, 2001). *Giardia* can cause intestinal problems in humans and animals when ingested (Bagley *et al.,* 1998). To infect new hosts, protozoans create hard casings known as oocysts (*Cryptosporidium*) or cysts (*Giardia*) that are shed in feces and travel through surface waters in search of a new host.

4.8.1 Concentrations

Concentrations of fecal coliform bacteria in urban stormwater typically exceed the 200 MPN/100 ml threshold set for human contact recreation (USGS, 2001b). Bacteria concentrations also tend to be highly variable from storm to storm. For example, a national summary of fecal coliform bacteria in stormwater runoff is shown in Figure 35 and Table 36. The variability in fecal coliform ranges from 10 to 500,000 MPN/100ml with a mean of 15,038 MPN/100ml (Schueler, 1999). Another national database of more than 1,600 stormwater events computed a mean concentration of 20,000

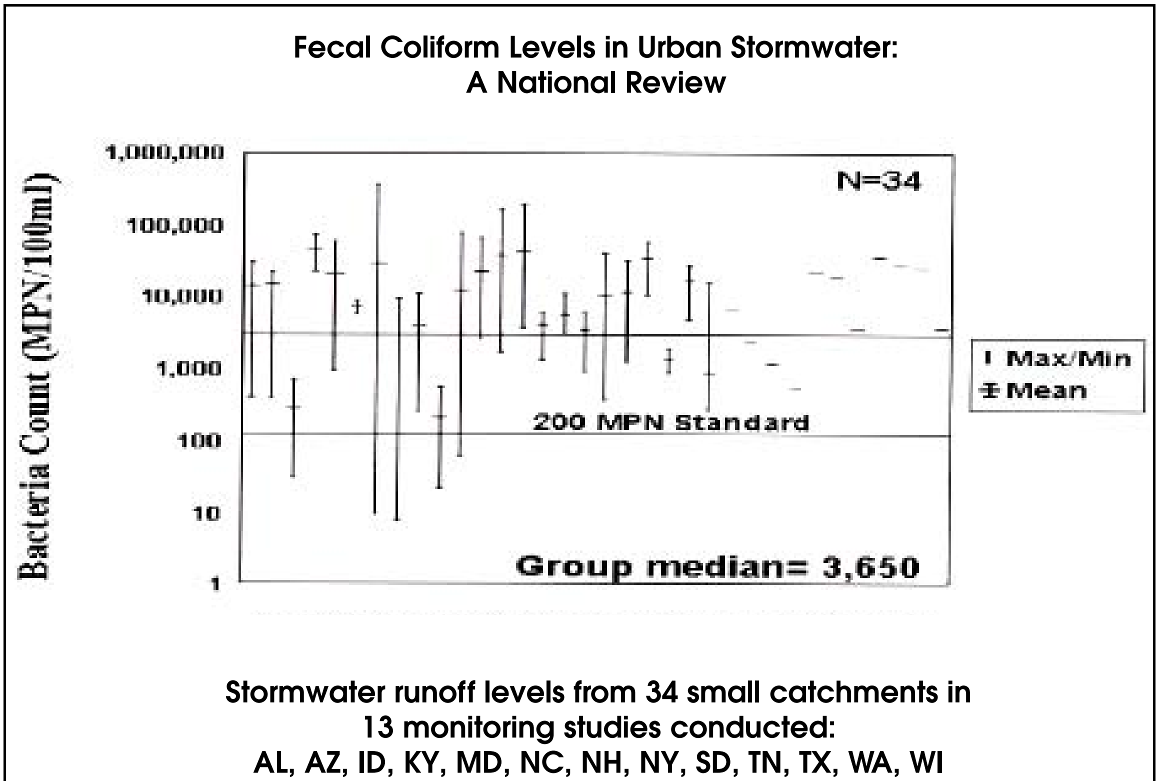


Figure 35: Fecal Coliform Levels in Urban Stormwater (Schueler, 1999)

Table 36: Bacteria EMCs in Urban Areas				
Bacteria Type	EMCs (MPN/100ml) Mean	Number of Events	Source	Location
Fecal Coliform	15,038	34	Schueler, 1999	U.S.
	20,000	1600	Pitt, 1998	U.S.
	7,653	27	Thomas and McClelland, 1995	GA
	20,000 **R*** 6900 **C** 9700 **I**	30*	Baird *et al.*, 1996	TX
	77,970	21 watersheds	Chang *et al.*, 1990	TX
	4,500	189	Varner, 1995	WA
	23,500	3	Young and Thackston, 1999	TN
Fecal Strep	35,351	17	Schueler, 1999	U.S.
	28,864 **R**	27	Thomas and McClelland, 1995	GA
	56,000 **R** * 18,000 **C** 6,100 **I**	30*	Baird *et al.*, 1996	TX

*N/R = Not Reported, R = Residential Area, C = Commercial Area, I = Industrial Area, * = Median*

MPN/100ml for fecal coliform (Pitt, 1998). Fecal streptococci concentrations for 17 urban sites across the country had a mean of 35,351 MPN/100ml (Schueler, 1999).

Young and Thackston (1999) showed that bacteria concentrations at four sites in metro Nashville were directly related to watershed IC. Increasing IC reflects the cumulative increase in potential bacteria sources in the urban landscape, such as failing septic systems, sewage overflows, dogs, and inappropriate discharges. Other studies show that concentrations of bacteria are typically higher in urban areas than rural areas (USGS, 1999a), but they are not always directly related to IC. For example, Hydroqual (1996) found that concentrations of fecal coliform in seven subwatersheds of the Kensico watershed in New York were generally higher for more developed basins, but fecal coliform concentrations did not directly increase with IC in the developed basins (Figure 36).

There is some evidence that higher concentrations of coliform are found in arid or semi-arid watersheds. Monitoring data from semi-arid regions in Austin, San Antonio, and Corpus Christi, Texas averaged 61,000, 37,500 and 40,500 MPN/100ml, respectively (Baird *et al.*,1996 and Chang *et al.* 1990). Schiff (1996), in a report of Southern California NPDES monitoring, found that median concentrations of fecal coliform in San Diego were 50,000 MPN/100ml and averaged 130,000 MPN/100ml in Los Angeles. In all of these arid and semi-arid regions, concentrations were significantly higher than the national average of 15,000 to 20,000 MPN/100ml.

Concentrations of *Cryptosporidium* and *Giardia* in urban stormwater are shown in Table 37. States *et al.* (1997) found high concentrations of *Cryptosporidium* and *Giardia* in storm samples from a combined sewer in Pittsburgh (geometric mean 2,013 oocysts/100ml and 28,881 cysts/100ml). There is evidence that urban stormwater runoff may have higher concentrations of *Cryptosporidium* and *Giardia* than other surface waters, as reported in Table 38 (Stern, 1996). Both pathogens were detected in about 50% of urban stormwater samples, suggesting some concern for drinking water supplies.

4.8.2 Impacts of Bacteria and Pathogens on Streams

Fecal coliform bacteria indicate the potential for harmful bacteria, viruses, or protozoans and are used by health authorities to determine public health risks. These standards were established to protect human health based on exposures to water during recreation and drinking. Bacteria standards for various water uses are presented in Table 39 and are all easily exceeded by typical urban stormwater concentrations. In fact, over 80,000 miles of streams and rivers are currently in non-attain-

Table 37: *Cryptosporidium* and *Giardia* EMCs

Pathogens	Units	EMCs		Number of Events	Source
		Mean	Median		
Cryptosporidium	oocysts	37.2	3.9	78	Stern, 1996
	oocysts/100ml	2013	N/R	N/R	States *et al.*, 1997
Giardia	cysts	41.0	6.4	78	Stern, 1996
	cysts/100ml	28,881	N/R	N/R	States *et al.*, 1997

N/R= Not reported

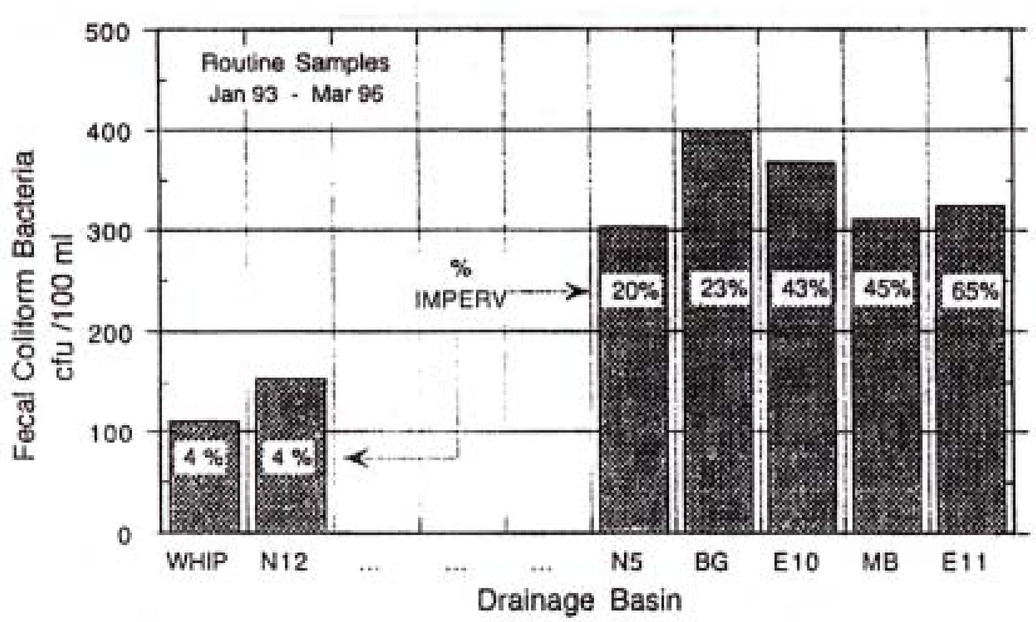


Figure 36: Relationship Between IC and Fecal Coliform Concentrations in New York Streams (Hydroqual, 1996)

Table 38: Percent Detection of *Giardia* cysts and *Cryptosporidium* oocysts in Subwatersheds and Wastewater Treatment Plant Effluent in the New York City Water Supply Watersheds (Stern, 1996)

Source Water Sampled	Number of Sources/ Number of Samples	Percent Detection			
		Total *Giardia*	Confirmed *Giardia*	Total *Cryptosporidium*	Confirmed *Cryptosporidium*
Wastewater Effluent	8/147	41.5%	12.9%	15.7%	5.4%
Urban Subwatershed	5/78	41.0%	6.4%	37.2%	3.9%
Agricultural Subwatershed	5/56	30.4%	3.6%	32.1%	3.6%
Undisturbed Subwatershed	5/73	26.0%	0.0%	9.6%	1.4%

Table 39: Typical Coliform Standards for Different Water Uses (USEPA, 1998)

Water Use	Microbial Indicator	Typical Water Standard
Water Contact Recreation	Fecal Coliform	<200 MPN per 100ml
Drinking Water Supply	Fecal Coliform	<20 MPN per 100ml
Shellfish Harvesting	Fecal Coliform	<14 MPN/ 100ml
Treated Drinking Water	Total Coliform	No more than 1% coliform positive samples per month
Freshwater Swimming	E.Coli	<126 MPN per 100ml

Important Note: Individual state standards may employ different sampling methods, indicators, averaging periods, averaging methods, instantaneous maximums and seasonal limits. MPN = most probable number. Higher or lower limits may be prescribed for different water use classes.

ment status because of high fecal coliform levels (USEPA, 1998).

4.8.3 Sources and Source Areas of Bacteria and Pathogens

Sources of coliform bacteria include waste from humans and wildlife, including livestock and pets. Essentially, any warm-blooded species that is present in significant numbers in a watershed is a potential culprit. Source identification studies, using methods such as DNA fingerprinting, have put the blame on species such as rats in urban areas, ducks and geese in stormwater ponds, livestock from hobby farms, dogs and even raccoons (Blankenship, 1996; Lim and Olivieri, 1982; Pitt, 1998; Samadpour and Checkowitz, 1998).

Transport of bacteria takes place through direct surface runoff, direct inputs to receiving waters, or indirect secondary sources. Source areas in the urban environment for direct runoff include lawns and turf, driveways, parking lots and streets. For example, dogs have high concentrations of fecal coliform in their feces and have a tendency to defecate in close proximity to IC (Schueler, 1999). Weiskel *et al.* (1996) found that direct inputs of fecal coliform from waterfowl can be very important; these inputs accounted for as much as 67% of the annual coliform load to Buttermilk Bay, Massachusetts.

Indirect sources of bacteria include leaking septic systems, illicit discharges, sanitary sewer overflows (SSOs), and combined sewer overflows (CSOs). These sources have the potential to deliver high coliform concentrations to urban streams. In fact, extremely high bacteria concentrations are usually associated with wastewater discharges. CSOs and SSOs occur when the flow into the sewer exceeds the capacity of the sewer lines to drain them. CSOs result from stormwater flow in the lines, and SSOs are a result of infiltration problems or blockages in the lines.

Illicit connections from businesses and homes to the storm drainage system can discharge sewage or washwater into receiving waters. Illicit discharges can often be identified by baseflow sampling of storm sewer systems. Leaking septic systems are estimated to comprise between 10 and 40% of the systems, and individual inspections are the best way to determine failing systems (Schueler, 1999).

There is also evidence that coliform bacteria can survive and reproduce in stream sediments and storm sewers (Schueler, 1999). During a storm event, they often become resuspended and add to the in-stream bacteria load. Source area studies reported that end of pipe concentrations were an order of magnitude higher than any source area on the land surface; therefore, it is likely that the storm sewer system itself acts as a source of fecal coliform (Bannerman *et al.*, 1993 and Steuer *et al.*, 1997). Resuspension of fecal coliform from fine stream sediments during storm events has been reported in New Mexico (NMSWQB, 1999). The sediments in-stream and in the storm sewer system may be significant contributors to the fecal coliform load.

Sources of *Cryptosporidium* and *Giardia* include human sewage and animal feces. *Cryptosporidium* is commonly found in cattle, dogs and geese. Graczyk *et al.* (1998) found that migrating Canada geese were a vector for *Cryptosporidium* and *Giardia*, which has implications for water quality in urban ponds that support large populations of geese.

4.9 Organic Carbon

Total organic carbon (TOC) is often used as an indicator of the amount of organic matter in a water sample. Typically, the more organic matter present in water, the more oxygen consumed, since oxygen is used by bacteria in the decomposition process. Adequate levels of dissolved oxygen in streams and receiving waters are important because they are critical to maintain aquatic life. Organic carbon is routinely found in urban stormwater, and high concentrations can result in an increase in Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD and COD are measures of the oxygen demand caused by the decay of organic matter.

4.9.1 Concentrations

Urban stormwater has a significant ability to exert a high oxygen demand on a stream or receiving water, even two to three weeks after an individual storm event (Field and Pitt, 1990). Average concentrations of TOC, BOD and COD in urban stormwater are presented in Table 40. Mean concentrations of TOC, BOD and COD during storm events in nationwide studies were 17 mg/l, 14.1 mg/l and 52.8 mg/l, respectively (Kitchell, 2001 and Smullen and Cave,1998).

4.9.2 Impacts of Organic Carbon on Streams

TOC is primarily a concern for aquatic life because of its link to oxygen demand in streams, rivers, lakes and estuaries. The initial effect of increased concentrations of TOC, BOD or COD in stormwater runoff may be a depression in oxygen levels, which may persist for many days after a storm, as deposited organic matter gradually decomposes (Field and Pitt, 1990).

TOC is also a concern for drinking water quality. Organic carbon reacts with chlorine during the drinking water disinfection process and forms trihalomethanes and other disinfection by-products, which can be a serious drinking water quality problem (Water, 1999). TOC concentrations greater than 2 mg/l in treated water and 4 mg/l in source water can result in unacceptably high levels of disinfection byproducts and must be treated to reduce TOC or remove the disinfection byproducts (USEPA, 1998). TOC can also be a carrier for other pollutants, such as trace metals, hydrocarbons and nutrients.

4.9.3 Sources and Source Areas of Total Organic Carbon

The primary sources of TOC in urban areas appear to be decaying leaves and other organic matter, sediment and combustion by-products. Source areas include curbs, storm drains, streets and stream channels. Dartiguenave *et al.* (1997) determined that about half of the annual TOC load in urban watersheds of Austin, TX was derived from the eroding streambanks.

Table 40: EMCs for Organic Carbon in Urban Areas

Organic Carbon Source	EMCs (mg/l)		Number of Events	Source
	Mean	Median		
Total Organic Carbon (TOC)	32.0	N/R	423	Barrett and Malina, 1998
	17	15.2	19 studies	Kitchell, 2001
Biological Oxygen Demand (BOD)	14.1	11.5	1035	Smullen and Cave, 1998
	10.4	8.4	474	USEPA, 1983
Chemical Oxygen Demand (COD)	52.8	44.7	2639	Smullen and Cave, 1998
	66.1	55	1538	USEPA, 1983

N/R = Not Reported

4.10 MTBE

Methyl tertiary butyl-ether (MTBE) is a volatile organic compound (VOC) that is added to gasoline to increase oxygen levels, which helps gas burn cleaner (called an oxygenate). MTBE has been used as a performance fuel additive since the 1970s. In 1990, the use of oxygenates was mandated by federal law and concentrations of MTBE in gasoline increased. Today, MTBE is primarily used in large metropolitan areas that experience air pollution problems. Since 1990, MTBE has been detected at increasing levels in both surface water and groundwater and is one of the most frequently detected VOCs in urban watersheds (USGS, 2001a). EPA has declared MTBE to be a potential human carcinogen at high doses. In March 2000, a decision was made by EPA to follow California's lead to significantly reduce or eliminate the use of MTBE in gasoline.

4.10.1 Concentrations

MTBE is highly soluble in water and therefore not easily removed once it enters surface or ground water. Delzer (1999) detected the presence of MTBE in 27% of the shallow wells monitored in eight urban areas across the country (Figure 37). Detection frequency was significantly higher in New England and Denver, as shown in Table 41. In a second study conducted in 16 metropolitan areas, Delzer (1999) found that 83% of MTBE detections occurred between October and March, the time when MTBE is primarily used as a fuel additive. The median MTBE concentration was 1.5 ppb, well below EPA's draft advisory level of 20 ppb (Delzer, 1996).

4.10.2 Impacts of MTBE on Streams

The primary concerns regarding MTBE are that it is a known carcinogen to small mammals, a suspected human carcinogen at higher

Table 41: MTBE Detection Frequency

Location	Detection Frequency	Source	Year
211 shallow wells in eight urban areas	27%	Delzer	1999
Surface water samples in 16 metro areas	7%	Delzer	1996

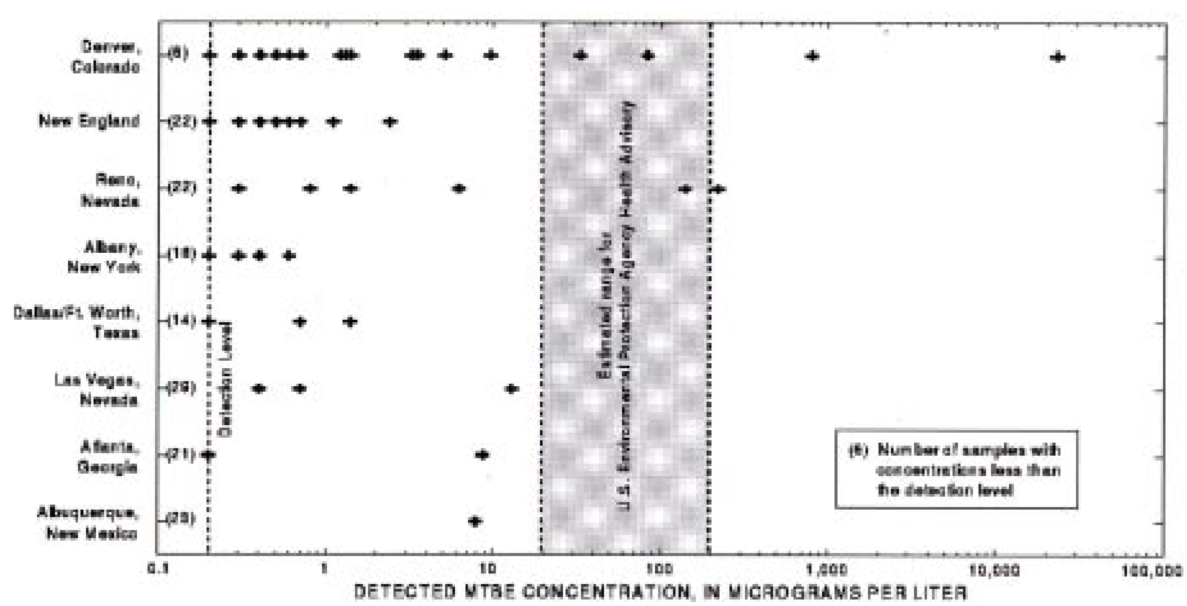


Figure 37: MTBE Concentrations in Surface Water from Eight Cities (Delzer, 1996)

doses and may possibly be toxic to aquatic life in small streams (Delzer, 1996). MTBE can also cause taste and odor problems in drinking water at fairly low concentrations. EPA issued a Drinking Water Advisory in 1997 that indicated that MTBE concentrations less than 20 ppb should not cause taste and odor problems for drinking water. However, the Association of California Water Agencies reports that some consumers can detect MTBE at levels as low as 2.5 ppb (ACWA, 2000). Because MTBE is frequently found in groundwater wells, it is thought to be a potential threat to drinking water (Delzer, 1999). For example, Santa Monica, California reportedly lost half of its groundwater drinking water supply due to MTBE contamination (Bay and Brown, 2000). MTBE has also been detected in human blood, especially in people frequently exposed to gasoline, such as gas station attendants (Squillace *et al.*, 1995).

4.10.3 Sources and Source Areas of MTBE

Since MTBE is a gasoline additive, its potential sources include any area that produces, transports, stores, or dispenses gasoline, particularly areas that are vulnerable to leaks and spills. Leaking underground storage tanks are usually associated with the highest MTBE concentrations in groundwater wells (Delzer, 1999). Vehicle emissions are also an important source of MTBE. Elevated levels are frequently observed along road corridors and drainage ditches. Once emitted, MTBE can travel in stormwater runoff or groundwater. Main source areas include heavily used multi-lane highways. Gas stations may also be a hotspot source area for MTBE contamination.

Another potential source of MTBE is watercraft, since two cycle engines can discharge as much as 20 to 30% of their fuel through the exhaust (Boughton and Lico, 1998). MTBE concentrations are clearly associated with increased use of gas engines, and there is concern that MTBE is an increasing component of atmospheric deposition (Boughton and Lico, 1998 and UC Davis, 1998).

4.11 Pesticides

Pesticides are used in the urban environment to control weeds, insects and other organisms that are considered pests. EPA estimates that nearly 70 million pounds of active pesticide ingredients are applied to urban lawns each year as herbicides or insecticides. Herbicides are used on urban lawns to target annual and perennial broadleaf weeds, while insecticides are used to control insects. Many types of pesticides are available for use in urban areas. Immerman and Drummond (1985) report that 338 different active ingredients are applied to lawns and gardens nationally. Each pesticide varies in mobility, persistence and potential aquatic impact. At high levels, many pesticides have been found to have adverse effects on ecological and human health. Several recent research studies by the USGS have shown that insecticides are detected with the greatest frequency in urban streams, and that pesticide detection frequency increases in proportion to the percentage of urban land in a watershed (Ferrari *et al.*, 1997; USGS, 1998, 1999a-b, 2001b). A national assessment by the USGS

Table 42: Median Concentrations and Detection Frequency of Herbicides and Insecticides in Urban Streams

Pollutant	Detection Frequency	Median Concentration (Fg/l)	Number of Samples	Source
Insecticides				
Diazinon	75%	0.025	326	USGS, 1998b
	92%	0.55	76	Brush *et al.*, 1995
	17%	0.002	1795	Ferrari *et al.*, 1997
Chlorpyrifos	41%	Non Detect	327	USGS, 1998b
	14%	0.004	1218	Brush *et al.*, 1995
Carbaryl	46%	Non Detect	327	USGS, 1998b
	22%	0.003	1128	Ferrari *et al.*, 1997
Herbicides				
Atrazine	86%	0.023	327	USGS, 1998b
	72%	0.099	2076	Ferrari *et al.*, 1997
Prometon	84%	0.031	327	USGS, 1998b
	56%	0.029	1531	Ferrari *et al.*, 1997
Simazine	88%	0.039	327	USGS, 1998b
	17%	0.046	1995	Ferrari *et al.*, 1997
2,4 -D	67%	1.1	11	Dindorf, 1992
	17%	0.035	786	Ferrari *et al.*, 1997
Dicamba	22%	1.8	4	Dindorf, 1992
MCPP	56%	1.8	10	Dindorf, 1992
MCPA	28%	1.0	5	Dindorf, 1992

(2001a) also indicates that insecticides are usually detected at higher concentrations in urban streams than in agricultural streams.

4.11.1 Concentrations

Median concentrations and detection frequency for common pesticides are shown in Table 42. Herbicides that are frequently detected in urban streams include atrazine; simazine; prometon; 2,4-D; dicamba; MCPP; and MCPA. Insecticides are also frequently encountered in urban streams, including diazinon, chlorpyrifos, malathion, and carbaryl. A USGS (1996) study monitored 16 sites in Gills Creek in Columbia, South Carolina over four days. This study reported that pesticide detection frequency increased as percent urban land increased.

Wotzka *et al.* (1994) monitored herbicide levels in an urban stream in Minneapolis, Minnesota during more than 40 storms. They found herbicides, such as 2,4-D; dicamba; MCPP; and MCPA in 85% of storm runoff events sampled. Total herbicide EMCs ranged from less than one to 70 µg/l. Ferrari *et al.* (1997) analyzed 463 streams in the mid-Atlantic region for the presence of 127 pesticide compounds. At least one pesticide was detected at more than 90% of the streams sampled.

Diazinon is one of the most commonly detected insecticides in urban stormwater runoff and dry weather flow. Diazinon was detected in 75% of National Water Quality Assessment (NAWQA) samples, 92% of stormflow samples from Texas, and 100% of urban stormflow samples in King County, Washington (Brush *et al.*, 1995 and USGS, 1999b). Diazinon is most frequently measured at concentrations greater than freshwater aquatic life criteria in urban stormwater (USGS, 1999a). USGS reports that diazinon concentrations were generally higher during urban stormflow (Ferrari *et al.,* 1997).

4.11.2 Impacts of Pesticides on Streams

Many pesticides are known or suspected carcinogens and can be toxic to humans and aquatic species. However, many of the known health effects require exposure to higher concentrations than typically found in the environment, while the health effects of chronic exposure to low levels are generally unknown (Ferrari *et al.*, 1997).

Studies that document the toxicity of insecticides and herbicides in urban stormwater have been focused largely on diazinon. Diazinon is responsible for the majority of acute toxicity in stormwater in Alameda County, California and King County, Washington (S.R. Hansen & Associates, 1995). Concentrations of diazinon in King County stormwater frequently exceed the freshwater aquatic life criteria (Figure 38). Similarly, research on Sacramento, California streams revealed acute toxicity for diazinon in 100% of stormwater samples using *Ceriodaphnia* as the test organism (Connor, 1995). Diazinon has a half-life of 42 days and is very soluble in water, which may explain its detection frequency and persistence in urban stormwater. Diazinon is also reported to attach fairly readily to organic carbon; consequently, it is likely re-suspended during storm events.

Insecticide concentrations exceeding acute and chronic toxicity thresholds for test organisms such as *Ceriodaphnia* have frequently been found in urban stormwater in New York, Texas, California, and Washington (Scanlin and Feng, 1997; Brush *et al.*, 1995; USGS, 1999b). The possibility exists that pesticides could have impacts on larger bodies of water, but there is a paucity of data on the subject at this time.

4.11.3 Sources and Source Areas of Pesticides

Sources for pesticides in urban areas include applications by homeowners, landscaping contractors and road maintenance crews. Source areas for pesticides in urban areas include lawns in residential areas; managed turf, such as golf courses, parks, and ball fields; and rights-of-way in nonresidential areas. Storage areas, which are subject to spills and leaks, can also be a source area. A study in San Francisco was able to trace high diazinon concentrations in some streams back to just a few households which had applied the pesticide at high levels (Scanlin and Feng, 1997). Two herbicides, simazine and atrazine, were detected in over 60% of samples in King County, WA stormwater but were not identified as being sold in retail stores. It is likely these herbicides are applied to nonresidential areas such as rights-of-way, parks and recreational areas (USGS, 1999b). Because pesticides are typically applied to turf, IC is not a direct indicator for pesticide concentrations, although they can drift onto paved surfaces and end up in stormwater runoff.

Active ingredient and trade name[1] example in parentheses	Freshwater aquatic-life criteria, in parts per billion (-- no aquatic-life criteria exist)		
Herbicide	**Acute**	**Chronic**	**RMC**
2,4-D (Weedone)	[4]10	[4]1	[5,2]4
Acetochlor (Guardian)	--	--	--
Atrazine (AAtrex)	[4]70	[4]7	[5]2
Dicamba (Banvel)	[4]390	[4]39	[5]10
Dichlobenil (Casoron)	--	--	[2]37
Dichlorprop (2,4-DP)	--	--	--
EPTC (Eptam)	--	--	--
MCPA (Kilsem)	--	--	[5]2.6
MCPP (Mecoprop)	--	--	--
Metolachlor (Dual)	--	--	[5]8
Napropamide (Devrinol)	--	--	--
Oxadiazon (Ronstar)	--	--	--
Prometon (Pramitol)	--	--	--
Simazine (Princep)	[4]100	[4]10	[2,5]10
Tebuthiuron (Spike)	--	--	--
Triclopyr (Garlon)	[4]5,600	[4]560	--
Trifluralin (Treflan)	--	--	[5]0.1
Insecticide			
Carbaryl (Sevin)	[4]0.17	[4]0.017	[2]0.02
Chlorpyrifos (Dursban)	[3,7]0.083	[3,7]0.041	[2]0.001
Diazinon (Diazinon)	[6]0.16	[6]0.04	[2]0.009
gamma-HCH (Lindane)	[3]0.95	[7]0.08	[2]0.02
Malathion (Malathion)	--	[3]0.1	[2]0.008
Fungicide			
Pentachlorophenol (Penta)	[3,8]19	[3,8]15	[5]0.5

1 Use of trade names is for descriptive purposes and does not imply endorsement by the U.S. Geological Survey, the Department of Ecology, or King County
2 National Academy of Sciences and National Academy of Engineering, 1973
3 U.S. Environmental Protection Agency, 1998
4 Norris and Dost, 1991, Table 3
5 Ministers of Health Canada and Environment Canada, 1995
6 Menconi and Cox, 1994
7 State of Washington, 1992
8 Criteria are pH dependent; values shown calculated at pH of 7.8

Figure 38: Concentrations of Pesticides in Stormwater in King County, WA (S.R. Hansen & Associates, 1995 and USGS, 1999b)

4.12 Deicers

Deicers are substances used to melt snow and ice to keep roads and walking areas safe. The most commonly used deicer is sodium chloride, although it may also be blended with calcium chloride or magnesium chloride. Other less frequently used deicers include urea and glycol, which are primarily used at airports to deice planes. Table 43 summarizes the composition, use and water quality effects of common deicers.

Chlorides are frequently found in snowmelt and stormwater runoff in most regions that experience snow and ice in the winter months (Oberts, 1994 and Sherman, 1998). Figure 39 shows that the application of deicer salts has increased since 1940 from 200,000 tons to 10 to 20 million tons per year in recent years (Salt Institute, 2001). Several U.S. and Canadian studies indicate severe inputs of road salts on water quality and aquatic life (Environment Canada, 2001 and Novotny *et al.*, 1999).

Table 43: Use and Water Quality Effect of Snowmelt Deicers (Ohrel, 1995; Sills and Blakeslee, 1992)

Deicer	Description	Use	Water Quality Effect
Chlorides	Chloride based deicer usually combined with Na, Ca or Mg	Road Deicer and Residential Use	Cl complexes can release heavy metals, affect soil permeability, impacts to drinking water, potential toxic effects to small streams
Urea	Nitrogen-based fertilizer product	Used as alternative to glycol	Increased nitrogen in water and potential toxicity to organisms
Ethylene Glycol	Petroleum based organic compounds, similar to antifreeze	Used at airports for deicing planes	Toxicity effects, high BOD and COD, hazardous air pollutant

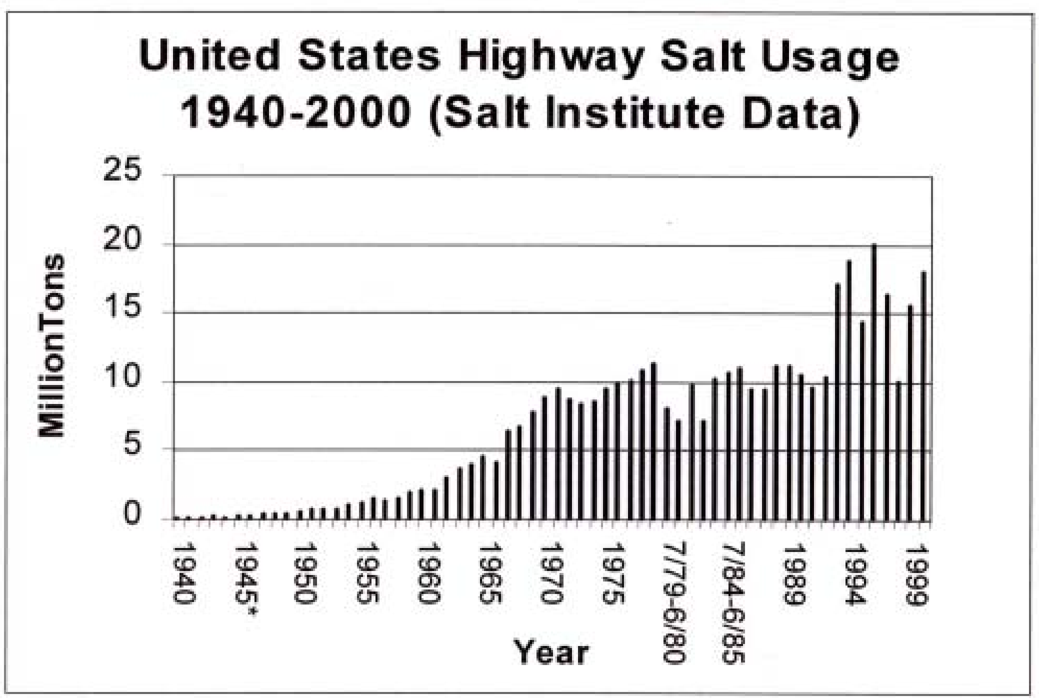


Figure 39: U.S. Highway Salt Usage Data (Salt Institute, 2001)

4.12.1 Concentrations

Chloride concentrations in snowmelt runoff depend on the amount applied and the dilution in the receiving waters. Data for snowmelt and stormwater runoff from several studies are presented in Table 44. For example, chloride concentrations in Lincoln Creek in Wisconsin were 1,612 mg/l in winter snowmelt runoff, as compared to 40 mg/l in non-winter runoff (Novotny *et al.*, 1999 and Masterson and Bannerman, 1994). Chloride concentrations in the range of 2,000 to 5,000 mg/l have been reported for Canadian streams (Environment Canada, 2001). Novotny *et al.* (1999) monitored chloride concentrations in snowmelt near Syracuse, New York and found that residential watersheds had higher chloride concentrations than rural watersheds.

Concentrations of glycol in stormwater runoff are also highly variable and depend on the amount of deicer used, the presence of a recovery system, and the nature of the precipitation event. Corsi *et al*. (2001) monitored streams receiving stormwater runoff from a Wisconsin airport. They found concentrations of propylene glycol as high as 39,000 mg/l at airport outfall sites during deicing operations and concentrations of up to 960 mg/l during low-flow sampling at an airport outfall site.

4.12.2 Impacts of Deicers on Streams

Chloride levels can harm aquatic and terrestrial life and contaminate groundwater and drinking water supplies (Ohrel, 1995). Generally, chloride becomes toxic to many organisms when it reaches concentrations of 500 to1,000 mg/l (Environment Canada, 2001). These concentrations are common in small streams in snow regions, at least for short periods of time. Many plant species are relatively intolerant to high salt levels in wetland swales and roadside corridors. Fish are also negatively affected by high chloride concentrations, with sensitivity as low as 600 mg/l for some species (Scott and Wylie, 1980).

Table 45 compares the maximum chloride concentrations for various water uses in eight states (USEPA, 1988). Snowmelt chloride concentrations typically exceed these levels.

Table 44: EMCs for Chloride in Snowmelt and Stormwater Runoff in Urban Areas

Form of Runoff	EMCs (mg/l)	Number of Events	Sources	Location
	Mean			
Snowmelt	116*	49	Oberts, 1994	MN
	2119	N/R	Sherman, 1998	Ontario
	1267 **R** 474 **U**	N/R	Novotny *et al.*, 1999	NY
	1612	N/R	Masterson and Bannerman, 1994	WI
	397	282	Environment Canada, 2001	Ontario, Canada
Non-winter Storm Event	42	61	Brush *et al.*, 1995	TX
	45	N/R	Sherman, 1998	Ontario
	40.5	N/R	Masterson and Bannerman, 1994	WI

*N/R = Not Reported, R = residential, U = urban, * = Median*

Chloride is a concern in surface drinking water systems because it can interfere with some of the treatment processes and can cause taste problems at concentrations as low as 250 mg/l. Chloride is also extremely difficult to remove once it enters the water.

Glycol-based deicers have been shown to be highly toxic at relatively low concentrations in streams receiving airport runoff. These deicers contain many proprietary agents, which may increase their toxicity and also make it very difficult to set standards for their use (Hartwell *et al.*, 1995). Corsi *et al.* (2001) observed acute toxicity of *Ceriodaphnia dubia*, *Pimephelas promelax*, *Hyalela azteca*, and *Chironimus tentans* in Wisconsin streams that experienced propylene glycol concentrations of 5,000 mg/l or more. Chronic toxicity was observed for *Ceriodaphnia dubia* and *Pimephelas promelax* at propylene glycol concentrations of 1,500 mg/l in the same study. In addition, glycol exerts an extremely high BOD on receiving waters, which can quickly reduce or eliminate dissolved oxygen. Glycol can also be toxic to small animals that are attracted by its sweet taste (Novotny *et al.*, 1999).

As with many urban pollutants, the effects of chloride can be diluted in larger waterbodies. In general, small streams are more likely to experience chloride effects, compared to rivers, which have a greater dilution ability.

4.12.3 Sources and Source Areas of Deicers

The main sources for deicers in urban watersheds include highway maintenance crews, airport deicing operations, and homeowner applications. Direct road application is the largest source of chloride, by far. Source areas include roads, parking lots, sidewalks, storm drains, airport runways, and snow collection areas. Because deicers are applied to paved surfaces, the primary means of transport to streams is through stormwater and meltwater runoff. Therefore, concentrations of deicer compounds are typically associated with factors such as road density or traffic patterns.

Table 45: Summary of State Standards for Salinity of Receiving Waters (USEPA, 1988)

State	Limiting Concentration (mg/l)	Beneficial Use
CO	250*	Drinking water
IL	500	General water supply
	250	Drinking water
IN	500	Drinking water
MA	250	Class A waters
MN	250	Drinking water
	500	Class A fishing and recreation
OH	250	Drinking water
SD	250	Drinking water
	100	Fish propagation
VA	250	Drinking water

** Monthly average*

4.13 Conclusion

IC collects and accumulates pollutants deposited from the atmosphere, leaked from vehicles, or derived from other sources. The pollutants build up over time but are washed off quickly during storms and are often efficiently delivered to downstream waters. This can create water quality problems for downstream rivers, lakes and estuaries.

As a result of local and national monitoring efforts, we now have a much better understanding of the nature and impacts of stormwater pollution. The typical sample of urban stormwater is characterized by high levels of many common pollutants such as sediment, nutrients, metals, organic carbon, hydrocarbons, pesticides, and fecal coliform bacteria. Other pollutants that have more recently become a concern in urban areas include MTBE, deicers, and the pathogens *Cryptosporidium* and *Giardia*. Concentrations of most stormwater pollutants can be characterized, over the long run, by event mean storm concentrations. Monitoring techniques have also allowed researchers to identify source areas for pollutants in the urban environment, including stormwater hotspots, which generate higher pollutant loads than normal development.

In general, most monitoring data shows that mean pollutant storm concentrations are higher in urban watersheds than in non-urban ones. For many urban pollutants, EMCs can be used to predict stormwater pollutant loads for urban watersheds, using IC as the key predictive variable. While a direct relationship between IC and pollutant concentrations does not usually exist, IC directly influences the volume of stormwater and hence, the total load. A few exceptions are worth noting. MTBE, deicers, and PAH appear to be related more to traffic or road density than IC. Additionally, MTBE and PAH concentrations may be greater at hotspot source areas, which are not always widely or uniformly distributed across a watershed. Pesticides, bacteria and pathogens are often associated with turf areas rather than IC. Bacteria and pathogen sources also include direct inputs from wildlife and inappropriate sewage discharges that are not uniformly distributed across a watershed and are not directly related to IC.

Further research into the relationship between stormwater pollutant loads and other watershed indicators may be helpful. For example, it would be interesting to see if turf cover is a good indicator of stream quality for impacted streams. Other important watershed indicators worth studying are the influence of watershed treatment practices, such as stormwater practices and stream buffers.

The direct effects of stormwater pollutants on aquatic systems appears to be a function of the size of the receiving water and the initial health of the aquatic community. For example, a small urban stream receiving high stormwater pollutant concentrations would be more likely to experience impacts than a large river, which is diluted by other land uses. Likewise, organisms in sensitive streams should be more susceptible to stormwater pollutants than pollution-tolerant organisms found in non-supporting streams.

Overall, the following conclusions can be made:

- Sediment, nutrient and trace metal loads in stormwater runoff can be predicted as a function of IC, although concentrations are not tightly correlated with watershed IC.
- Violations of bacteria standards are indirectly associated with watershed IC.
- It is not clear whether loads of hydrocarbons, pesticides or chlorides can be predicted on the basis of IC at the small watershed level.
- More research needs to be conducted to evaluate the usefulness of other watershed indicators to predict stormwater pollutant loads. For example, traffic, road density or hotspots may be useful in predicting MTBE, deicer and hydrocarbon loads. Also, watershed turf cover may be useful in predicting pesticide and bacterial loads.

- Most research on pollutants in stormwater runoff has been conducted at the small watershed level. Additional research is needed to evaluate the impact of watershed treatment, such as stormwater and buffer practices to determine the degree to which these may change stormwater concentrations or loads.
- Regional differences are evident for many stormwater pollutants, and these appear to be caused by either differences in rainfall frequency or snowmelt.

Chapter 5: Biological Impacts of Impervious Cover

This chapter reviews research on the impact of urbanization on the aquatic community, focusing on aquatic insects, fish, amphibians, freshwater mussels, and freshwater wetlands. Specifically, the relationship between the health of the aquatic community and the amount of watershed IC is analyzed within the context of the Impervious Cover Model (ICM).

The chapter is organized as follows:

5.1 Introduction
5.2 Indicators and General Trends
5.3 Effects on Aquatic Insect[1] Diversity
5.4 Effects on Fish Diversity
5.5 Effects on Amphibian Diversity
5.6 Effects on Wetland Diversity
5.7 Effects on Freshwater Mussel Diversity
5.8 Conclusion

5.1 Introduction

A number of studies, crossing different ecoregions and utilizing various techniques, have examined the link between watershed urbanization and its impact on stream and wetland biodiversity. These studies reveal that a relatively small amount of urbanization has a negative effect on aquatic diversity, and that as watersheds become highly urban, aquatic diversity becomes extremely degraded. As documented in prior chapters, hydrologic, physical, and water quality changes caused by watershed urbanization all stress the aquatic community and collectively diminish the quality and quantity of available habitat. As a result, these stressors generally cause a decline in biological diversity, a change in trophic structure, and a shift towards more pollution-tolerant organisms.

Many different habitat conditions are critical for supporting diverse aquatic ecosystems. For example, streambed substrates are vulnerable to deposition of fine sediments, which affects spawning, egg incubation and fry-rearing. Many aquatic insect species shelter in the large pore spaces among cobbles and boulders, particularly within riffles. When fine sediment fills these pore spaces, it reduces the quality and quantity of available habitat. The aquatic insect community is typically the base of the food chain in streams, helps break down organic matter and serves as a food source for juvenile fish.

Large woody debris (LWD) plays a critical role in the habitat of many aquatic insects and fish. For example, Bisson *et al.* (1988) contend that no other structural component is more important to salmon habitat than LWD, especially in the case of juvenile coho salmon. Loss of LWD due to the removal of stream side vegetation can significantly hinder the survival of more sensitive aquatic species. Since LWD creates different habitat types, its quality and quantity have been linked to salmonid rearing habitat and the ability of multiple fish species to coexist in streams.

The number of stream crossings (e.g., roads, sewers and pipelines) has been reported to increase directly in proportion to IC (May *et al.*, 1997). Such crossings can become partial or total barriers to upstream fish migration, particularly if the stream bed downcuts below the fixed elevation of a culvert or pipeline. Fish barriers can prevent migration and recolonization of aquatic life in many urban streams.

Urbanization can also increase pollutant levels and stream temperatures. In particular, trace metals and pesticides often bind to sediment particles and may enter the food chain, particularly by aquatic insects that collect and filter particles. While in-stream data is rare, some data are available for ponds. A study of trace

[1]*Throughout this chapter, the term “aquatic insects” is used rather than the more cumbersome but technically correct “benthic macroinvertebrates.”*

metal bioaccumulation of three fish species found in central Florida stormwater ponds discovered that trace metal levels were significantly higher in urban ponds than in non-urban control ponds, often by a factor of five to 10 (Campbell, 1995; see also Karouna-Renier, 1995). Although typical stormwater pollutants are rarely acutely toxic to fish, the cumulative effects of sublethal pollutant exposure may influence the stream community (Chapter 4).

Table 46 summarizes some of the numerous changes to streams caused by urbanization that have the potential to alter aquatic biodiversity. For a comprehensive review of the impacts of urbanization on stream habitat and biodiversity, the reader should consult Wood and Armitage (1997) and Hart and Finelli (1999).

Table 46: Review of Stressors to Urban Streams and Effects on Aquatic Life

Stream Change	Effects on Organisms
Increased flow volumes/ Channel forming storms	Alterations in habitat complexity Changes in availability of food organisms, related to timing of emergence and recovery after disturbance Reduced prey diversity Scour-related mortality Long-term depletion of LWD Accelerated streambank erosion
Decreased base flows	Crowding and increased competition for foraging sites Increased vulnerability to predation Increased fine sediment deposition
Increase in sediment transport	Reduced survival of eggs and alevins, loss of habitat due to deposition Siltation of pool areas, reduced macroinvertebrate reproduction
Loss of pools and riffles	Shift in the balance of species due to habitat change Loss of deep water cover and feeding areas
Changes in substrate composition	Reduced survival of eggs Loss of inter-gravel fry refugial spaces Reduced aquatic insect production
Loss of LWD	Loss of cover from predators and high flows Reduced sediment and organic matter storage Reduced pool formation and organic substrate for aquatic insects
Increase in temperature	Changes in migration patterns Increased metabolic activity, increased disease and parasite susceptibility Increased mortality of sensitive fish
Creation of fish blockages	Loss of spawning habitat for adults Inability to reach overwintering sites Loss of summer rearing habitat, Increased vulnerability to predation
Loss of vegetative rooting systems	Decreased channel stability Loss of undercut banks Reduced streambank integrity
Channel straightening or hardening	Increased stream scour Loss of habitat complexity
Reduction in water quality	Reduced survival of eggs and alevins Acute and chronic toxicity to juveniles and adult fish Increased physiological stress
Increase in turbidity	Reduced survival of eggs Reduced plant productivity Physiological stress on aquatic organisms
Algae blooms	Oxygen depletion due to algal blooms, increased eutrophication rate of standing waters

5.2 Indicators and General Trends

Stream indicators are used to gauge aquatic health in particular watersheds. The two main categories of stream indicators are **biotic** and **development** indices. **Biotic** indices use stream diversity as the benchmark for aquatic health and use measures, such as species abundance, taxa richness, EPT Index, native species, presence of pollution-tolerant species, dominance, functional feeding group comparisons, or proportion with disease or anomalies. **Development** indices evaluate the relationship between the degree of watershed urbanization and scores for the biotic indices. Common development indices include watershed IC, housing density, population density, and percent urban land use.

5.2.1 Biological Indicators

Biotic indices are frequently used to measure the health of the aquatic insect or fish community in urban streams. Because many aquatic insects have limited migration patterns or a sessile mode of life, they are particularly well-suited to assess stream impacts over time. Aquatic insects integrate the effects of short-term environmental variations, as most species have a complex but short life cycle of a year or less. Sensitive life stages respond quickly to environmental stressors, but the overall community responds more slowly. Aquatic insect communities are comprised of a broad range of species, trophic levels and pollution tolerances, thus providing strong information for interpreting cumulative effects. Unlike fish, aquatic insects are abundant in most small, first and second order streams. Individuals are relatively easy to identify to family level, and many "intolerant" taxa can be identified to lower taxonomic levels with ease.

Fish are good stream indicators over longer time periods and broad habitat conditions because they are relatively long-lived and mobile. Fish communities generally include a range of species that represents a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, and piscivores). Fish tend to integrate the effects of lower trophic levels; thus, their community structure reflects the prevailing food sources and habitat conditions. Fish are relatively easy to collect and identify to the species level. Most specimens can be sorted and identified in the field by experienced fisheries scientists and subsequently released unharmed.

A review of the literature indicates that a wide variety of metrics are used to measure the aquatic insect and fish community. Community indices, such as the Index of Biotic Integrity (IBI) for fish and the Benthic Index of Biotic Integrity (B-IBI) for the aquatic insect community are a weighted combination of various metrics that typically characterize the community from "excellent" to "poor." Common metrics of aquatic community are often based on a composite of measures, such as species richness, abundance, tolerance, trophic status, and native status. Combined indices (C-IBI) measure both fish and aquatic insect metrics and a variety of physical habitat conditions to classify streams. Table 47 lists several common metrics used in stream assessments. It should be clearly noted that community and combined indices rely on different measurements and cannot be directly compared. For a comprehensive review of aquatic community indicators, see Barbour *et al.*(1999).

5.2.2 Watershed Development Indices

Watershed IC, housing density, population density, and percent urban land have all been used as indices of the degree of watershed development. In addition, reverse indicators such as percent forest cover and riparian continuity have also been used. The majority of studies so far have used IC to explore the relationship between urbanization and aquatic diversity. Percent urban land has been the second most frequently used indicator to describe the impact of watershed development. Table 48 compares the four watershed development indices and the thresholds where significant impacts to aquatic life are typically observed.

Table 47: Examples of Biodiversity Metrics Used to Assess Aquatic Communities

Measurement	Applied to:	Definition of Measurement
Abundance	Fish, Aquatic Insects	Total number of individuals in a sample; sometimes modified to exclude tolerant species.
Taxa Richness	Fish, Aquatic Insects	Total number of unique taxa identified in a sample. Typically, an increase in taxa diversity indicates better water and habitat quality.
EPT Index	Aquatic Insects	Taxa belonging to the following three groups: *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), *Trichoptera* (caddisflies). Typically, species in these orders are considered to be pollution-intolerant taxa and are generally the first to disappear with stream quality degradation.
Native Status	Fish	Native vs. non-native taxa in the community.
Specific Habitat	Fish	Riffle benthic insectivorous individuals. Total number of benthic insectivores. Often these types of individuals, such as darters, sculpins, and dace are found in high velocity riffles and runs and are sensitive to physical habitat degradation.
		Minnow species Total number of minnow species present. Often used as an indicator of pool habitat quality. Includes all species present in the family Cyprinidae, such as daces, minnows, shiners, stonerollers, and chubs.
Tolerant Species	Fish, Aquatic Insects	The total number of species sensitive to and the number tolerant of degraded conditions. Typically, intolerant species decline with decreasing water quality and stream habitat. A common high pollution-tolerant species that is frequently used is Chironomids.
Dominance	Fish, Aquatic Insects	The proportion of individuals at each station from the single most abundant taxa at that particular station. Typically, a community dominated by a single taxa may be indicative of stream degradation.
Functional Feeding Group Comparisons	Fish	Omnivores/ Generalists: The proportion of individuals characterized as omnivores or generalists to the total number of individuals. Typically, there is a shift away from specialized feeding towards more opportunistic feeders under degraded conditions as food sources become unreliable.
		Insectivores: The proportion of individuals characterized as insectivores to the total number of individuals. Typically, the abundance of insectivores decreases relative to increasing stream degradation.
	Aquatic Insects	Others: The proportion of individuals characterized as shredders, scrapers, or filter feeders to the total number of individuals. Typically, changes in the proportion of functional feeders characterized as shredders can be reflective of contaminated leaf matter. In addition, an overabundance of scrapers over filterers can be indicative of increased benthic algae.
Disease/ Anomalies	Fish	Proportion of individuals with signs of disease or abnormalities. This is ascertained through gross external examination for abnormalities during the field identification process. Typically, this metric assumes that incidence of disease and deformities increases with increasing stream degradation.

** This table is not meant to provide a comprehensive listing of metrics used for diversity indices; it is intended to provide examples of types of measures used in biological stream assessments (see Barbour* et al., *1999).*

5.2.3 General Trends

Most research suggests that a decline in both species abundance and diversity begins at or around 10% watershed IC (Schueler, 1994a). However, considerable variations in aquatic diversity are frequently observed from five to 20% IC, due to historical alterations, the effectiveness of watershed management, prevailing riparian conditions, co-occurrence of stressors, and natural biological variation (see Chapter 1).

Figures 40 through 42 display the negative relationship commonly seen between biotic indices and various measures of watershed development. For example, stream research in the Maryland Piedmont indicated that IC was the best predictor of stream condition, based on a combined fish and aquatic insect IBI (MNCPPC, 2000). In general, streams with less than 6% watershed IC were in "excellent" condition, whereas streams in "good" condition had less than 12% IC, and streams in "fair" condition had less than 20%. Figure 40 shows the general boundaries and typical variation seen in MNCPPC stream research.

Figure 41 illustrates that B-IBI scores and Coho Salmon/Cutthroat Trout Ratio are a function of IC for 31 streams in Puget Sound, Washington. The interesting finding was that "good" to "excellent" B-IBI scores (greater than 25) were reported in watersheds that had less than 10% IC, with eight notable outliers. These outliers had greater IC (25 to 35%) but similar B-IBI scores. These outliers are unique in that they had a large upstream wetland and/ or a large, intact riparian corridor upstream (i.e. >70% of stream corridor had buffer width >100 feet).

Figure 42 depicts the same negative relationship between watershed urbanization and fish-IBI scores but uses population density as the primary metric of development (Dreher, 1997). The six-county study area included the Chicago metro area and outlying rural watersheds. Significant declines in fish-IBI scores were noted when population density exceeded 1.5 persons per acre.

The actual level of watershed development at which an individual aquatic species begins to decline depends on several variables, but may be lower than that indicated by the ICM. Some researchers have detected impacts for individual aquatic species at watershed IC levels as low as 5%. Other research has suggested that the presence of certain stressors, such as sewage treatment plant discharges (Yoder and Miltner, 2000) or construction sites (Reice, 2000) may alter the ICM and lower the level of IC at which biodiversity impacts become evident.

Table 48: Alternate Land Use Indicators and Significant Impact Levels (Brown, 2000; Konrad and Booth, 2002)

Land Use Indicator	Level at which Significant Impact Observed	Typical Value for Low Density Residential Use	Comments
% IC	10-20%	10%	Most accurate; highest level of effort and cost
Housing Density	>1 unit/acre	1 unit/acre	Low accuracy in areas of substantial commercial or industrial development; less accurate at small scales
Population Density	1.5 to 8+ people/acre	2.5 people/acre	Low accuracy in areas of substantial commercial or industrial development; less accurate at small scales
% Urban Land Use	33% (variable)	10-100%	Does not measure intensity of development; moderately accurate at larger watershed scales
Road Density	5 miles/square mile	2 miles/square mile	Appears to be a potentially useful indicator

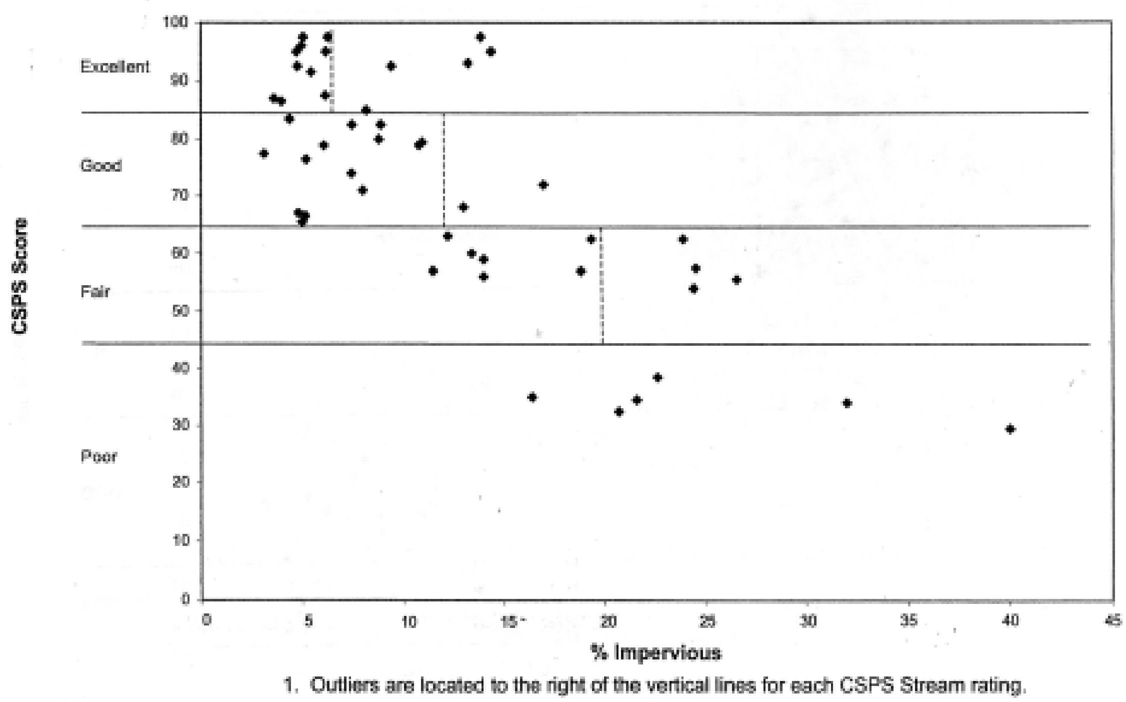


Figure 40: Combined Fish and Benthic IBI vs. IC in Maryland Piedmont Streams (MNCPPC, 2000)

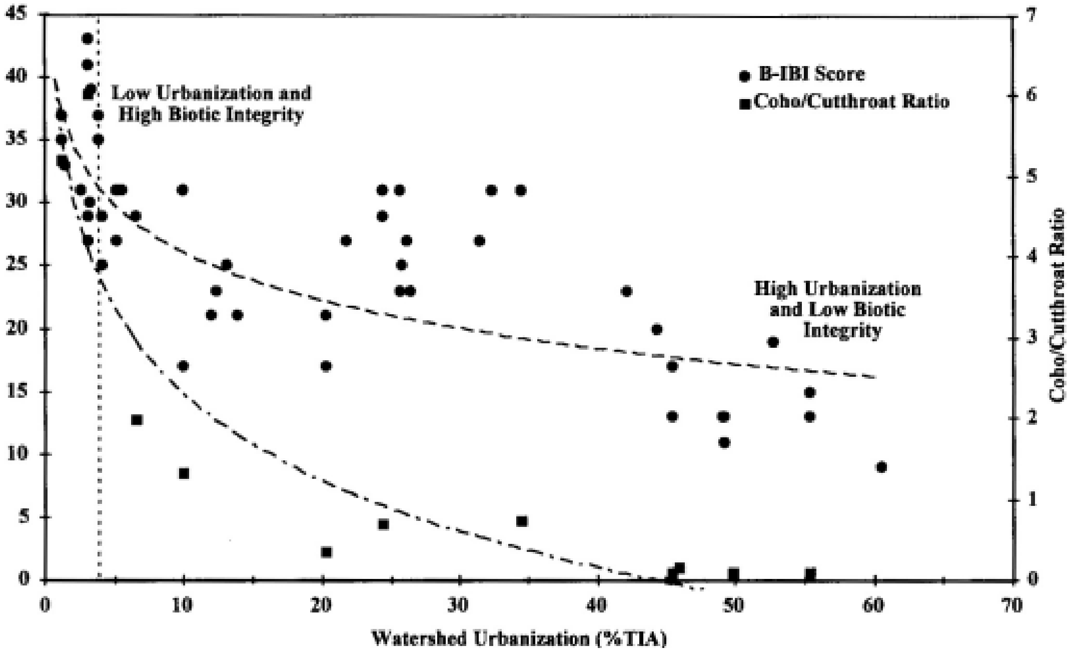


Figure 41: Relationship Between B-IBI, Coho/Cutthroat Ratios, and Watershed IC in Puget Sound Streams (Horner *et al.*, 1997)

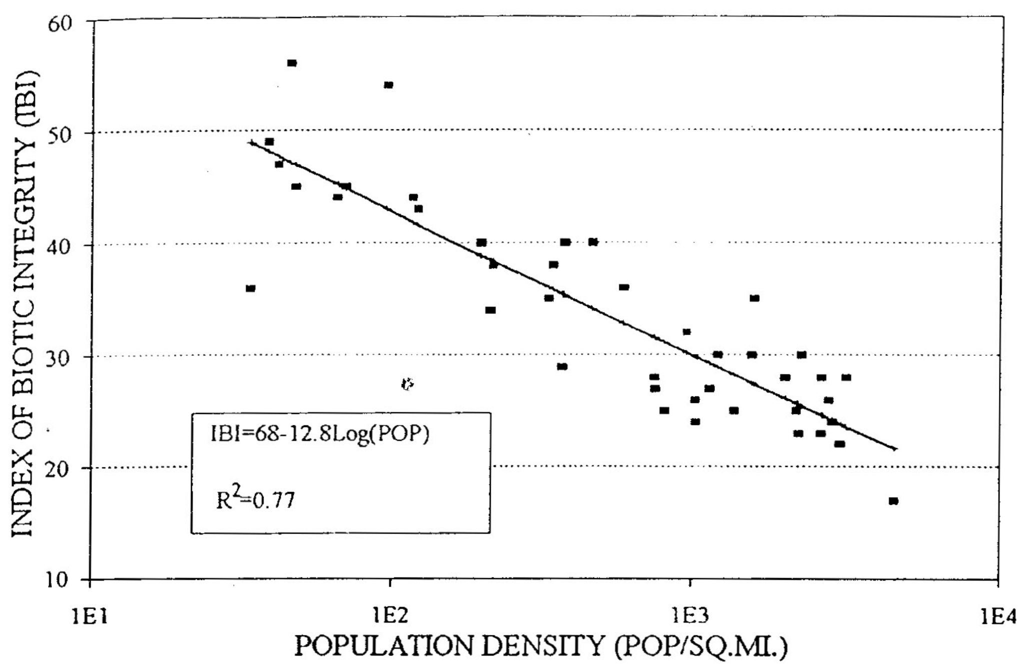


Figure 42: Index for Biological Integrity as a Function of Population Density in Illinois (Dreher, 1997)

5.3 Effects on Aquatic Insect Diversity

The diversity, richness and abundance of the aquatic insect community is frequently used to indicate urban stream quality. Aquatic insects are a useful indicator because they form the base of the stream food chain in most regions of the country. For this reason, declines or changes in aquatic insect diversity are often an early signal of biological impact due to watershed development. The aquatic insect community typically responds to increasing development by losing species diversity and richness and shifting to more pollution-tolerant species. More than 30 studies illustrate how IC and urbanization affect the aquatic insect community. These are summarized in Tables 49 and 50.

5.3.1 Findings Based on IC Indicators

Klein (1979) was one of the first researchers to note that aquatic insect diversity drops sharply in streams where watershed IC exceeded 10 to 15%. While "good" to "fair" diversity was noted in all headwater streams with less than 10% IC, nearly all streams with 12% or more watershed IC recorded "poor" diversity. Other studies have confirmed this general relationship between IC and the decline of aquatic insect species diversity. Their relationships have been an integral part in the development of the ICM. The sharp drop in aquatic insect diversity at or around 12 to 15% IC was also observed in streams in the coastal plain and Piedmont of Delaware (Maxted and Shaver, 1997).

Impacts at development thresholds lower than 10% IC have also been observed by Booth (2000), Davis (2001), Horner *et al.* (1997) and Morse (2001). There seems to be a general recognition that the high levels of variability observed below 10% IC indicate that other factors, such as riparian condition, effluent discharges, and pollution legacy may be better indicators of aquatic insect diversity (Horner and May, 1999; Kennen, 1999; Steedman, 1988; Yoder *et al.*, 1999).

The exact point at which aquatic insect diversity shifts from fair to poor is not known with absolute precision, but it is clear that few, if any, urban streams can support diverse aquatic insect communities with more than 25% IC. Indeed, several researchers failed to find aquatic insect communities with good or excellent diversity in any highly urban stream (Table 52). Indeed, MNCPPC (2000) reported that all streams with more than 20% watershed IC were rated as "poor."

Several good examples of the relationship between IC and B-IBI scores are shown in Figures 43 through 45. Figure 43 depicts the general trend line in aquatic insect diversity as IC increased at 138 stream sites in Northern Virginia (Fairfax County, 2001). The survey study concluded that stream degradation occurred at low levels of IC, and that older developments lacking more efficient site design and stormwater controls tended to have particularly degraded streams. Figures 44 and 45 show similar trends in the relationship between IC and aquatic insect B-IBI scores in Maryland and Washington streams. In particular, note the variability in B-IBI scores observed below 10% IC in both research studies.

Often, shift in the aquatic insect community from pollution-sensitive species to pollution-tolerant species occurs at relatively low IC levels (<10%). This shift is often tracked using the EPT metric, which evaluates sensitive species found in the urban stream community in the orders of *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies), and *Trichoptera* (caddisflies). EPT species frequently disappear in urban streams and are replaced by more pollution-tolerant organisms, such as chironomids, tubificid worms, amphipods and snails.

In undisturbed streams, aquatic insects employ specialized feeding strategies, such as shredding leaf litter, filtering or collecting organic matter that flows by, or preying on other insects. These feeding guilds are greatly reduced in urban streams and are replaced by grazers, collectors and deposit feeders. Maxted and Shaver (1997) found that 90% of sensitive

Table 49: Recent Research Examining the Relationship Between IC and Aquatic Insect Diversity in Streams			
Index	**Key Finding (s)**	**Source**	**Location**
Community Index	Three years stream sampling across the state at 1000 sites found that when IC was >15%, stream health was never rated good based on a C-IBI.	Boward *et al.*, 1999	MD
Community Index	Insect community and habitat scores were all ranked as poor in five subwatersheds that were greater than 30% IC.	Black and Veatch, 1994	MD
Community Index	Puget sound study finds that some degradation of aquatic invertebrate diversity can occur at any level of human disturbance (at least as measured by IC). 65% of watershed forest cover usually indicates a healthy aquatic insect community.	Booth, 2000	WA
Community Index	In a Puget Sound study, the steepest decline of B-IBI was observed after 6% IC. There was a steady decline, with approximately 50% reduction in B-IBI at 45% IC.	Horner *et al.*, 1997	WA
Community Index	B-IBI decreases with increasing urbanization in study involving 209 sites, with a sharp decline at 10% IC. Riparian condition helps mitigate effects.	Steedman, 1988	Ontario
Community Index	Wetlands, forest cover and riparian integrity act to mitigate the impact of IC on aquatic insect communities.	Horner *et al.*, 2001	WA, MD, TX
Community Index	B-IBI declines for aquatic insect with increasing IC at more than 200 streams.	Fairfax Co., 2001	VA
Community Index	Two-year stream study of eight Piedmont watersheds reported B-IBI scores declined sharply at an IC threshold of 15-30%.	Meyer and Couch,2000	GA
Community Index	Montgomery County study; subwatersheds with <12% IC generally had streams in good to excellent condition based on a combined fish and aquatic insect IBI. Watersheds with >20% IC had streams in poor condition.	MNCPPC, 2000	MD
Community Index	Study of 1st, 2nd, and 3rd order streams in the Patapsco River Basin showed negative relationship between B-IBI and IC.	Dail *et al.*, 1998	MD
Community Index	While no specific threshold was observed, impacts were seen at even low levels of IC. B-IBI values declined with increasing IC, with high scores observed only in reaches with <5% IC or intact riparian zones or upstream wetlands.	Horner and May, 1999	WA
Community Index	The C-IBI also decreased by 50% at 10-15% IC. These trends were particularly strong at low-density urban sites (0-30% IC).	Maxted and Shaver, 1997	DE
Diversity	In both coastal plain and Piedmont streams, a sharp decline in aquatic insect diversity was found around 10-15% IC.	Shaver *et al.*, 1995	DE
Diversity	In a comparison of Anacostia subwatersheds, there was significant decline in the diversity of aquatic insects at 10% IC.	MWCOG, 1992	DC
Diversity	In several dozen Piedmont headwater streams, aquatic diversity declined significantly beyond 10-12% IC.	Klein, 1979	MD
EPT Value	In a 10 stream study with watershed IC ranging from three to 30%, a significant decline in EPT values was reported as IC increased (r2 = 0.76).	Davis, 2001	MO
Sensitive Species	In a study of 38 wadeable, non-tidal streams in the urban Piedmont, 90% of sensitive organisms were eliminated from the benthic community after watershed IC reaches 10-15%.	Maxted and Shaver, 1997	DE
Species Abundance EPT values	For streams draining 20 catchments across the state, an abrupt decline in species abundance and EPT taxa was observed at approximately 6% IC.	Morse, 2001	ME

Table 50: Recent Research Examining the Relationship of Other Indices of Watershed Development on Aquatic Insect Diversity in Streams			
Biotic	**Key Finding (s)**	**Source**	**Location**
	Percent Urban Land use		
Community Index	Study of 700 streams in 5 major drainage basins found that the amount of urban land and total flow of municipal effluent were the most significant factors in predicting severe impairment of the aquatic insect community. Amount of forested land in drainage area was inversely related to impairment severity.	Kennen, 1999	NJ
Community Index	All 40 urban sites sampled had fair to very poor B-IBI scores, compared to undeveloped reference sites.	Yoder, 1991	OH
Community Index	A negative correlation between B-IBI and urban land use was noted. Community characteristics show similar patterns between agricultural and forested areas the most severe degradation being in urban and suburban areas.	Meyer and Couch, 2000	GA
EPT Value, Diversity, Community Index	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had substantially lower EPT scores (22% vs 5% as number of all taxa, 65% vs 10% as percent abundance) and IBI scores in the poor range.	Crawford and Lenat, 1989	NC
Sensitive Species	Urbanization associated with decline in sensitive taxa, such as mayflies, caddisflies and amphipods while showing increases in oligochaetes.	Pitt and Bozeman, 1982	CA
Sensitive Species	Dramatic changes in aquatic insect community were observed in most urbanizing stream sections. Changes include an abundance of pollution-tolerant aquatic insect species in urban streams.	Kemp and Spotila, 1997	PA
Diversity	As watershed development levels increased, the aquatic insect diversity declined.	Richards *et al.*, 1993	MN
Diversity	Significant negative relationship between number of aquatic insect species and degree of urbanization in 21 Atlanta streams.	Benke *et al.*, 1981	GA
Diversity	Drop in insect taxa from 13 to 4 was noted in urban streams.	Garie and McIntosh, 1986	NJ
Diversity	Aquatic insect taxa were found to be more abundant in non-urban reaches than in urban reaches of the watershed.	Pitt and Bozeman, 1982	CA
Diversity	A study of five urban streams found that as watershed land use shifted from rural to urban, aquatic insect diversity decreased.	Masterson and Bannerman, 1994	WI
	Other Land Use Indicators		
Community Index	Most degraded streams were found in developed areas, particularly older developments lacking newer and more efficient stormwater controls.	Fairfax Co., 2001	VA
Diversity	Urban streams had sharply lower aquatic insect diversity with human population above four persons/acre in northern VA.	Jones and Clark, 1987	VA
EPT Value	Monitoring of four construction sites in three varying regulatory settings found that EPT richness was related to enforcement of erosion and sediment controls. The pattern demonstrated that EPT richness was negatively affected as one moved from upstream to at the site, except for one site.	Reice, 2000	NC
Sensitive Species	In a Seattle study, aquatic insect community shifted to chironomid, oligochaetes and amphipod species that are pollution-tolerant and have simple feeding guild.	Pedersen and Perkins,1986	WA

species (based on EPT richness, % EPT abundance, and Hilsenhoff Biotic Index) were eliminated from the aquatic insect community when IC exceeded 10 to 15% in contributing watersheds of Delaware streams (Figure 46). In a recent study of 30 Maine watersheds, Morse (2001) found that reference streams with less than 5% watershed IC had significantly more EPT taxa than more urban streams. He also observed no significant differences in EPT Index values among streams with six to 27% watershed IC (Figure 47).

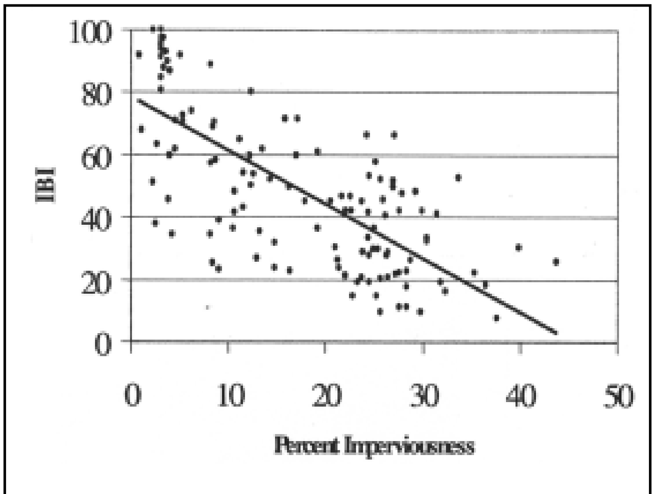


Figure 43: Trend Line Indicating Decline in Benthic IBI as IC Increases in Northern VA Streams (Fairfax County, 2001)

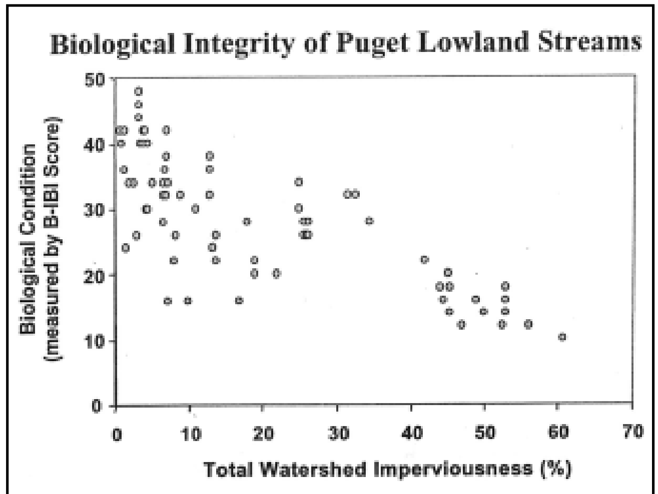


Figure 44: Relationship Between IC and B-IBI Scores in Aquatic Insects in Streams of the Puget Sound Lowlands (Booth, 2000)

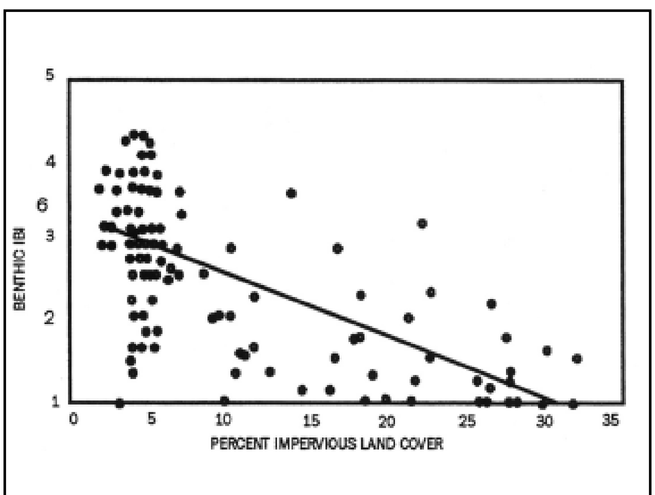


Figure 45: IC and B-IBI at Stream Sites in the Patapsco River Basin, MD (Dail *et al.*, 1998)

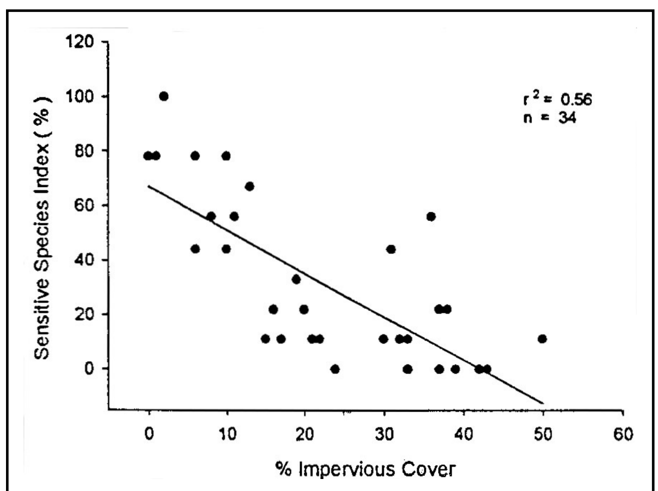


Figure 46: IC vs. Aquatic Insect Sensitivity - EPT Scores in Delaware Streams (Maxted and Shaver, 1997)

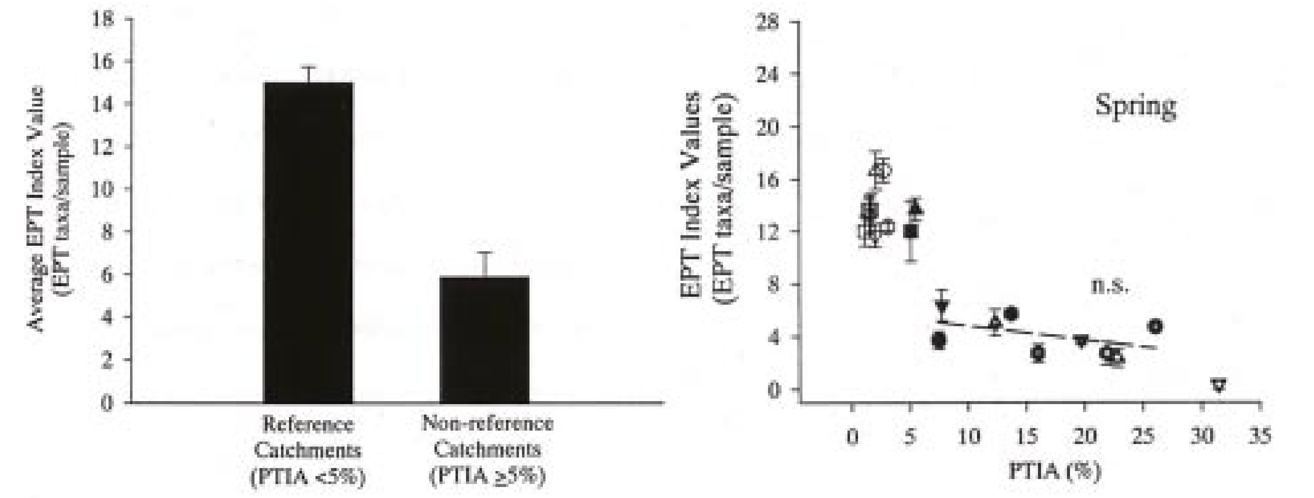


Figure 47: Average and Spring EPT Index Values vs.% IC in 20 Small Watersheds in Maine (Morse, 2001)

5.3.2 Findings Based on Other Development Indicators

Development indices, such as percent urban land use, population density, and forest and riparian cover have also been correlated with changes in aquatic insect communities in urban streams. Declines in benthic IBI scores have frequently been observed in proportion to the percent urban land use in small watersheds (Garie and McIntosh, 1986; Kemp and Spotila, 1997; Kennen, 1999; Masterson and Bannerman, 1994; Richards *et al.*, 1993; USEPA, 1982).

A study in Washington state compared a heavily urbanized stream to a stream with limited watershed development and found that the diversity of the aquatic insect community declined from 13 taxa in reference streams to five taxa in more urbanized streams (Pedersen and Perkins, 1986). The aquatic insect taxa that were lost were poorly suited to handle the variable erosional and depositional conditions found in urban streams. Similarly, a comparison of three North Carolina streams with different watershed land uses concluded the urban watershed had the least taxa and lowest EPT scores and greatest proportion of pollution-tolerant species (Crawford and Lenat, 1989).

Jones and Clark (1987) monitored 22 streams in Northern Virginia and concluded that aquatic insect diversity diminished markedly once watershed population density exceeded four or more people per acre. The population density roughly translates to ½ - 1 acre lot residential use, or about 10 to 20 % IC. Kennen (1999) evaluated 700 New Jersey streams and concluded that the percentage of watershed forest was positively correlated with aquatic insect density. Meyer and Couch (2000) reported a similar cover relationship between aquatic insect diversity and watershed and riparian forest cover for streams in the Atlanta, GA region. A study in the Puget Sound region found that aquatic insect diversity declined in streams once forest cover fell below 65% (Booth, 2000).

5.4 Effects on Fish Diversity

Fish communities are also excellent environmental indicators of stream health. In general, an increase in watershed IC produces the same kind of impact on fish diversity as it does for aquatic insects. The reduction in fish diversity is typified by a reduction in total species, loss of sensitive species, a shift toward more pollution-tolerant species, and decreased survival of eggs and larvae. More than 30 studies have examined the relationship between watershed development and fish diversity; they are summarized in Tables 51 and 52. About half of the research studies used IC as the major index of watershed development, while the remainder used other indices, such as percent urban land use, population density, housing density, and forest cover.

5.4.1 Findings Based on IC Indicators

Recent stream research shows a consistent, negative relationship between watershed development and various measures of fish diversity, such as diversity metrics, species loss and structural changes.

Typically, a notable decline in fish diversity occurs around 10 to 15% watershed IC (Boward *et al.*, 1999; Galli, 1994; Klein, 1979; Limburg and Schmidt, 1990; MNCPPC, 2000; MWCOG, 1992; Steward, 1983). A somewhat higher threshold was observed by Meyer and Couch (2000) for Atlanta streams with 15 to 30% IC; lower thresholds have also been observed (Horner *et al.*, 1997 and May *et al.*, 1997). A typical relationship between watershed IC and fish diversity is portrayed in Figure 48, which shows data from streams in the Patapsco River Basin in Maryland (Dail *et al.*, 1998). Once again, note the variability in fish-IBI scores observed below 10% IC.

Wang *et al.* (1997) evaluated 47 Wisconsin streams and found an apparent threshold around 10% IC. Fish-IBI scores were "good" to "excellent" below this threshold, but were consistently rated as "fair" to "poor." Additionally, Wang documented that the total number of fish species drops sharply when IC increases (Figure 49). Often, researchers also reported that increases in IC were strongly correlated with several fish metrics, such as increases in non-native and pollution-tolerant species in streams in Santa Clara, California (EOA, Inc., 2001).

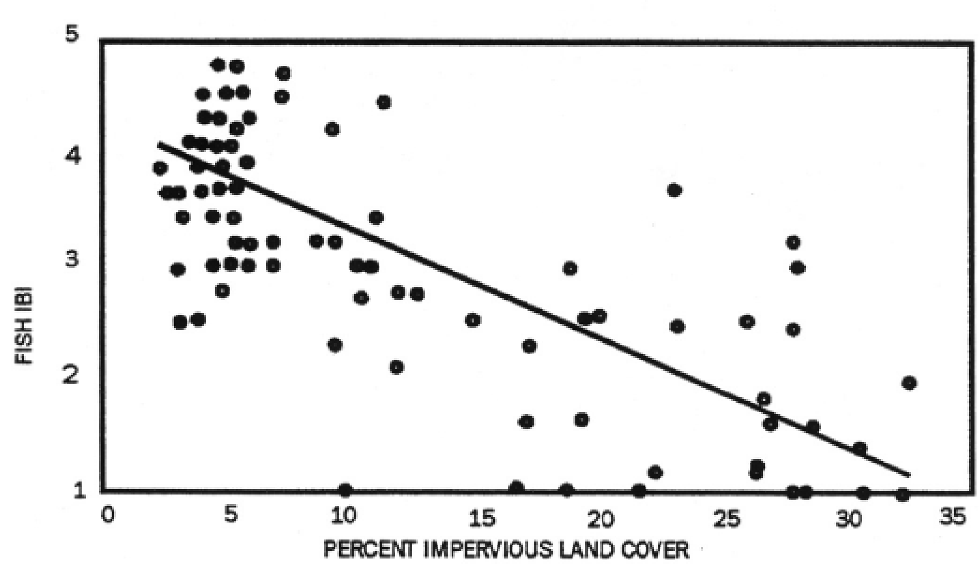


Figure 48: Fish-IBI vs. Watershed IC for Streams in the Patapsco River Basin, MD (Dail *et al.*, 1998)

Table 51: Recent Research Examining the Relationship Between Watershed IC and the Fish Community

Biotic	Key Finding (s)	Source	Location
Abundance	Brown trout abundance and recruitment declined sharply at 10-15% IC.	Galli, 1994	MD
Salmonids	Seattle study showed marked reduction in coho salmon populations noted at 10-15% IC at nine streams.	Steward, 1983	WA
Anadromous Fish Eggs	Resident and anadromous fish eggs and larvae declined in 16 subwatersheds draining to the Hudson River with >10% IC area.	Limburg and Schmidt, 1990	NY
Community Index	1st, 2nd, and 3rd order streams in the Patapsco River Basin showed negative relationship between IBI and IC.	Dail *et al.*, 1998	MD
Community Index	Fish IBI and habitat scores were all ranked as poor in five subwatersheds that were greater than 30% IC.	Black and Veatch, 1994	MD
Community Index	In the Potomac subregion, subwatersheds with < 12% IC generally had streams in good to excellent condition based on a combined fish and aquatic insect IBI. Watersheds with >20% IC had streams in poor condition.	MNCPPC, 2000	MD
Community Index	In a two-year study of Piedmont streams draining eight watersheds representing various land uses in Chattahochee River Basin, fish community quality dropped sharply at an IC threshold of 15-30%.	Meyer and Couch, 2000	GA
Diversity	Of 23 headwater stream stations, all draining <10% IC areas, rated as good to fair; all with >12% were rated as poor. Fish diversity declined sharply with increasing IC between 10-12%.	Schueler and Galli, 1992	MD
Diversity, Sensitive Species	Comparison of 4 similar subwatersheds in Piedmont streams, there was significant decline in the diversity of fish at 10% IC. Sensitive species (trout and sculpin) were lost at 10-12%.	MWCOG, 1992	MD
Diversity, Community Index	In a comparison of watershed land use and fish community data for 47 streams between the 1970s and 1990s, a strong negative correlation was found between number species and IBI scores with effective connected IC. A threshold of 10% IC was observed with community quality highly variable below 10% but consistently low above 10% IC.	Wang *et al.*, 1997	WI
Diversity	In several dozen Piedmont headwater streams fish diversity declined significantly in areas beyond 10-12% IC.	Klein, 1979	MD
Diversity , Abundance, Non-native Species	IC strongly associated with several fisheries species and individual-level metrics, including number of pollution-tolerant species, diseased individuals, native and non-native species and total species present	EOA, Inc., 2001	CA
Juvenile Salmon Ratios	In Puget Sound study, the steepest decline of biological functioning was observed after six percent IC. There was a steady decline, with approximately 50% reduction in initial biotic integrity at 45% IC area.	Horner *et al.*, 1997	WA
Juvenile Salmon Ratio	Physical and biological stream indicators declined most rapidly during the initial phase of the urbanization process as total IC area exceeded the five to 10% range.	May *et al.*, 1997	WA
Salmonoid	Negative effects of urbanization (IC) with the defacto loss of non-structural BMPs (wetland forest cover and riparian integrity) on salmon ratios	Horner *et al.*, 2001	WA, MD, TX
Salmonoid, Sensitive Species	While no specific threshold was observed (impacts seen at even low levels of IC), Coho/cutthroat salmon ratios >2:1 were found when IC was < 5%. Ratios fell below one at IC levels below 20 %.	Horner and May, 1999	WA
Sensitive species, Salmonid	Three years stream sampling across the state (approximately 1000 sites), MBSS found that when IC was >15%, stream health was never rated good based on CBI, and pollution sensitive brook trout were never found in streams with >2% IC.	Boward *et al.*, 1999	MD
Sensitive Species, Salmonids	Seattle study observed shift from less tolerant coho salmon to more tolerant cutthroat trout population between 10 and 15% IC at nine sites.	Luchetti and Feurstenburg 1993	WA

Sensitive fish are defined as species that strongly depend on clean and stable bottom substrates for feeding and/or spawning. Sensitive fish often show a precipitous decline in urban streams. The loss of sensitive fish species and a shift in community structure towards more pollution-tolerant species is confirmed by multiple studies. Figure 50 shows the results of a comparison of four similar subwatersheds in the Maryland Piedmont that were sampled for the number of fish species present (MWCOG, 1992). As the level of watershed IC increased, the number of fish species collected dropped. Two sensitive species, including sculpin, were lost when IC increased from 10 to 12%, and four more species were lost when IC reached 25%. Significantly, only two species remained in the fish community at 55% watershed IC.

Salmonid fish species (trout and salmon) and anadromous fish species appear to be particularly impacted by watershed IC. In a study in the Pacific Northwest, sensitive coho salmon were seldom found in watersheds above 10 or 15% IC (Luchetti and Feurstenburg, 1993 and Steward, 1983). Key stressors in urban streams, such as higher peak flows, lower dry weather flows, and reduction in habitat complexity (e.g. fewer pools, LWD, and hiding places) are believed to change salmon species composition, favoring cutthroat trout populations over the natural coho populations (WDFW, 1997).

A series of studies from the Puget Sound reported changes in the coho/cutthroat ratios of juvenile salmon as watershed IC increased (Figure 51). Horner *et al.* (1999) found Coho/Cutthroat ratios greater than 2:1 in watersheds with less than 5 % IC. Ratios fell below 1:1 when IC exceeded 20%. Similar results were reported by May *et al.* (1997). In the mid-Atlantic region, native trout have stringent temperature and habitat requirements and are seldom present in watersheds where IC exceeds 15% (Schueler, 1994a). Declines in trout spawning success are evident above 10% IC. In a study of over 1,000 Maryland streams, Boward *et al.* (1999) found that sensitive brook trout were never found in streams that had more than 4% IC in their contributing watersheds.

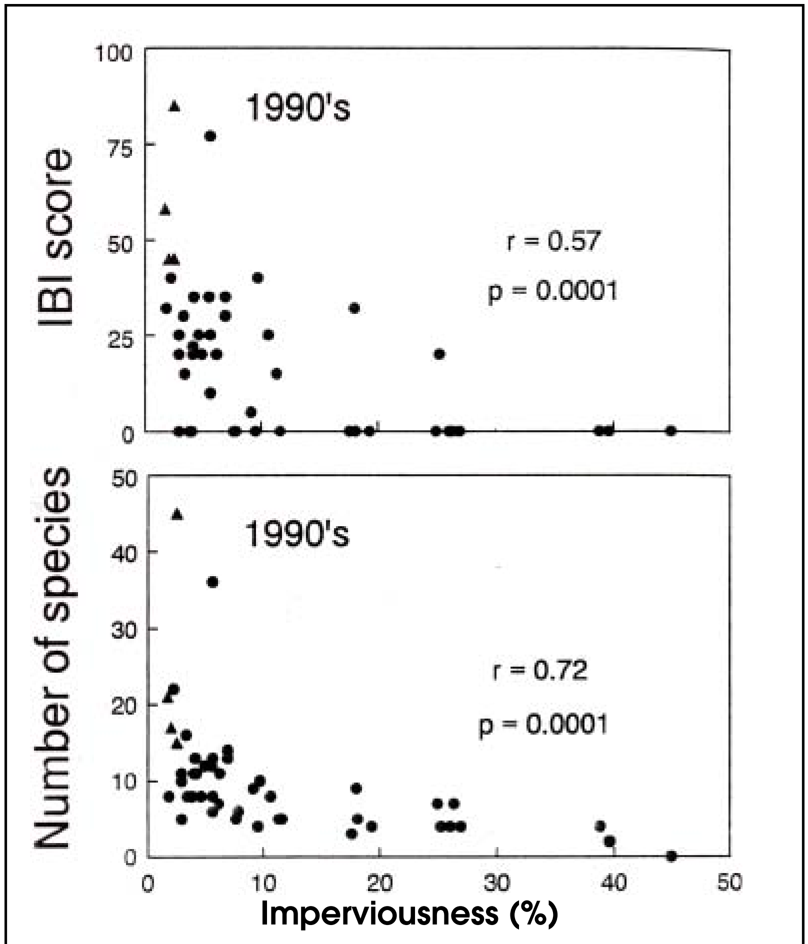


Figure 49: Fish-IBI and Number of Species vs. % IC in Wisconsin Streams (Wang *et al.*, 1997)

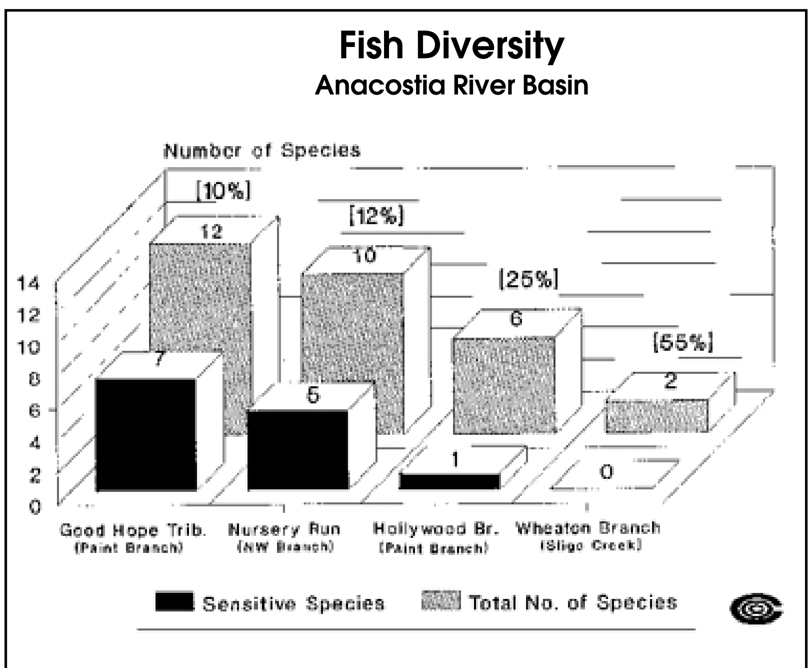


Figure 50: IC and Effects on Fish Species Diversity in Four Maryland Subwatersheds (MWCOG, 1992)

Table 52: Recent Research Examining Urbanization and Freshwater Fish Community Indicators

Biotic	Key Finding (s)	Source	Location
	Urbanization		
Community Index	All 40 urban sites sampled had fair to very poor IBI scores, compared to undeveloped reference sites.	Yoder, 1991	OH
Community Index	Negative correlations between biotic community and riparian conditions and forested areas were found. Similar levels of fish degradation were found between suburban and agricultural; urban areas were the most severe.	Meyer and Couch, 2000	GA
Community Index	Residential urban land use caused significant decrease in fish-IBI scores at 33%. In more urbanized Cuyahoga, a significant drop in IBI scores occurred around 8% urban land use in the watershed. When watersheds smaller than 100mi^2 were analyzed separately, the level of urban land associated with a significant drop in IBI scores occurred at around 15%. Above one du/ac, most sites failed to attain biocriteria regardless of degree of urbanization.	Yoder *et al.*, 1999	OH
Community Index, Abundance	As watershed development increased to about 10%, fish communities simplified to more habitat and trophic generalists and fish abundance and species richness declined. IBI scores for the urbanized stream fell from the good to fair category.	Weaver, 1991	VA
Diversity	A study of five urban streams found that as land use shifted from rural to urban, fish diversity decreased.	Masterson and Bannerman, 1994	WI
Diversity, Community Index	A comparison of three stream types found urban streams had lowest diversity and richness. Urban streams had IBI scores in the poor range.	Crawford and Lenat, 1989	NC
Salmon Spawning, Flooding Frequency	In comparing three streams over a 25-year period (two urbanizing and one remaining forested), increases in flooding frequencies and decreased trends in salmon spawning were observed in the two urbanizing streams, while no changes in flooding or spawning were seen in the forested system.	Moscript and Montgomery, 1997	WA
Sensitive Species	Observed dramatic changes in fish communities in most urbanizing stream sections, such as absence of brown trout and abundance of pollution-tolerant species in urban reaches.	Kemp and Spotila, 1997	PA
Sensitive Species, Diversity	Decline in sensitive species diversity and composition and changes in trophic structure from specialized feeders to generalists was seen in an urbanizing watershed from 1958 to 1990. Low intensity development was found to affect warm water stream fish communities similarly as more intense development.	Weaver and Garman, 1994	VA
Warm Water Habitat Biocriteria	25-30% urban land use defined as the upper threshold where attainment of warm water habitat biocriterion is effectively lost. Non-attainment also may occur at lower thresholds given the co-occurrence of stressors, such as pollution legacy, WTPs and CSOs.	Yoder and Miltner, 2000	OH
Community Index, Habitat	The amount of urban land use upstream of sample sites had a strong negative relationship with biotic integrity, and there appeared to be a threshold between 10 and 20% urban land use where IBI scores declined dramatically. Watersheds above 20% urban land invariably had scores less than 30 (poor to very poor). Habitat scores were not tightly correlated with degraded fish community attributes.	Wang *et al.*, 1997	WI
Community Index	A study in the Patapsco Basin found significant correlation of fish IBI scores with percent urbanized land over all scales (catchment, riparian area, and local area).	Roth *et al.*, 1998	MD

Table 52 (continued): Recent Research Examining Urbanization and Freshwater Fish Community Indicators			
Biotic	**Key Finding (s)**	**Source**	**Location**
	Urbanization		
Sensitive Species	Evaluated effects of runoff in both urban and non-urban streams; found that native species dominated the non-urban portion of the watershed but accounted for only seven percent of species found in the urban portions of the watershed.	Pitt, 1982	CA
	Other Land Use Indicators		
Community Index, Habitat	Atlanta study found that as watershed population density increased, there was a negative impact on urban fish and habitat. Urban stream IBI scores were inversely related to watershed population density, and once density exceeded four persons/acre, urban streams were consistently rated as very poor.	Couch *et al.*, 1997	GA
Community Index	In an Atlanta stream study, modified IBI scores declined once watershed population density exceeds four persons/acre in 21 urban watersheds	DeVivo *et al.*, 1997	GA
Community Index	In a six-county study (including Chicago, its suburbs and outlying rural/agricultural areas), streams showed a strong correlation between population density and fish community assessments such that as population density increased, community assessment scores went from the better - good range to fair - poor. Significant impacts seen at 1.5 people/acre.	Dreher, 1997	IL
Community Index	Similarly, negative correlations between biotic community and riparian conditions and forested areas were also found. Similar levels of fish degradation were found between suburban and agricultural; urban areas were the most severe.	Meyer and Couch, 2000	GA
Community Index	Amount of_forested land in basin directly related to IBI scores for fish community condition.	Roth *et al.*, 1996	MD
Salmonid, Sensitive Species	Species community changes from natural coho salmon to cutthroat trout population with increases in peak flow, lower low flow, and reductions in stream complexity.	WDFW, 1997	WA

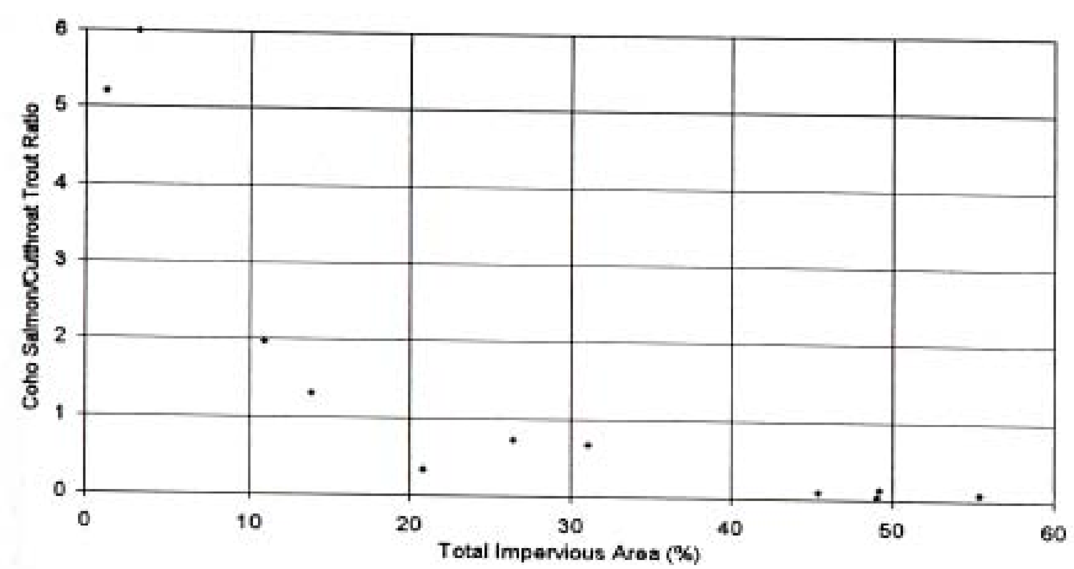


Figure 51: Coho Salmon/Cutthroat Trout Ratio for Puget Sound Streams (Horner *et al.*, 1997)

Many fish species have poor spawning success in urban streams and poor survival of fish eggs and fry. Fish barriers, low intragravel dissolved oxygen, sediment deposition and scour are all factors that can diminish the ability of fish species to successfully reproduce. For example, Limburg and Schmidt (1990) discovered that the density of anadromous fish eggs and larvae declined sharply in subwatersheds with more than 10% IC.

5.4.2 Findings Based on Other Development Indicators

Urban land use has frequently been used as a development indicator to evaluate the impact on fish diversity. Streams in urban watersheds typically had lower fish species diversity and richness than streams located in less developed watersheds. Declines in fish diversity as a function of urban land cover have been documented in numerous studies (Crawford and Lenat, 1989; Masterson and Bannerman, 1994; Roth *et al., 1998;* Yoder, 1991, and Yoder *et al.*, 1999). USEPA (1982) found that native fish species dominated the fish community of non-urban streams, but accounted for only 7% of the fish community found in urban streams. Kemp and Spotila (1997) evaluated streams in Pennsylvania and noted the loss of sensitive species (e.g. brown trout) and the increase of pollution-tolerant species, such as sunfish and creek chub (Figure 52).

Wang *et al.* (1997) cited percentage of urban land in Wisconsin watersheds as a strong negative factor influencing fish-IBI scores in streams and observed strong declines in IBI scores with 10 to 20% urban land use. Weaver and Garman (1994) compared the historical changes in the warm-water fish community of a Virginia stream that had undergone significant urbanization and found that many of the sensitive species present in 1958 were either absent or had dropped sharply in abundance when the watershed was sampled in 1990. Overall abundance had dropped from 2,056 fish collected in 1958 to 417 in 1990. In addition, the 1990 study showed that 67% of the catch was bluegill and common shiner, two species that are habitat and trophic "generalists." This shift in community to more habitat and trophic generalists was observed at 10% urban land use (Weaver, 1991).

Yoder *et al.* (1999) evaluated a series of streams in Ohio and reported a strong decrease in warm-water fish community scores around 33% residential urban land use. In the more urbanized Cuyahoga streams, sharp drops in

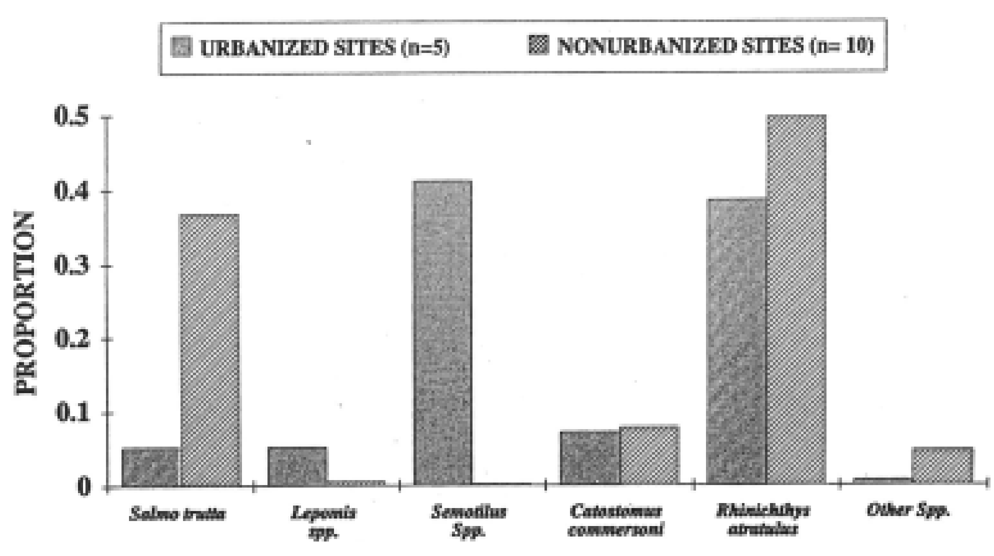


Figure 52: Mean Proportion of Fish Taxa in Urban and Non-Urban Streams, Valley Forge Watershed, PA (Kemp and Spotila, 1997)

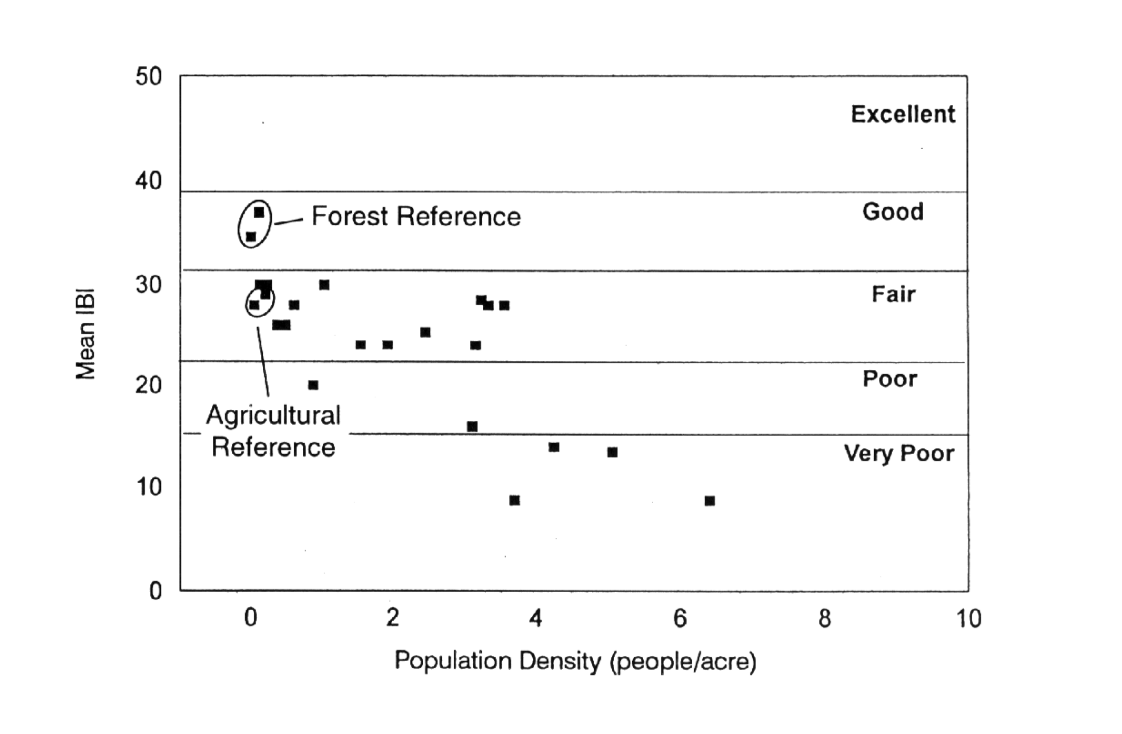


Figure 53: Relationship Between Watershed Population Density and Stream IBI Scores in Georgia Streams (DeVivo *et al.*, 1997)

fish-IBI scores occurred around 8% urban land use, primarily due to certain stressors which functioned to lower the non-attainment threshold. When watersheds smaller than $100mi^2$ were analyzed separately, the percentage of urban land use associated with a sharp drop in fish-IBI scores was around 15%. In a later study, Yoder and Miltner (2000) described an upper threshold for quality warm-water fish habitat at 25 to 30% urban land use.

Watershed population and housing density have also been used as indicators of the health of the fish community. In a study of 21 urban watersheds in Atlanta, DeVivo *et al.* (1997) observed a shift in mean fish-IBI scores from "good to fair" to "very poor" when watershed population density exceeded four people/acre (Figure 53). A study of Midwest streams in metropolitan Illinois also found a negative relationship between increase in population density and fish communities, with significant impacts detected at population densities of 1.5 people or greater per acre (Dreher, 1997). In the Columbus and Cuyahoga watersheds in Ohio, Yoder *et al.* (1999) concluded that most streams failed to attain fish biocriteria above one dwelling unit/acre.

5.5 Effects on Amphibian Diversity

Amphibians spend portions of their life cycle in aquatic systems and are frequently found within riparian, wetland or littoral areas. Relatively little research has been conducted to directly quantify the effects of watershed development on amphibian diversity. Intuitively, it would appear that the same stressors that affect fish and aquatic insects would also affect amphibian species, along with riparian wetland alteration. We located four research studies on the impacts of watershed urbanization on amphibian populations; only one was related to streams (Boward *et al.,* 1999), while others were related to wetlands (Table 53).

A primary factor influencing amphibian diversity appears to be water level fluctuations (WLF) in urban wetlands that occur as a result of increased stormwater discharges. Chin (1996) hypothesized that increased WLF and other hydrologic factors affected the abundance of egg clutches and available amphibian breeding habitat, thereby ultimately influencing amphibian richness. Increased WLF can limit reproductive success by eliminating mating habitat and the emergent vegetation to which amphibians attach their eggs.

Taylor (1993) examined the effect of watershed development on 19 freshwater wetlands in King County, WA and concluded that the additional stormwater contributed to greater annual WLF. When annual WLF exceeded about eight inches, the richness of both the wetland plant and amphibian communities dropped sharply. Large increases in WLF were consistently observed in freshwater wetlands when IC in upstream watersheds exceeded 10 to 15%. Further research on streams and wetlands in the Pacific northwest by Horner *et al.* (1997) demonstrated the correlation between watershed IC and diversity of amphibian species. Figure 54 illustrates the relationship between amphibian species abundance and watershed IC, as documented in the study.

Table 53: Recent Research on the Relationship Between Percent Watershed Urbanization and the Amphibian Community

Indicator	Key Finding(s)	Reference Year	Location
% IC			
Reptile and Amphibian Abundance	In a three-year stream sampling across the state (approximately 1000 sites), MBSS found only hardy pollution-tolerant reptiles and amphibians in stream corridors with >25% IC drainage area.	Boward *et al.*, 1999	MD
Amphibian Density	Mean annual water fluctuation inversely correlated to amphibian density in urban wetlands. Declines noted beyond 10% IC.	Taylor, 1993	WA
Other Studies			
Species Richness	In 30 wetlands, species richness of reptiles and amphibians was significantly related to density of paved roads on lands within a two kilometer radius.	Findlay and Houlahan, 1997	Ontario
Species Richness	Decline in amphibian species richness as wetland WLF increased. While more of a continuous decline rather than a threshold, WLF = 22 centimeters may represent a tolerance boundary for amphibian community.	Horner *et al.*, 1997	WA
Amphibian Density	Mean annual water fluctuation inversely correlated to amphibian density in urban wetlands.	Taylor, 1993	WA

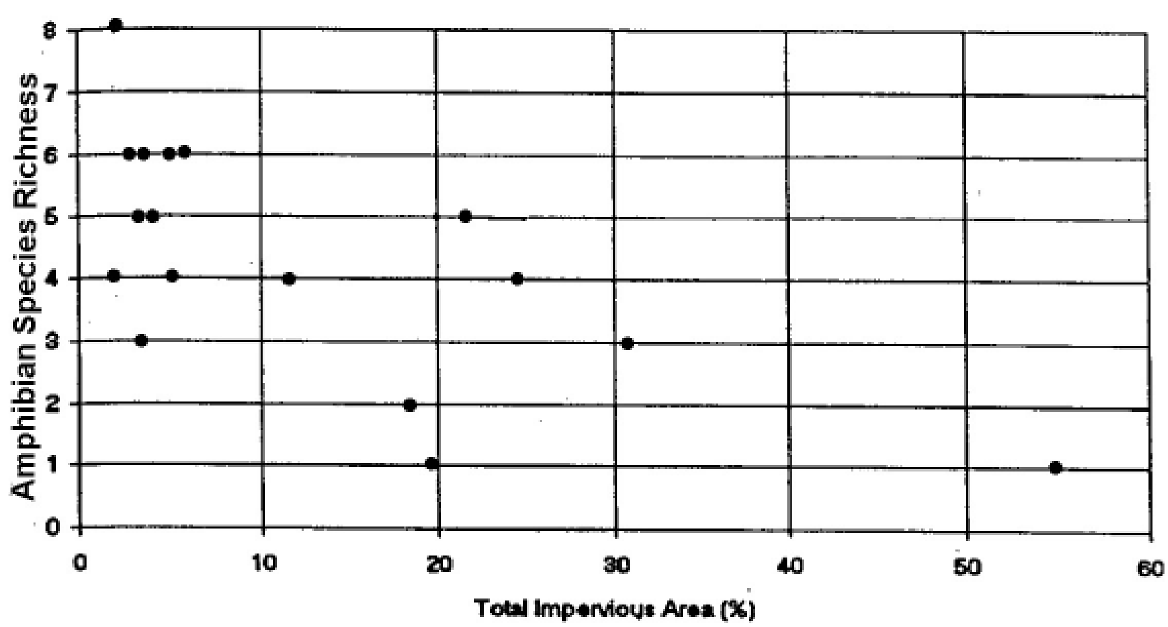


Figure 54: Amphibian Species Richness as a Function of Watershed IC in Puget Sound Lowland Wetlands (Horner *et al.*, 1997)

5.6 Effects on Wetland Diversity

We found a limited number of studies that evaluated the impact of watershed urbanization on wetland plant diversity (Table 54). Two studies used IC as an index of watershed development and observed reduced wetland plant diversity around or below 10% IC (Hicks and Larson, 1997 and Taylor, 1993). WLF and road density were also used as indicators (Findlay and Houlahan, 1997; Horner *et al.*, 1997; Taylor, 1993).

Horner *et al.* (1997) reported a decline in plant species richness in emergent and scrub-shrub wetland zones of the Puget Sound region as WLF increased. They cautioned that species numbers showed a continuous decline rather than a threshold value; however, it was indicated that WLF as small as 10 inches can represent a tolerance boundary for wetland plant communities. Horner further stated that in 90% of the cases where WLF exceeded 10 inches, watershed IC exceeded 21%.

Table 54: Recent Research Examining the Relationship Between Watershed Development and Urban Wetlands			
Watershed Indicator Biotic	Key Finding(s)	Reference	Location
% IC			
Insect Community	Significant declines in various indicators of wetland aquatic macro-invertebrate community health were observed as IC increased to 8-9%.	Hicks and Larson, 1997	CT
WLF, Water Quality	There is a significant increase in WLF, conductivity, fecal coliform bacteria, and total phosphorus in urban wetland as IC exceeds 3.5%.	Taylor *et al.*, 1995	WA
Plant Density	Declines in urban wetland plant density noted in areas beyond 10% IC.	Taylor, 1993	WA
Other Watershed Indicators			
Plant Density	Mean annual water fluctuation inversely correlated to plant density in urban wetlands.	Taylor, 1993	WA
Plant Species Richness	Decline in plant species richness in emergent and scrub-shrub wetland zones as WLF increased. While more of a continuous decline, rather than a threshold, WLF=22 centimeters may represent a tolerance boundary for the community	Horner *et al.*, 1997	WA
Plant Species Richness	In 30 wetlands, species richness was significantly related to density of paved roads within a two kilometer radius of the wetland. Model predicted that a road density of 2kilometers per hectare in paved road within 1000 meters of wetland will lead to a 13% decrease in wetland plant species richness.	Findlay and Houlahan,1997	Ontario

5.7 Effects on Freshwater Mussel Diversity

Freshwater mussels are excellent indicators of stream quality since they are filter-feeders and essentially immobile. The percentage of imperiled mussel species in freshwater ecoregions is high (Williams *et al.*, 1993). Of the 297 native mussel species in the United States, 72% are considered endangered, threatened, or of special concern, including 21 mussel species that are presumed to be extinct. Seventy mussel species (24%) are considered to have stable populations, although many of these have declined in abundance and distribution. Modification of aquatic habitats and sedimentation are the primary reasons cited for the decline of freshwater mussels (Williams *et al.,* 1993).

Freshwater mussels are very susceptible to smothering by sediment deposition. Consequently, increases in watershed development and sediment loading are suspected to be a factor leading to reduced mussel diversity. At sublethal levels, silt interferes with feeding and metabolism of mussels in general (Aldridge *et al.*, 1987). Major sources of mortality and loss of diversity in mussels include impoundment of rivers and streams, and eutrophication (Bauer, 1988). Changes in fish diversity and abundance due to dams and impoundments can also influence the availability of mussel hosts (Williams *et al.*, 1992).

Freshwater mussels are particularly sensitive to heavy metals and pesticides (Keller and Zam, 1991). Although the effects of metals and pesticides vary from one species to another, sub-lethal levels of PCBs, DDT, Malathion, Rotenone and other compounds are generally known to inhibit respiratory efficiency and accumulate in tissues (Watters, 1996). Mussels are more sensitive to pesticides than many other animals tested and often act as “first-alerts” to toxicity long before they are seen in other organisms.

We were unable to find any empirical studies relating impacts of IC on the freshwater mussel communities of streams.

5.8 Conclusion

The scientific record is quite strong with respect to the impact of watershed urbanization on the integrity and diversity of aquatic communities. We reviewed 35 studies that indicated that increased watershed development led to declines in aquatic insect diversity and about 30 studies showing a similar impact on fish diversity. The scientific literature generally shows that aquatic insect and freshwater fish diversity declines at fairly low levels of IC (10 to 15%), urban land use (33%), population density (1.5 to eight people/acre) and housing density (>1 du/ac). Many studies also suggest that sensitive elements of the aquatic community are affected at even lower levels of IC. Other impacts include loss of sensitive species and reduced abundance and spawning success. Research supports the ICM, although additional research is needed to establish the upper threshold at which watershed development aquatic biodiversity can be restored.

One area where more research is needed involves determining how regional and climatic variations affect aquatic diversity in the ICM. Generally, it appears that the 10% IC threshold applies to streams in the East Coast and Midwest, with Pacific Northwest streams showing impacts at a slightly higher level. For streams in the arid and semi-arid Southwest, it is unclear what, if any, IC threshold exists given the naturally stressful conditions for these intermittent and ephemeral streams (Maxted, 1999). Southwestern streams are characterized by seasonal bursts of short but intense rainfall and tend to have aquatic communities that are trophically simple and relatively low in species richness (Poff and Ward, 1989).

Overall, the following conclusions can be drawn:

- IC is the most commonly used index to assess the impacts of watershed urbanization on aquatic insect and fish diversity. Percent urban land use is also a common index.
- The ICM may not be sensitive enough to predict biological diversity in watersheds with low IC. For example, below 10% watershed IC, other watershed variables such as riparian continuity, natural forest cover, cropland, ditching and acid rain may be better for predicting stream health.
- More research needs to be done to determine the maximum level of watershed development at which stream diversity can be restored or maintained. Additionally, the capacity of stormwater treatment practices and stream buffers to mitigate high levels of watershed IC warrants more systematic research.
- More research is needed to test the ICM on amphibian and freshwater mussel diversity.

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Glossary

1st order stream: The smallest perennial stream. A stream that carries water throughout the year and does not have permanently flowing tributaries.

2nd order stream: Stream formed by the confluence of two 1st order streams.

3rd order stream: Stream formed by the confluence of two 2nd order streams.

Acute toxicity: Designates exposure to a dangerous substance or chemical with sufficient dosage to precipitate a severe reaction, such as death.

Alluvial: Pertaining to processes or materials associated with transportation or deposition by running water.

Anadromous: Organisms that spawn in freshwater streams but live most of their lives in the ocean.

Annual Pollutant Load: The total mass of a pollutant delivered to a receiving water body in a year.

Bankfull: The condition where streamflow just fills a stream channel up to the top of the bank and at a point where the water begins to overflow onto a floodplain.

Baseflow: Stream discharge derived from ground water that supports flow in dry weather.

Bedload: Material that moves along the stream bottom surface, as opposed to suspended particles.

Benthic Community: Community of organisms living in or on bottom substrates in aquatic habitats, such as streams.

Biological Indicators: A living organism that denotes the presence of a specific environmental condition.

Biological Oxygen Demand (BOD): An indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by bacterial processes breaking down organic waste.

Carcinogen: A cancer-causing substance or agent.

Catchment: The smallest watershed management unit. Defined as the area of a development site to its first intersection with a stream, usually as a pipe or open channel outfall.

Chemical Oxygen Demand (COD): A chemical measure of the amount of organic substances in water or wastewater. Non-biodegradable and slowly degrading compounds that are not detected by BOD are included.

Chronic Toxicity: Showing effects only over a long period of time.

Combined Sewer Overflow (CSO): Excess flow (combined wastewater and stormwater runoff) discharged to a receiving water body from a combined sewer network when the capacity of the sewer network and/or treatment plant is exceeded, typically during storm events.

Combined Indices (C-IBI or CSPS): Combined indices that use both fish and aquatic insect metrics and a variety of specific habitat scores to classify streams.

Cryptosporidium parvum: A parasite often found in the intestines of livestock which contaminates water when animal feces interacts with a water source.

Deicer: A compound, such as ethylene glycol, used to melt or prevent the formation of ice.

Dissolved Metals: The amount of trace metals dissolved in water.

Dissolved Phosphorus: The amount of phosphorus dissolved in water.

Diversity: A numerical expression of the evenness and distribution of organisms.

Ecoregion: A continuous geographic area over which the climate is uniform to permit the development of similar ecosystems on sites with similar geophysical properties.

Embeddedness: Packing of pebbles or cobbles with fine-grained silts and clays.

EPT Index: A count of the number of families of each of the three generally pollution-sensitive orders: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).

Escherichia coli (E. coli): A bacteria that inhabits the intestinal tract of humans and other warm-blooded animals. Although it poses no threat to human health, its presence in drinking water does indicate the presence of other, more dangerous bacteria.

Eutrophication: The process of over-enrichment of water bodies by nutrients, often typified by the presence of algal blooms.

Fecal coliform: Applied to E. coli and similar bacteria that are found in the intestinal tract of humans and animals. Coliform bacteria are commonly used as indicators of the presence of pathogenic organisms. Their presence in water indicates fecal pollution and potential contamination by pathogens.

Fecal streptococci: Bacteria found in the intestine of warm-blooded animals. Their presence in water is considered to verify fecal pollution.

Fish Blockages: Infrastructures associated with urbanization, such as bridges, dams, and culverts, that affect the ability of fish to move freely upstream and downstream in watersheds. Can prevent re-colonization of resident fish and block the migration of anadromous fish.

Flashiness: Percent of flows exceeding the mean flow for the year. A flashy hydrograph would have larger, shorter-duration hydrograph peaks.

Geomorphic: The general characteristic of a land surface and the changes that take place in the evolution of land forms.

Giardia lamblia: A flagellate protozoan that causes severe gastrointestinal illness when it contaminates drinking water.

Herbicide: Chemicals developed to control or eradicate plants.

Hotspot: Area where land use or activities generate highly contaminated runoff, with concentrations of pollutants in excess of those typically found in stormwater.

Hydrograph: A graph showing variation in stage (depth) or discharge of a stream of water over a period of time.

Illicit discharge: Any discharge to a municipal separate storm sewer system that is not composed entirely of storm water, except for discharges allowed under an NPDES permit.

Impervious Cover: Any surface in the urban landscape that cannot effectively absorb or infiltrate rainfall.

Impervious Cover Model (ICM): A general watershed planning model that uses percent watershed impervious cover to predict various stream quality indicators. It predicts expected stream quality declines when watershed IC exceeds 10% and severe degradation beyond 25% IC.

Incision: Stream down-cuts and the channel expands in the vertical direction.

Index of Biological Integrity (IBI): Tool for assessing the effects of runoff on the quality of the aquatic ecosystem by comparing the condition of multiple groups of organisms or taxa against the levels expected in a healthy stream.

Infiltration: The downward movement of water from the surface to the subsoil. The infiltration capacity is expressed in terms of inches per hour.

Insecticide: Chemicals developed to control or eradicate insects.

Large Woody Debris (LWD): Fundamental to stream habitat structure. Can form dams and pools; trap sediment and detritus; provide stabilization to stream channels; dissipate flow energy and promote habitat complexity.

Mannings N: A commonly used roughness coefficient; actor in velocity and discharge formulas representing the effect of channel roughness on energy losses in flowing water.

Methyl Tertiary-Butyl Ether: An oxygenate and gasoline additive used to improve the efficiency of combustion engines in order to enhance air quality and meet air pollution standards. MTBE has been found to mix and move more easily in water than many other fuel components, thereby making it harder to control, particularly once it has entered surface or ground waters.

Microbe: Short for microorganism. Small organisms that can be seen only with the aid of a microscope. Most frequently used to refer to bacteria. Microbes are important in the degradation and decomposition of organic materials.

Nitrate: A chemical compound having the formula NO_3. Excess nitrate in surface waters can lead to excessive growth of aquatic plants.

Organic Matter: Plant and animal residues, or substances made by living organisms. All are based upon carbon compounds.

Organic Nitrogen: Nitrogen that is bound to carbon-containing compounds. This form of nitrogen must be subjected to mineralization or decomposition before it can be used by the plant community.

Overbank Flow: Water flow over the top of the bankfull channel and onto the floodplain.

Oxygenate: To treat, combine, or infuse with oxygen.

Peak Discharge: The maximum instantaneous rate of flow during a storm, usually in reference to a specific design storm event.

Pesticides: Any chemical agent used to control specific organisms, for example, insecticides, herbicides, fungicides and rodenticides.

Piedmont: Any plain, zone or feature located at the foot of a mountain. In the United States, the Piedmont (region) is a plateau extending from New Jersey to Alabama and lying east of the Appalachian Mountains.

Pool: A stream feature where there is a region of deeper, slow-moving water with fine bottom materials. Pools are the slowest and least turbulent of the riffle/run/pool category.

Protozoan: Any of a group of single-celled organisms.

Rapid Bioassessment Protocols (RBP): An integrated assessment, comparing habitat, water quality and biological measures with empirically defined reference conditions.

Receiving Waters: Rivers, lakes, oceans, or other bodies of water that receive water from another source.

Riffle: Shallow rocky banks in streams where water flows over and around rocks disturbing the water surface; often associated with whitewater. Riffles often support diverse biological communities due to their habitat niches and increased oxygen levels created by the water disturbance. Riffles are the most swift and turbulent in the riffle/run/pool category.

Roughness: A measurement of the resistance that streambed materials, vegetation, and other physical components contribute to the flow of water in the stream channel and flood-plain. It is commonly measured as the Manning's roughness coefficient (Manning's N).

Run: Stream feature characterized by water flow that is moderately swift flow, yet not particularly turbulent. Runs are considered intermediate in the riffle/run/pool category.

Runoff Coefficient: A value derived from a site impervious cover value that is applied to a given rainfall volume to yield a corresponding runoff volume.

Salmonid: Belonging to the family Salmonidae, which includes trout and salmon.

Sanitary Sewer Overflow (SSO): Excess flow of wastewater (sewage) discharged to a receiving water body when the capacity of the sewer network and/or treatment plant is exceeded, typically during storm events.

Semi-arid: Characterized by a small amount of annual precipitation, generally between 10 and 20 inches.

Simple Method: Technique used to estimate pollutant loads based on the amount of IC found in a catchment or subwatershed.

Sinuosity: A measure of channel curvature, usually quantified as the ratio of the length of the channel to the length of a straight line along the valley axis. It is, in essence, a ratio of the stream's actual running length to its down-gradient length.

Soluble Phosphorus: The amount of phosphorus available for uptake by plants and animals.

Stormwater: The water produced as a result of a storm.

Subwatershed: A smaller geographic section of a larger watershed unit with a drainage area of between two to 15 square miles and whose boundaries include all the land area draining to a point where two 2^{nd} order streams combine to form a 3^{rd} order stream.

Total Dissolved Solids (TDS): A measure of the amount of material dissolved in water (mostly inorganic salts).

Total Kjeldhal Nitrogen (TKN): The total concentration of nitrogen in a sample present as ammonia or bound in organic compounds.

Total Recoverable Metals: The amount of a metal that is in solution after a representative suspended sediment sample has been digested by a method (usually using a dilute acid solution) that results in dissolution of only readily soluble substances).

Total Maximum Daily Load (TMDL): The maximum quantity of a particular water pollutant that can be discharged into a body of water without violating a water quality standard.

Total Nitrogen (Total N): A measure of the total amount of nitrate, nitrite and ammonia concentrations in a body of water.

Total Organic Carbon (TOC): A measure of the amount of organic material suspended or dissolved in water.

Total Phosphorous (Total P): A measure of the concentration of phosphorus contained in a body of water.

Total Suspended Solids (TSS): The total amount of particulate matter suspended in the water column.

Trophic Level: The position of an organism in a food chain or food pyramid.

Turbidity: A measure of the reduced transparency of water due to suspended material which carries water quality and aesthetic implications. Applied to waters containing suspended matter that interferes with the passage of light through the water or in which visual depth is restricted.

Volatile Organic Compounds (VOC): Chemical compounds which are easily transported into air and water. Most are industrial chemicals and solvents. Due to their low water solubility they are commonly found in soil and water.

United States General Accounting Office

GAO

Report to Congressional Requesters

June 2001

WATER QUALITY

Better Data and Evaluation of Urban Runoff Programs Needed to Assess Effectiveness

Accountability * Integrity * Reliability

GAO-01-679

Contents

Abbreviations

BMP	best management practices
CSO	combined sewer overflow
DOT	Department of Transportation
DPW	Department of Public Works
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
MCTT	Multi-Chambered Treatment Tank
MDE	Maryland Department of Environment
MS4	Municipal Separate Storm Sewer System
NPDES	National Pollutant Discharge Elimination System
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
TEA-21	Transportation Equity Act for the 21st Century
TMDL	total maximum daily load
USGS	U.S. Geological Survey
WDNR	Wisconsin Department of Natural Resources
WPDES	Wisconsin Pollutant Discharge Elimination System

GAO
Accountability * Integrity * Reliability

United States General Accounting Office
Washington, D.C. 20548

June 29, 2001

The Honorable Olympia Snowe
United States Senate

The Honorable Sherrod Brown
The Honorable Martin Meehan
The Honorable James Oberstar
The Honorable Jack Quinn
House of Representatives

Nonpoint source pollution—that is, pollution from contaminants picked up and carried into surface water by water running over land—is known to be one of the leading causes of water quality problems in the United States. Water that runs over developed areas, including paved surfaces such as roads and parking lots, before reaching a water body is known as urban runoff and is an increasingly important category of water pollution. As urban areas have expanded over the past several decades, the amount of urban runoff has also increased. Although the overall quality of the nation's waters has improved since the passage of the Clean Water Act in 1972, a significant number of water bodies still suffer from poor water quality. Because the act brought discharges from "point sources," such as industrial plants and municipal treatment plants, under control, the continuing pollution of these waters suggests that other sources, including urban runoff, are contributing to water quality problems. As a result, the Environmental Protection Agency (EPA) now classifies urban runoff as a significant cause of impairment to water quality. The Water Quality Act of 1987, which amended the Clean Water Act, required EPA, among other things, to regulate as a point source urban runoff that reaches municipal sewer systems. EPA's National Pollutant Discharge Elimination System Program for storm water requires that certain local governments take measures to control storm water runoff.

Concerned about the degradation of water quality in urban areas, you asked us to report on (1) the amount of runoff from urban areas, particularly from roads, highways, and other impervious surfaces,[1] and its effects on water quality and (2) the programs that federal regulations require local governments to develop to address urban runoff, and the costs and effectiveness of those programs. To address these issues, we reviewed federal and other studies and interviewed experts on the relationship between the amount of paved and other impervious surfaces and the amount of runoff, and on the types of materials typically contained in urban runoff. We also reviewed studies and interviewed experts on the sources of these materials and any actual or potential effects on water quality from urban runoff. We visited five urban areas and organizations that are affiliated with their watersheds[2] to obtain site-specific information about urban runoff problems, programs these areas have implemented in response to federal requirements, and the costs and effectiveness of these programs. Finally, we reviewed studies and estimates of the costs and investment requirements associated with implementing storm water management programs. Because this report focuses on local governments' actions, we did not review the portions of the National Pollutant Discharge Elimination System Storm Water Program that address industrial facilities and construction sites.

We performed our review from August 2000 through May 2001 in accordance with generally accepted government auditing standards.

Results in Brief

The volume of urban storm water runoff increased throughout the United States in the last half of the 20th century because of the growth in impervious surfaces that resulted from the development of urban and suburban areas. According to the U.S. Department of Agriculture, between 1945 and 1997, land devoted to urban areas in the United States has increased by about 327 percent; according to EPA, paved road mileage has increased by 278 percent. Because paved surfaces are almost impervious, they allow little storm water to infiltrate the ground; therefore, the storm water runs off into creeks, rivers, and lakes. As storm water runs across these impervious surfaces and land, it picks up pollutants from these surfaces and carries them to receiving bodies of water—either directly or

[1]An impervious surface keeps water from soaking into soils.

[2]A watershed is an area of land in which all surface water drains to a common point.

through conveyances such as gutters, storm sewers, and culverts. EPA's 1998 *National Water Quality Inventory Report to Congress* showed that certain rivers, streams, lakes, and estuaries are impaired in terms of their ability to support such uses as aquatic life, swimming, and fish consumption, and concluded that urban runoff was a major source of this impairment. Studies have shown that urban runoff and the pollutants it carries can cause increases in sedimentation, water temperature, and pathogen levels and decreases in dissolved oxygen levels in bodies of water. These changes can lead to the degradation of habitat in these water bodies and a decline in diversity of aquatic life and can endanger public health. For example, metals, a pollutant typically found in urban runoff, can be toxic to aquatic organisms. Pathogens, such as bacteria from animal waste, another pollutant commonly found in urban runoff, can pose public health problems when present in waters used for recreational purposes. The magnitude and nature of these effects vary by region, depending on the type and concentration of pollutants in storm water, rainfall characteristics, land use, and other factors.

Local governments are required to address urban runoff through EPA's National Pollutant Discharge Elimination System Storm Water Program. Under permits that EPA and states issue through this program, over 1,000 local governments must meet EPA's requirements to implement storm water management programs to reduce contaminants in storm water to the "maximum extent practicable." EPA recommends that these cities use "best management practices" to reduce contaminants in storm water runoff. The most typical practices included controlling runoff through a combination of structural means, such as detention ponds, and nonstructural means, such as increasing the frequency of street sweeping and educating the public about how to prevent pollutants from reaching storm sewers. Cities also used specialized practices to address specific local runoff problems. For example, Baltimore, Maryland, has focused on reducing the level of nutrients, such as fertilizers, in its runoff because of its proximity to the Chesapeake Bay, which suffers from high nutrient levels.

Neither the overall costs of implementing the storm water program nor the program's effectiveness has been determined. EPA estimated in a 1996 report to congress that the potential need for spending on storm water runoff and overflows of sewage resulting from runoff was over $50 billion over 20 years, but the agency also believes this estimate will increase when it issues its next report in 2002. EPA's regulations require that permitted cities annually report the costs of implementing their storm water programs, along with the results of their monitoring of storm water runoff and water quality. However, in part because EPA has not established guidelines for reporting costs, these data have not been calculated or reported consistently and, therefore, are not currently useful in characterizing the program's overall cost. EPA, state, and city officials generally believe that managing storm water runoff will reduce the volume of runoff and concentrations of pollutants in the runoff, as well as improve water quality, but no systematic effort to evaluate the program's results has been started. EPA and the states have generally been unsuccessful in developing measurable program goals and in demonstrating program effectiveness through the review of water quality data reported by local governments.

We believe it is time for EPA to begin evaluating this program, which is directed at one of the nation's most significant water quality problems. Therefore, this report includes a recommendation to EPA to work with states to develop program goals, establish standards for reporting on program costs and effectiveness, and review reported water quality data to determine whether the current storm water management programs are having the intended effect of improving the quality of the nation's waters and how much the programs cost. We provided a draft of this report to EPA and the Department of Transportation (DOT). EPA generally agreed with the report and plans to take action to implement several parts of the recommendation; the agency did not comment on the other parts of the recommendation. DOT generally agreed with the report. (See the Agency Comments and Our Evaluation section of this report.)

Background

Nonpoint source pollution can result when water, such as precipitation, runs over land surfaces and into bodies of water. Significant nonpoint sources of pollution can include paved urban areas, agricultural practices, forestry, and mining. However, in urban and suburban areas, this runoff generally enters a sewer system that can be regulated as a point source of water pollution. For example, precipitation from rain or snowmelt may run into a municipal separate storm sewer system (MS4 or storm sewer) that eventually discharges into a body of water. The precipitation may also run into a combined sewer system, which carries a combination of storm water runoff, industrial waste, and raw sewage in a single pipe to a sewage treatment facility for discharge after treatment. Lastly, the precipitation may run off of land or paved surfaces directly into nearby receiving waters.

EPA's Office of Wastewater Management, which is within the Office of Water, implements the National Pollutant Discharge Elimination System (NPDES) Program. The program was created in 1972 with the passage of the Clean Water Act. Created to control water pollution from point sources—those sources, such as a factory or wastewater treatment plant, that contribute pollutants directly into a body of water from a pipe or other conveyance—the NPDES Program did not specifically address storm water discharges. In 1987, the Congress amended the Clean Water Act with the Water Quality Act, which directed EPA to also control storm water discharges that enter MS4s—essentially requiring EPA to treat such storm water as a point source.[3] MS4s are defined as those sewers that collect and convey storm water; are owned or operated by the federal, state, or local government; and are not part of a publicly owned treatment (sewage) facility.

To regulate urban storm water runoff, EPA published regulations in 1990 that established the NPDES Storm Water Program and described permit application requirements. According to EPA, the program's objective, in part, is to preserve, protect, and improve water quality by, among other things, controlling the volume of runoff from paved surfaces and by reducing the level of runoff pollutants to the maximum extent practicable using best management practices (BMP).[4] The 1987 act also authorized EPA to implement a program that provides federal funds and technical assistance to states to develop their own nonpoint source pollution management programs. States can use the federal funds they receive for nonpoint source programs to address nonpoint sources of pollution as well as urban runoff.

Currently, EPA manages NPDES Storm Water programs in six states (Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico) and has delegated authority to the remaining 44 states to manage these programs. The storm water program is being implemented in two phases. Local governments meeting the following criteria must comply with EPA's storm water program regulations. First, Phase I of the program requires that municipalities with a population of 100,000 or more obtain a permit for their MS4 system; second, the program requires that entities obtain a

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[3]Section 402(p) of the Clean Water Act.

[4]According to EPA, a best management practice is a device, practice, or method for removing, reducing, retarding, or preventing targeted storm water runoff constituents, pollutants, and contaminants from reaching receiving waters.

permit if they discharge storm water from sites with industrial activities, including construction activities that disturb 5 acres or more of land. In addition, NPDES permitting authorities may also bring other municipalities and industrial entities into the program if they deem it necessary. Municipalities that meet these conditions must submit a permit application to EPA or the governing regulatory state agency. In 1990, the regulations specifically identified 220 municipalities throughout the United States that were required to apply for a Phase I permit. According to EPA, as of April 2001, about 256 Phase 1 MS4 permits had been issued and about 17 more still needed to be issued. Because some permits cover more than one municipality, these permits cover about 1,000 medium and large municipalities nationwide.

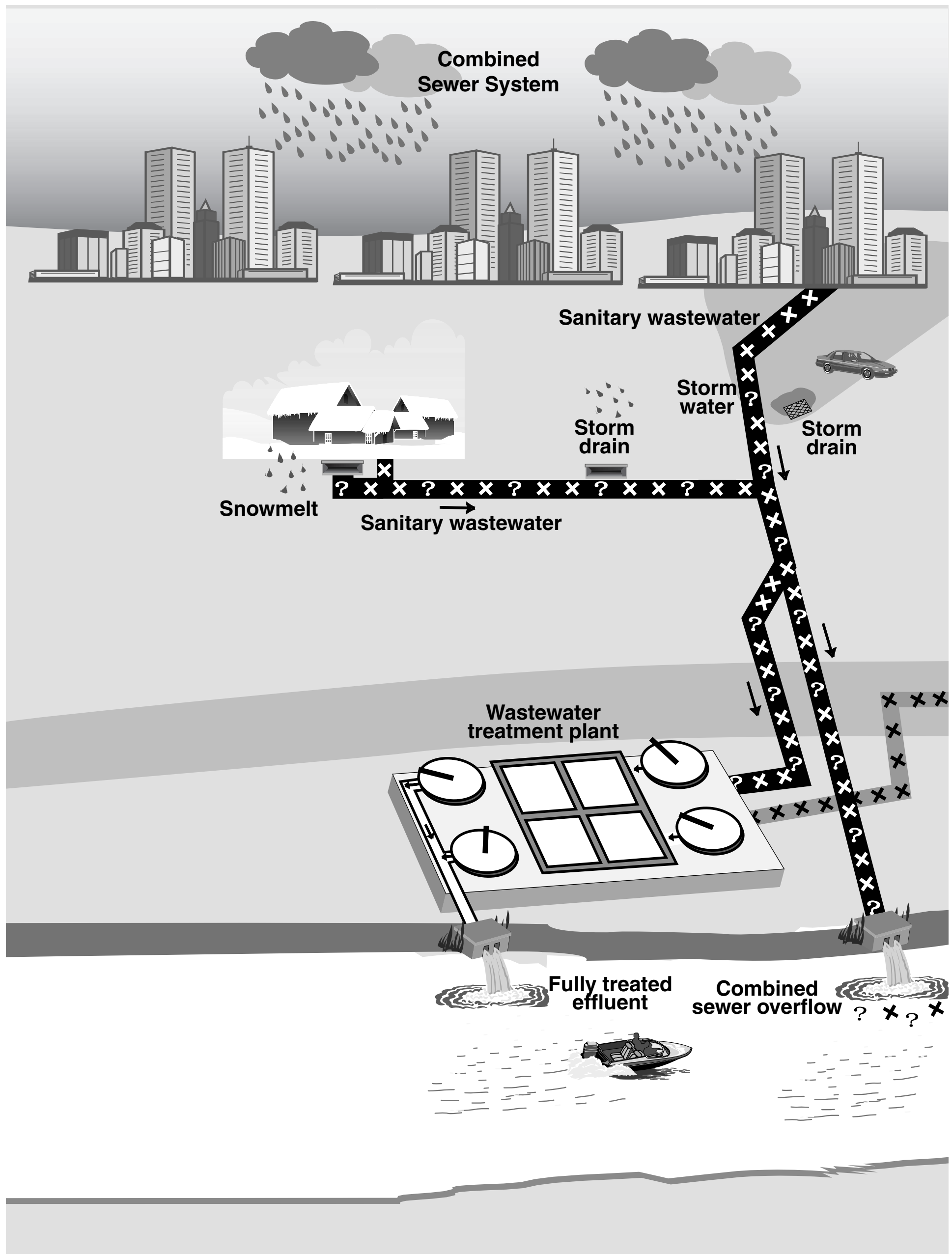
The final rule for Phase II of the program was issued in December 1999. Phase II extends Phase I efforts by requiring that a storm water discharge permit be obtained by (1) operators of all MS4s not already covered by Phase I of the program in urbanized areas[5] and (2) construction sites that disturb areas equal to or greater than 1 acre and less than 5 acres of land. As with Phase I of the program, permitting authorities may require additional small MS4s and construction sites to obtain a permit if they are a significant contributor of pollutants. Currently, EPA anticipates that about 5,000 municipalities may be subject to permitting requirements under Phase II of the storm water program. These municipalities are required to obtain permits no later than March 10, 2003.

[5]The Bureau of the Census generally defines an urbanized area as a land area comprising one or more places—central place(s)—and the adjacent densely settled surrounding area—urban fringe—that together have a residential population of at least 50,000 and an overall population density of at least 1,000 per square mile.

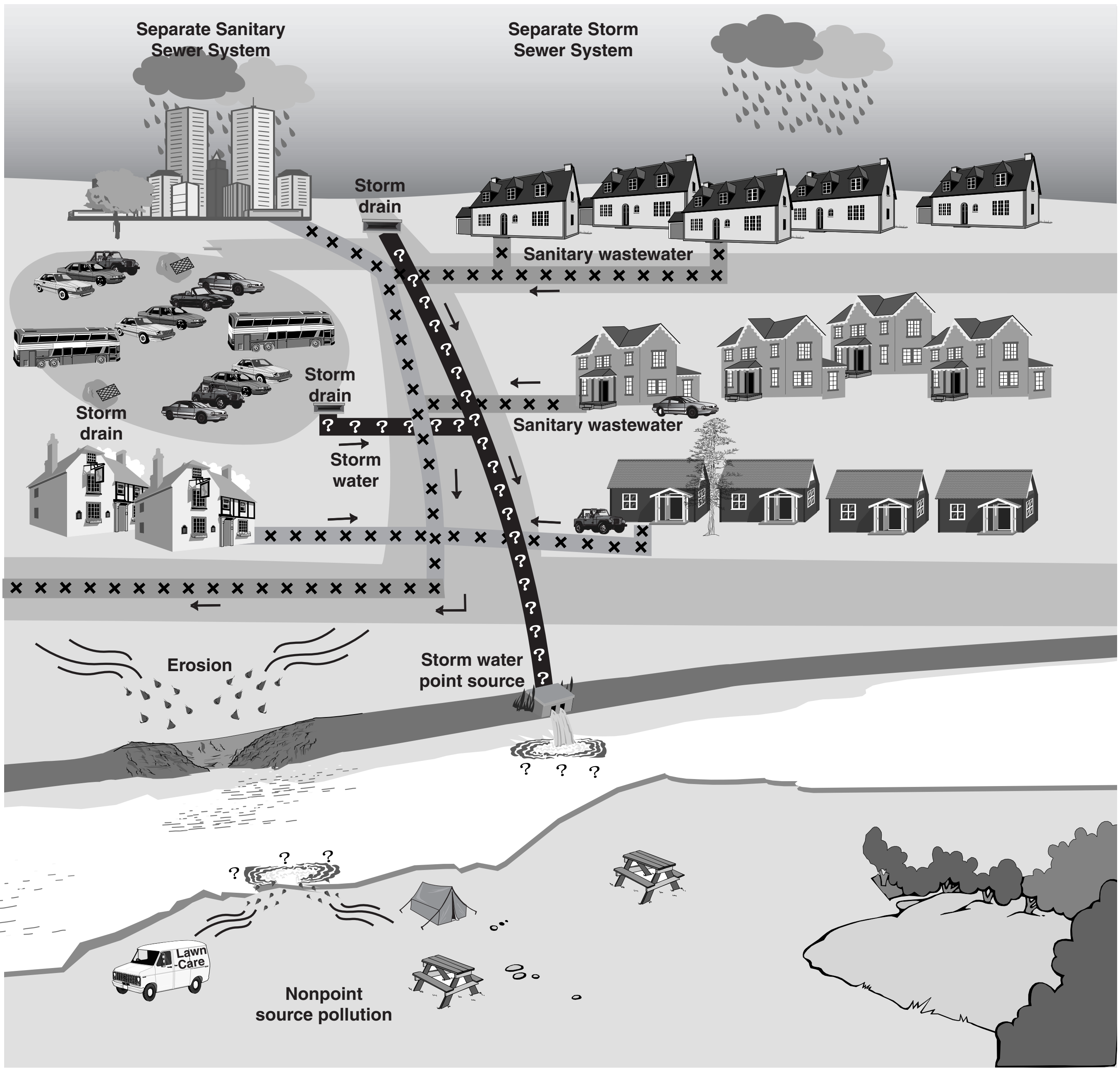
EPA also regulates combined sewer overflows (CSO) that can be caused by urban storm water runoff. Combined sewer systems, in which storm water enters pipes already carrying sewage, may overflow when rain or snowmelt entering the system exceeds the system's flow capacity. In the CSO that results, the mixture of untreated sewage and runoff bypasses the water treatment facility and is diverted directly into receiving waters. (See fig. 1 for an illustration of combined and separate sewer systems.) These combined systems generally serve the older parts of approximately 900 cities in the United States. Pipes carrying sewage and storm water separately generally serve newer parts of cities. EPA's 1994 CSO policy requires communities with combined sewer systems to take immediate and long-term actions to address CSO problems. The policy contains provisions for developing appropriate, site-specific NPDES permit requirements for all combined sewer systems that overflow because of wet-weather events. The Wet Weather Water Quality Act of 2000 requires that any permit, order, or decree issued for a CSO conform to the 1994 policy. Under this act, EPA is also required to submit a report to the Congress by September 2001 on the status of the program.[6]

[6]Sanitary sewer overflows, which are illegal under the Clean Water Act, can also result from rainfall. A sanitary sewer overflow may occur when rainwater or snowmelt leaks into sanitary sewage pipes, thereby exceeding the pipes' capacity and causing them to overflow. This discharge of raw sewage from municipal sanitary sewer systems can release untreated sewage into places such as streams, basements, and streets. EPA proposed regulations to require municipalities to reduce the number of overflows. However, these regulations have been withdrawn for further review.

Figure 1: Urban Runoff Flows in Different Types of Sewer Systems



× Sanitary sewage/wastewater
? Storm water runoff with potential contaminants



Source: GAO illustration based on EPA data.

The Total Maximum Daily Load (TMDL) Program, established under the Clean Water Act, is intended to address water bodies that do not meet water quality standards because of pollutant loadings from point and nonpoint sources. Currently, it is unclear how and when this program will affect EPA's and states' issuance of storm water permits. A TMDL is a calculation of the maximum amount of a pollutant that a body of water can receive and still meet the water quality standard set by the state. Under EPA's regulations, the state is to allocate this "pollutant load" among the point and nonpoint pollutant sources that flow into the water body and then take steps to ensure that no source exceeds its assigned load. In 1996, EPA issued a policy that outlined an interim approach to including water quality standards in storm water permits. The policy promoted the use of BMPs in the first 5-year term permits, followed by a tailoring of BMPs in the second round of permits as necessary to comply with water quality standards. Until recently, few TMDLs had been established, and citizen organizations sued EPA for its lack of action. EPA issued a new set of regulations for the TMDL Program in 2000, but the Congress prevented EPA from spending money to implement the rule in 2000 and 2001. It is possible that establishing a TMDL for a body of water could result in the application of a numeric effluent limit to outfalls[7] that release storm water into that body of water. Some city officials we spoke with generally felt that numeric effluent limits would significantly increase the cost of managing storm water.

Volume of Urban Runoff Increases With the Expansion of Urban Development and Can Affect Water Quality

Since World War II, urban runoff has increased throughout the United States. This increase is directly related to growth in the amount of impervious surfaces due to urban and suburban development and the construction of roads, highways, and other impervious surfaces. Coinciding with this growth in impervious surfaces has been a reduction in wetlands and in the amount of storm water that infiltrates the ground to recharge aquifers. Moreover, the loss of vegetation due to development and related runoff can cause major erosion. Ultimately, much of this runoff is channeled into gutters, storm drains, and paved channels, and vegetation and sediment removed with the runoff may end up in receiving waters. EPA has identified urban storm water runoff as one of the leading sources of pollution to the nation's rivers, streams, lakes, and estuaries. Runoff from impervious surfaces picks up potentially harmful pollutants and

[7]An outfall is an outlet, such as a pipe, that allows storm water to flow into a river, lake, or other body of water.

carries them into receiving waters. Studies have shown that urban runoff and the pollutants it carries can negatively affect water quality, aquatic life, and public health.

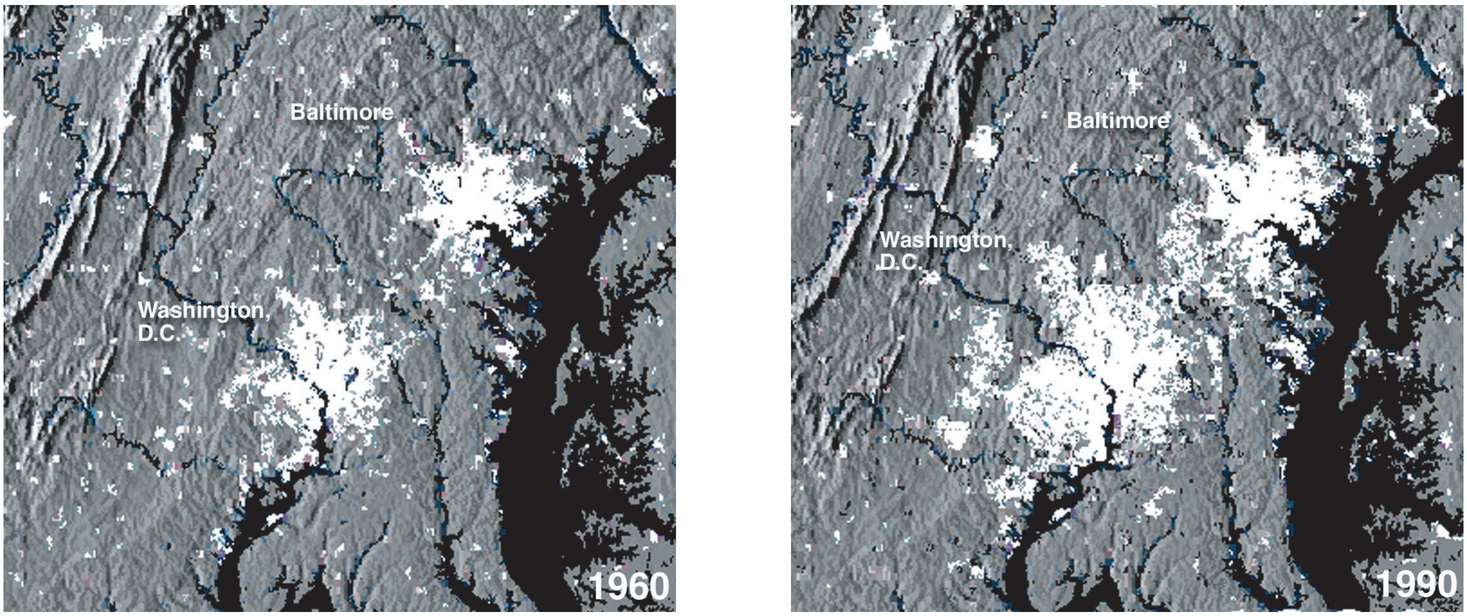
Paved Surfaces Have Increased With Urban and Suburban Expansion and Growth in Automobile Use

According to the U.S. Department of Agriculture, between 1945 and 1997, urban land area increased by almost 327 percent, from 15 million acres to about 64 million acres in the contiguous 48 states. From 1992 through 1997, the annual rate of development averaged about 1 million acres per year. The land developed between 1945 and 1997 came primarily from forestland and pasture and range.[8] For example, according to the Bureau of the Census, between 1960 and 1990, the amount of land used for urban purposes in Baltimore, Maryland, and Washington, D.C., grew by about 170 percent and 177 percent, respectively. As a result, urbanization, with its accompanying expansion of impervious surfaces like sidewalks, roofs, parking lots, and roads, has significantly increased the nation's total developed land and paved surface area.[9] Figure 2 demonstrates the growth in the urbanized areas of Baltimore and Washington, D.C., over the last half of the 20th century.

[8] *Agricultural Resources and Environmental Indicators, 2000,* U.S. Department of Agriculture, Economic Research Service, Resource Economics Division.

[9] *Our Built and Natural Environments, A Technical Review of the Interaction Between Land Use, Transportation and Environmental Quality,* U.S. Environmental Protection Agency (EPA 231-R-00-005, Nov. 2000).

Figure 2: Increase in Urbanized Land in Selected Cities, 1960-90

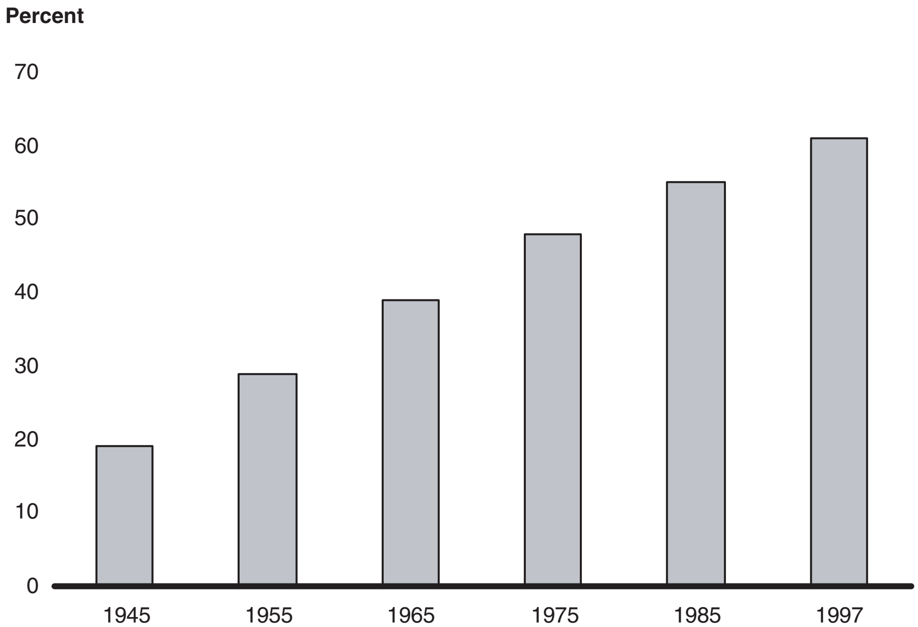


Source: U.S. Geological Survey.

The increase in paved surfaces has been spurred not only by urban and suburban development, but also by a steady increase in the use of automobiles, the primary mode of daily transportation for most Americans. Roads also play an important role in the economy of the United States, since trucks carry about 75 percent of the value of all goods shipped. According to EPA, paved road mileage in the United States increased by 278 percent from 1945 to 1997. In 1945, 19 percent of the public roads in the country were paved; by 1997, that percentage had increased to 61. (See fig. 3.) According to a 1999 study, motor-vehicle infrastructure, such as roads and parking lots, accounts for close to half of the land area in U.S. urban cities.[10]

[10] *Stormwater Strategies, Community Responses to Runoff Pollution,* Natural Resources Defense Council (May 1999).

Figure 3: Percentage of Paved Public Road Miles, 1945-97



Source: EPA.

Increase in Impervious Surfaces Leads to Increased Runoff

The increase in impervious surfaces over the past several decades has led to an increase in storm water runoff. In part, this has occurred because highways and other developments have reduced the amount of wetlands and other undeveloped land. Wetlands mitigate the effects of storm water runoff by acting as a natural form of flood control, facilitating sediment replenishment, and improving water quality by removing excess nutrients and other chemical contaminants before the contaminants can affect receiving waters. According to a 2000 EPA report,[11] of the 12 states that listed wetland losses, six reported that they had significant losses due to highway construction, and 10 reported that they had significant losses due to residential growth and development. However, the effect of road building on wetland loss has been reduced in recent years. According to a Federal Highway Administration (FHWA) official, since 1996, wetlands have been replaced and restored under the Federal-Aid Highway Program

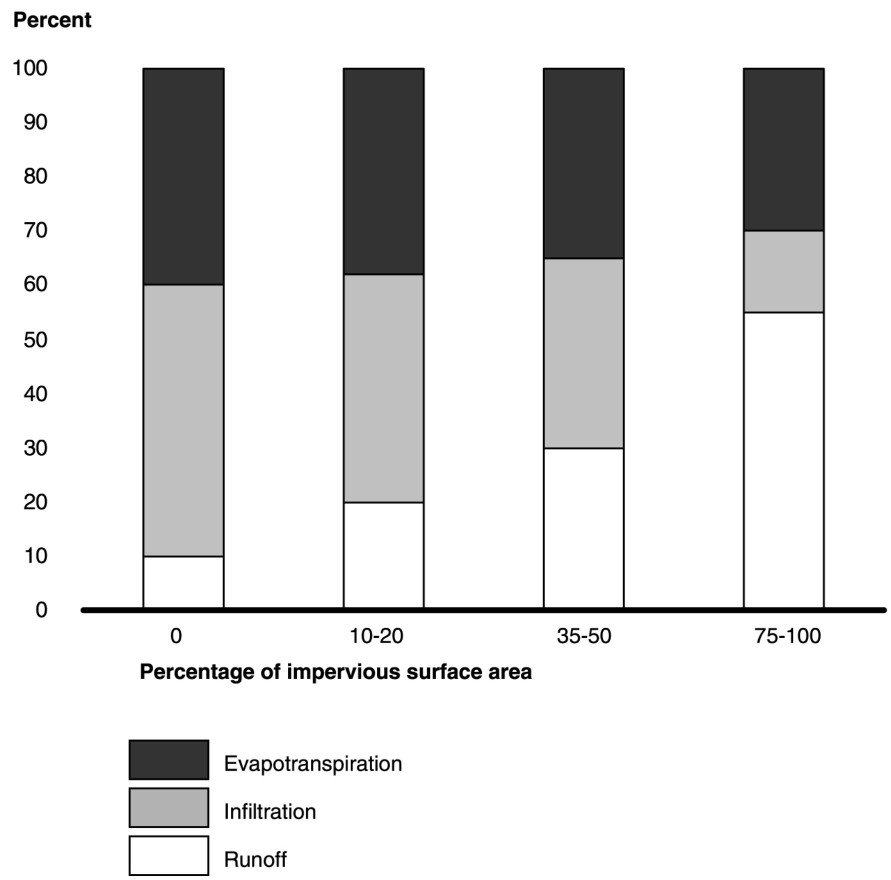
[11]See footnote 9.

at an average rate of 2.7 acres for every acre lost to highway building. Other undeveloped land with vegetation also performs some of the roles that wetlands play in managing runoff, although to a lesser extent.

Furthermore, as impervious surfaces increase, less storm water is able to infiltrate through the soil to groundwater. Impervious areas allow only a very small amount of initial infiltration compared with unpaved areas whose infiltration capacity varies, depending on the soil type. Figure 4 demonstrates EPA's estimates of the impact of impervious surfaces on the percentages of storm water that runs off, infiltrates the ground, and is lost through evapotranspiration.[12] When natural ground cover is present over an entire site, normally 10 percent of precipitation runs off the land into nearby creeks, rivers, and lakes. In contrast, when a site is 75- to 100-percent impervious, 55 percent of the precipitation runs off into these receiving waters. However, according to an FHWA official, the runoff rates can be reduced if developers take mitigating actions to develop and implement BMPs to control flooding or runoff.

[12]Evapotranspiration represents water loss from evaporation and the absorption and eventual release into the atmosphere of water that plants and trees have collected. The extent to which evapotranspiration occurs is dependent primarily on the solar energy available to vaporize the water. As a result, the effect of evapotranspiration varies greatly across the country.

Figure 4: Impact of Impervious Surfaces on the Amount of Storm Water That Runs Off, Infiltrates, and Evapotranspires



Source: EPA.

The decrease in storm water infiltration that accompanies urbanization also reduces the amount of water that is available to recharge groundwater supplies. For this reason, reduced infiltration may lead to problems with the water table in certain urban areas. For example, a Massachusetts Department of Environmental Protection official noted that a low recharge rate affects water quality because it can result in a loss of wetlands and adversely affect aquatic habitat as water-table levels fall during dry weather.[13] In addition, officials from the Charles River Watershed Association in Massachusetts are concerned that the lack of infiltration might cause some communities to run short of drinking water in the next 20 years.

Urban Runoff Has the Potential to Impair Water Quality and Disrupt Biological Integrity

Urban runoff can adversely affect the quality of the nation's waters, and urban storm water runoff has been identified as one of the leading sources of pollution to rivers, streams, lakes, and estuaries.[14] Section 305(b) of the Clean Water Act requires states and other jurisdictions to report on the quality of their waters to EPA every 2 years. The 1998 *National Water Quality Inventory Report to Congress* showed that 35 percent of assessed river and stream miles, 45 percent of assessed lake acres, and 44 percent of assessed estuarine square miles were impaired in terms of their ability to support uses such as aquatic life, swimming, and fish consumption.[15] The report identified urban storm water runoff as one of the leading sources of impairment to the assessed waters.

[13]Dry weather is defined as a period when rainfall measuring at least 0.10 of an inch has not occurred for 72 hours.

[14]Other leading sources of pollution include agricultural runoff, municipal point sources, hydrologic modifications, and atmospheric deposition.

[15]Information contained in the 1998 report reflects only those waters assessed by states and other jurisdictions and cannot be used to characterize nationwide water quality. Furthermore, water quality standards among states are not identical, and the monitoring design used to collect data differed among states.

Studies have shown that as the percentage of impervious cover increases within a watershed, biodiversity also declines. Research conducted by the Center for Watershed Protection found that, generally speaking, when a watershed has 10 percent or less impervious cover, the associated stream can be categorized as sensitive.[16] Sensitive streams are characterized as having high fish diversity and good water quality. Once the percentage of impervious cover exceeds 25 to 30 percent of the watershed, however, streams tend to become nonsupporting. Nonsupporting streams are highly unstable, have poor diversity of fish and aquatic life, and have poor water quality. For example, one study evaluated the relationship between the extent of impervious cover in watersheds to the number and diversity of fish populations in 47 small streams in southeastern Wisconsin between the 1970s and 1990s.[17] The results revealed that the number of fish species per site was highly variable for drainage areas that had less than 10-percent imperviousness. In contrast, sites that had greater than 10-percent imperviousness had consistently low numbers of fish species.

Other studies have associated urban runoff with basic changes in the receiving body of water. Runoff can carry sediment into surface water, and this sediment can carry contaminants, harm aquatic plants, and smother organisms. Runoff can also be warmed by the impervious surfaces it flows across. When sufficient amounts of warmed runoff enter a water body, the water temperature can rise. Less oxygen is then available for aquatic organisms because water holds less oxygen as it becomes warmer. These combined factors lead to the degradation of aquatic habitat. According to EPA, the common effects of these types of pollution on aquatic life include a decline in biodiversity and an increase in invasive species.

An increase in the volume of storm water runoff also increases the likelihood of erosion, which allows for transport of eroded sediment downstream into receiving waters. For example, during a site visit, we observed extensive erosion along the Gingerville Creek Subbasin in Anne Arundel County, Maryland, that was caused by urban runoff channeled into the creek. Figure 5 depicts the eroded banks and channel of this creek.

[16]"The Importance of Imperviousness," *Watershed Protection Techniques*, v.1:3, Fall, 1994. The article reviews 18 studies on the relationship between urbanization and stream quality.

[17]L. Wang and others, "Watershed Urbanization and Changes in Fish Communities in Southeastern Wisconsin Streams," *Journal of the American Water Resources Association,* Oct. 2000, Vol. 36, No. 5.

Figure 5: Damage Caused by Storm Water Runoff From Urbanized Areas in the Gingerville Creek Subbasin

Source: Anne Arundel County, Maryland, Department of Public Works.

Contaminants in Urban Runoff Can Affect Aquatic Life and Human Health

There have been several efforts to characterize the chemicals and other constituents in urban runoff. The Nationwide Urban Runoff Program, conducted by EPA between 1978 and 1983, examined the characteristics of urban runoff. Another federal effort to characterize urban runoff is an ongoing joint project of the U.S. Geological Survey (USGS) and the FHWA to evaluate guidelines for highway runoff. As table 1 indicates, these studies and others have shown that the principal contaminants found in urban runoff include nutrients, solids, pathogens, metals, hydrocarbons, organics, salt, and trash. Water flowing over various surfaces, such as streets, parking lots, construction sites, industrial facilities, rooftops, and lawns, carries these pollutants to receiving waters. The contaminants have the potential to impair water quality, degrade aquatic ecosystems, and pose health risks to swimmers.

Table 1: Storm Water Pollutants in Urban Runoff, Including Sources and Potential Impacts

Contaminant	Source	Potential impact
Nutrients		
Nitrogen, phosphorous	Animal waste, fertilizers, failing septic systems, atmospheric deposition,[a] CSOs	Nutrient enrichment can cause an excessive growth of algae. Nuisance levels of algae are associated with dissolved oxygen deficiencies leading to fish kills, loss of submerged aquatic vegetation that serves as a habitat for aquatic organisms, and loss of natural biodiversity.
Solids		
Sediment	Construction sites, other disturbed and/or nonvegetated lands, eroding banks, road sanding	Sediment can cause infection and disease among fish, scour submerged aquatic vegetation, prevent sunlight from reaching aquatic plants, and bury bottom-dwelling aquatic organisms.
Pathogens		
Bacteria, viruses	Animal waste, failing septic systems, illicit connections and discharges to storm sewer system, CSOs	Pathogens entering waters used for recreational purposes can pose human health risks.
Metals		
Lead, cadmium, copper, zinc, mercury, chromium, aluminum, and others	Industrial processes, normal wear of automobile brake linings and tires, automobile emissions, automobile fluid leaks, metal roofs	Metals can cause acute or chronic toxicity for aquatic organisms.
Hydrocarbons		
Oil and grease, polycyclic aromatic hydrocarbons	Industrial processes, automobile wear, automobile emissions, automobile fluid leaks, waste oil	Hydrocarbons have the potential to be acutely toxic for aquatic organisms and several are suspected carcinogens.
Organics		
Pesticides, polychlorinated biphenyls (PCB), synthetic chemicals	Pesticides (herbicides, insecticides, fungicides, rodenticides, etc.), industrial processes	Low concentrations of some organics have the potential to bioaccumulate in the food chain.

(Continued From Previous Page)

Contaminant	Source	Potential impact
Salt		
Sodium Chlorides	Road salting and uncovered salt storage	Salt can damage roadside vegetation, transport high levels of chlorides to receiving waters, and degrade aquatic ecosystems. Chloride can be harmful to some species of fish.
Trash		
	Street refuse and improperly discarded waste material	Trash impairs water quality by inhibiting the growth of aquatic vegetation and conveys nutrients, toxic substances, and other pollutants to aquatic ecosystems.

[a]Atmospheric deposition occurs when pollutants in the air fall on land or water.

Sources: Massachusetts Department of Environmental Protection Stormwater Policy; EPA reports and guidance, including *Preliminary Data Summary of Urban Storm Water Best Management Practices, Combined Sewer Overflow Control Policy, Innovative Urban Wet-Weather Flow Management Systems*, and the 1998 *National Water Quality Inventory Report to Congress*; the California Regional Water Quality Control Board; the Natural Resources Defense Council's *Stormwater Strategies: Community Responses to Runoff Pollution*; "Accretion of Pollutants in Roadway Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities - Part I," Draft;[18] and USGS' National Water Quality Assessment Program.

[18]J.J. Sansalone and D.W. Glenn, "Accretion of Pollutants in Roadway Snow Exposed to Urban Traffic and Winter Storm Maintenance Activities –Part I," DRAFT.

In our visits to cities with Phase I permits and their watersheds, we identified specific instances in which these contaminants had affected water quality. The Chesapeake Bay, for example, has been polluted with the nutrients nitrogen and phosphorus and with excess sediment caused, in part, by urban runoff. The excess nutrients cause algae blooms that block sunlight from reaching bay grasses—which are a source of food, shelter, and nursery grounds for many aquatic species. In an effort to control nutrient pollution in the Chesapeake Bay, the Executive Council of the Chesapeake Bay Program[19] established a goal to reduce the nitrogen and phosphorus entering the Chesapeake Bay by 40 percent, including through control of runoff from urban areas. In addition, an assessment of the status of chemical contaminant effects on living resources in the bay's tidal rivers found "hot spots" of contaminated sediment. As a result, the Baltimore Harbor and the Patapsco River in Maryland; the Anacostia River in Washington, D.C.; and the Elizabeth River in Virginia were designated as "regions of concern." Urban storm water runoff is a significant source of contaminants in the three regions. The Chesapeake Executive Council has committed to reduce by 30 percent the chemicals of concern in the regions of concern by 2010 through pollution prevention measures and other voluntary means.[20]

Pathogens such as bacteria and viruses, which are often present in urban runoff, can pose public health problems. For example, the Santa Monica Bay Restoration Project conducted a study to identify adverse health effects of untreated urban runoff by surveying over 13,000 swimmers at three bay beaches. [21] The study established a positive association between an increased risk of illness and swimming near flowing storm-drain outlets. Table 2 explains health outcome measures at various distances from storm drains. For example, the study found a 1-in-14 chance of fever for swimmers in front of the drain versus a 1-in-22 chance at 400 or more yards away.

[19]The Chesapeake Executive Council includes the governors of Maryland, Pennsylvania, and Virginia; the Administrator of the U.S. Environmental Protection Agency; the mayor of the District of Columbia; and the chair of the Chesapeake Bay Commission.

[20]Chesapeake Bay Program Office, *Toxics 2000 Strategy: A Chesapeake Bay Watershed Strategy for Chemical Contaminant Reduction, Prevention, and Assessment,* Dec. 2000.

[21]R.W. Haile and others, "The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff," *Epidemiology,* July 1999, Vol. 10, No. 4.

Table 2: Comparative Health Outcomes for Swimming in Front of Drains Versus 400 or More Yards Away

Health outcomes	0 yards	400 or more yards
Fever	1:14	1:22
Chills	1:26	1:42
Ear discharge	1:68	1:143
Coughing with phlegm	1:20	1:33
Significant respiratory disease (fever and nasal congestion, fever and sore throat, and cough with phlegm)	1:12	1:22

Note: This table includes the statistically significant health outcomes.

Source: GAO analysis of data from "The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff," *Epidemiology*, July 1999, Vol. 10, No. 4.

Metals and polycyclic aromatic hydrocarbons (PAH) in urban runoff can present a threat to aquatic life. Studies have found the following:

- Storm water runoff from an urban area proved to be toxic to sea urchin fertilization in the Santa Monica Bay, and dissolved zinc and copper were determined to be contributors to this toxicity. [22]
- Brown bullheads (a bottom-dwelling catfish) in the Anacostia River developed tumors that were believed to be caused by PAHs associated in part with urban runoff.[23]
- High PAH and heavy metal concentrations were found in crayfish tissue samples from several urban streams in Milwaukee. The study associated these contaminants with storm water runoff.[24]

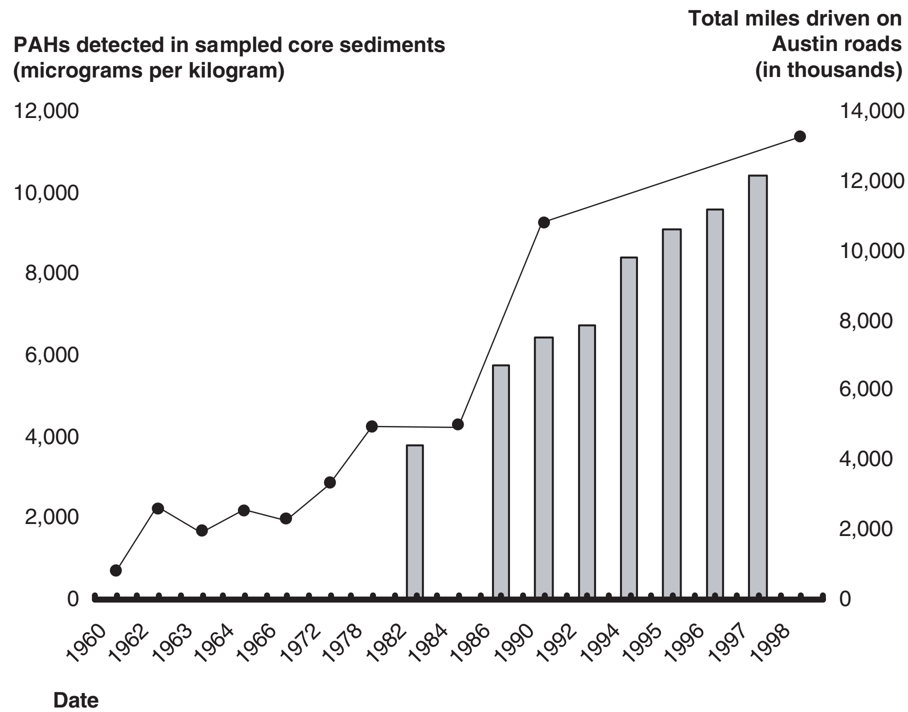
[22]Southern California Coastal Water Research Project, *Study of the Impact of Stormwater Discharge on Santa Monica Bay –Executive Summary,* Nov. 1, 1999.

[23]Chesapeake Bay Program Office.

[24]J.P. Masterson and R.T. Bannerman, "Impacts of Stormwater Runoff on Urban Streams in Milwaukee County, Wisconsin," *National Symposium on Water Quality, American Water Resources Association,* Nov. 1994.

In addition, USGS tracked trends in the concentrations of PAHs found in sediment in 10 lakes and reservoirs in six metropolitan areas over the last several decades. This study found that PAH concentrations in developed watersheds are increasing and that these increases may be linked to the amount of urban development and vehicle traffic in urban and suburban areas.[25] For example, from 1982 to 1996, PAH concentrations in the sediment core in Town Lake (Austin, Texas) and total miles driven in greater Austin both increased by about 2.5 times. Figure 6 illustrates this correlation.

Figure 6: Comparison of Town Lake PAHs and Traffic Trends



Note: According to USGS, irregularities in the date pattern are due to intervals at which sediment samples were collected.

Source: USGS National Water Quality Assessment Reconstructed Trends Program.

[25] P. Van Metre, B. Mahler, and E. Furlong, "Urban Sprawl Leaves Its PAH Signature," *Environmental Science and Technology,* Vol. 34, No. 19, 2000.

Although the studies we reviewed show that certain contaminants are likely to be present in urban runoff, factors such as land development practices, climate conditions, atmospheric deposition, and traffic characteristics all can affect the characteristics of runoff from a particular area. Therefore, given the diffuse nature of many storm water discharges and the variability of other contributing factors, characterizing the concentrations of pollutants contained in storm water runoff has been challenging. Recent USGS reports also suggest that improvements are needed in the methods used to analyze sediment and metals in runoff.[26]

Local Governments Take Actions to Manage Urban Storm Water Runoff, but Information Is Limited on the Cost and Effectiveness of These Actions

To comply with federal and state storm water management for Phase I permitting requirements, permitted municipalities must create and implement storm water management programs. The three primary activities used in these programs include efforts to characterize storm water runoff; BMPs aimed at reducing pollutants in storm water runoff to the maximum extent practicable; and reporting program activities, monitoring results, and costs of implementing the program. Some BMPs are structural—meaning that they are designed to trap and detain runoff until constituents settle or are filtered out. Other BMPs are nonstructural—meaning that they are designed to prevent contaminants from entering storm water through actions like street sweeping and inspections. Many permitted municipalities use specialized BMPs tailored to address particular runoff problems in their locations. Over 1,000 cities are undertaking these efforts under the NPDES Storm Water Program, but information on the overall costs of managing urban runoff and the effectiveness of the actions taken is limited. EPA's attempts to forecast costs have not encompassed the entire program or are out of date. In addition, the permitted municipal agencies we visited estimated their annual storm water management costs and reported them to state agencies or EPA, but the approaches they used to calculate these estimates varied considerably, making it difficult to draw any conclusions. Although EPA and state agencies believe that the program will be effective in improving water quality, EPA has not made a systematic effort to evaluate the program. Without such an effort, EPA cannot tell what effect the program is having on water quality nationally.

[26]The USGS reports indicate that certain methods used to analyze sediment and metals samples can be unreliable. For example, sample collection and processing methods can have an effect on measured concentrations of metals.

Municipalities Comply With Federal and State Requirements Through Monitoring, Best Management Practices, and Reporting

The NPDES Storm Water Program requires municipalities operating under a Phase I MS4 permit to characterize and monitor storm water runoff, implement BMPs to reduce pollutants to the maximum extent practicable, and report costs and monitoring results to the permitting authorities. Because of these requirements, local governments have generally shifted the focus of their storm water management from water quantity control or flood management to water quality concerns.

Besides following the basic federal requirements, municipalities must follow any additional regulations developed by states that have been delegated the authority to manage the NPDES Storm Water Program. For example, Wisconsin's Department of Natural Resources broadened the requirements for determining which municipalities must get permits. The state requires local governments with storm sewer systems in priority watersheds (based on the significance of storm water runoff as a pollutant source) that serve a populace of 50,000 or more[27] to obtain a permit with requirements similar to those for a Phase I permit. Wisconsin's Department of Natural Resources also requires municipalities that are located in one of the state's five Great Lakes Areas of Concern[28] to obtain a state permit. Furthermore, in line with specific criteria in Wisconsin's Administrative Code, the state requires other municipalities to obtain a permit if the municipality is found to significantly contribute storm water pollutants to waters of the state. These various requirements increased the number of municipalities that must get permits from the two under federal requirements to over 70 under the states' requirements.

The local governments we reviewed were undertaking three primary activities when applying for permits and implementing their storm water management programs. Specifically, these activities were (1) characterizing storm water runoff; (2) developing BMPs to reduce discharges of pollutants to the maximum extent practicable; and (3) reporting program activities, monitoring results, and reporting program costs.

First, to characterize runoff, applicants are to provide quantitative data that describe the volume and quality of discharges from municipal storm

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[27]For example, we visited West Allis, Wisconsin, which has a permit even though its population is under 100,000.

[28]Areas of concern have persistent water quality problems, which impair beneficial uses.

sewers. For example, cities must map all storm sewer outfalls—an undertaking that one group representing cities described as significant. After the permit application is approved, additional monitoring is required throughout the life of the permit to facilitate the design of effective storm water management programs and to document the nature of the storm water. The local governments we visited were all monitoring for a variety of purposes, including characterizing runoff from different types of land use in order to target their BMPs, testing the effectiveness of a particular BMP, or establishing a baseline for their storm water quality evaluations.

Second, the storm water management programs that local governments develop focus on implementing BMPs. While active treatment, such as sending storm water through a treatment facility, is a possible BMP, the cities we visited were generally not using active treatment. EPA's February 2000 report[29] on the Phase I program described the program as based on the "use of low-cost, common-sense solutions." The five cities we visited were generally using similar types of structural and nonstructural BMPs, as follows:

- Structural BMPs are designed to separate contaminants from storm water. For example, detention ponds temporarily hold storm water runoff to allow solids and other constituents in the runoff to settle before the water is released at a predetermined rate into receiving waters. In addition, catch-basin inserts, placed in a storm drain, catch trash and other debris, and particle separators, placed beneath the surface of an impervious area such as a parking lot, separate oils from runoff and allow sediment and debris to settle. Structural devices such as these require regular maintenance to function properly and remain effective.
- Nonstructural BMPs are primarily designed to minimize the contaminants that enter storm water. These nonstructural BMPs include
  - "good housekeeping" practices by the local government, such as oil collection and recycling, spill response, household and hazardous waste collection, pesticide controls, flood control management, and street sweeping;

[29] *Report to Congress on the Phase I Storm Water Regulations*, U.S. Environmental Protection Agency, February 2000. This report includes information on the program for local governments, industries, and construction sites.

- public education programs, such as storm-drain stenciling, to remind the public that trash, motor oil, and other pollutants thrown into storm drains end up in nearby receiving waters;[30]
- new ordinances to control pollution sources, such as prohibiting the disposal of lawn clippings in storm drains and requiring pet owners to clean up after their pets;[31]
- requirements that developers comply with storm water regulations and incorporate erosion and sediment controls at all new development sites;
- requirements that runoff from properties owned or activities sponsored by the municipality be properly controlled; and
- efforts to identify and eliminate illicit connections and illegal discharges to the storm sewer systems, such as those from pipes carrying sewage.

We found that the NPDES Program's requirements allowed local governments to tailor their storm water management efforts to prioritize local concerns, such as a particular type of contaminant, a particular climatic condition, or a particular body of water. Some cities also developed specialized BMPs to address these concerns. The following information highlights specific storm water-related concerns in the five cities we visited and the specialized BMPs these municipalities have developed to address these particular concerns. (See apps. I to V for additional information on these cities' storm water management programs.)

[30]Other public education programs we observed included in-school education programs, partnerships with grassroots organizations concerned with water quality issues, and the identification of commercial businesses and industries to educate owners on methods to control storm water runoff.

[31]According to Worcester, Massachusetts' April 2000 *City of Worcester DPW Stormwater Management Program Annual Report*, the city has proposed ordinances that prohibit the disposal of lawn clippings and other yard waste in catch basins and that require pet owners to clean up after their pets. As of April 2001, neither ordinance had been implemented.

- In **Baltimore, Maryland**, excessive levels of nutrients, particularly phosphorus and nitrogen, are among the city's major water quality concerns because of the city's participation in the Chesapeake Bay Program. Baltimore City agreed to assist the state in reaching the Chesapeake Bay Program's goal to reduce nutrients discharged to the bay by 40 percent by the year 2000. According to a Chesapeake Bay Program Office representative,[32] as of March 2001, the program has not met this goal but expects to reach it within the next several years.
- In **Boston, Massachusetts**, the Boston Water and Sewer Commission, which holds the permit for Boston's storm sewer system, is concerned about runoff from roadways, especially runoff containing salt and sand used in the winter months and dissolved metals (copper and zinc) from automobiles. In September 2000, the commission began a 3-year program to develop and implement a citywide catch-basin inspection, cleaning, and preventive maintenance program. The program will also include the development of a database and map that can be linked to the commission's Geographic Information System.
- **Los Angeles County, California**, is responding to a TMDL for trash in the Los Angeles River Watershed that will require the county, over a 10-year period, to eliminate trash in runoff. The county is testing a variety of devices that remove trash from runoff and specialized catch-basin devices that are designed to prevent trash from ever reaching the storm sewers.
- **Milwaukee, Wisconsin**, changed its monitoring and public education activities in its recent permit to test the effectiveness of a BMP targeting public education efforts to a specific community. The new permit also requires a monitoring program aimed at the community, its associated watershed, and city employees who work in the area.
- **Worcester, Massachusetts**, had a significant problem with illicit connections to its storm sewers and with flow in these sewers during dry weather. Worcester's Department of Public Works (DPW) screened 71 of its storm water outfalls and determined that 32 of them had drainage areas that carried both sanitary sewage and storm drainage in separate conduits through common manholes. DPW has retrofitted over 65 percent of the manholes to prevent sewage from mixing with storm water.

[32]The Chesapeake Bay Program Office, U.S. EPA Region III, was founded in 1983 with the formation of the Chesapeake Bay Program. The program is a voluntary regional partnership that leads and directs restoration of the Chesapeake Bay. Members of the Chesapeake Bay Program include Maryland, Pennsylvania, Virginia, the District of Columbia, the Chesapeake Bay Commission (a tristate legislative body), EPA, and participating citizen advisory groups.

Third, local governments participating in the Phase I program are required to report annually to EPA or the state regulatory agency on their storm water programs. These reports are to include a status report on the program; a summary of data, including monitoring results collected during the reporting year; information on annual expenditures on the program and a budget for the coming year; and a description of any water quality improvements or degradation.

Information on the Costs of Addressing Storm Water Runoff Is Limited

Good information about the cost of implementing federal storm water requirements is limited. EPA conducted a survey to estimate the nation's future water infrastructure needs over a 20-year period—from 1996 to 2016. In its 1996 report,[33] EPA estimated that states would require over $50 billion to meet their current (as of 1996) water infrastructure needs. The estimate consists of storm water management needs (at $7.4 billion) and CSO needs (at $44.7 billion).[34] EPA noted, however, that estimated storm water management needs are likely too low and could increase following an analysis of data collected to prepare the agency's 2000 clean water needs survey—to be released in 2002. According to EPA, many cities have implemented the Phase I program since EPA reported to the Congress in 1996, and municipalities should now be better able to provide documented cost data. As a result, EPA will need to rely less on modeled storm water needs than it did in the 1996 needs survey. EPA did not project the costs and benefits of the program when it was initiated; therefore, no initial cost estimates are available. When EPA promulgated the Phase I program regulations in 1990, the agency decided that the storm water program did not meet the requirements for preparing a benefit/cost analysis.

[33] *1996 Clean Water Needs Survey Report to Congress*, U.S. Environmental Protection Agency (Sept. 1997). EPA's estimate represents the estimated capital costs for water quality projects eligible for state revolving fund support.

[34] EPA also estimates that $81.9 billion of its 20-year water infrastructure needs cost can be attributed to sanitary sewer overflows. These overflows may occur when rainwater or snowmelt leaks into sanitary sewage pipes, exceeding the pipes' capacity and causing them to overflow. This overflow can release untreated sewage from municipal sanitary sewer systems into streams, basements, and streets.

The costs to local governments of complying with the Phase I program have generally been portrayed as high. However, because of inconsistencies in cost accounting and reporting practices, we could not determine the cost of the program to several of the cities we visited. Although municipalities are required to provide information on the expenditures that they anticipate will be needed to implement their storm water management programs for each fiscal year covered by the permit, EPA has not issued any cost reporting guidelines. Consequently, while the reported fiscal year 1999 total cost to manage and treat storm water runoff across the five municipalities in our review ranged from less than $1 million (Milwaukee) to $135 million (Los Angeles County),[35] these numbers are not comparable because the municipalities did not have consistent cost accounting and reporting practices and did not fully express storm water management costs.[36] For example, some cities reported only the costs of activities that were funded by the city department that held the permit. Significant activities funded by other city departments were not reported, even if they were important components of the storm water program. Officials in the Milwaukee Department of Infrastructure Services and the Boston Water and Sewer Commission told us that other city departments perform and fund activities such as street sweeping and flood control. The costs of these activities are not reported as storm water program costs because the activities serve other purposes besides preventing storm water pollution.

In addition, according to some city officials, these activities were in place before the permit was issued and, therefore, cannot be characterized solely as storm water costs. The cost of street sweeping can be significant—for fiscal year 1999, Baltimore City and Worcester, which did include street-sweeping costs in their storm water program's cost estimate, stated that their street-sweeping expenses totaled about $9.5 million and $1.2 million, respectively. Similarly, Milwaukee did not report the cost of a significant project related to storm water runoff because it was mostly funded by the state of Wisconsin.

[35]Los Angeles County's cost was projected by the municipal permit holder and represents the cost of the 85 cities covered by the permit.

[36]We were unable to obtain comprehensive information on the total cost to the Boston Water and Sewer Commission of managing storm water, so their fiscal year 1999 costs could not be included in this range.

An EPA official told us that the agency had not yet made a national effort to analyze the information that Phase I permittees submitted on the costs of their storm water programs. This official cited the inconsistent formats of the annual reports as a reason that the information was not readily available at the national level and also indicated that adequate staff are not available to analyze the data. In addition, other EPA officials informed us that the Office of Wastewater Management must divide its resources among a number of issues that will challenge the agency's water program over the next decade.

Several officials in the cities we visited said that their annual costs are likely to increase. A number of factors could affect the costs. For example, a Baltimore City official explained that the anticipated, future program costs depend on several factors, including (1) requirements in watershed-management plans currently being developed, (2) pollution-reduction goals the city will be required to achieve, (3) requirements of the state regulatory agency in future permits, and (4) requirements the city may have to meet if TMDLs or numeric effluent limits are incorporated into NPDES storm water permits. Other city officials also expressed concern about the extent to which TMDLs could affect their future costs. These city officials are concerned that when and if TMDLs are established, their future storm water permits may require that storm water runoff meet specific water quality standards. For example, Los Angeles County's trash TMDL could potentially drive the county's storm water management costs upward, and the county expects additional TMDLs to be imposed. On the other hand, Worcester officials estimated that their future storm water costs would be about the same as they were at the time of our review—about $4.5 million per year.

In a separate analysis, EPA estimated in 1999 that it will cost Phase II municipalities about $848 million to $981 million per year (in 1998 dollars) to manage storm water runoff. Because Phase II permits have not been issued as of May 2001, we did not gather any cost information on them from these cities.

Funding for Managing Storm Water Runoff Is Available From Local and Federal Sources

The five cities we visited had not generally obtained federal funds for their storm water management efforts. They used local sources, including general revenues, bonds, revenue from specifically created storm water utilities, state grants, and inspection and permit fees.

While several sections of the Clean Water Act provide funding that can be used for municipal storm water control, relatively few federal funds have been directed to these types of projects. The most significant source of funds is the state revolving loan funds administered by states.[37] These revolving loan funds provide loans for eligible storm water control projects. In some cases, nonpoint source projects may also qualify for funding when storm water permits are not required or issued. However, municipal storm water management is generally a low priority in these programs. Specifically, in the year 2000, revolving fund loans were made in the "storm sewers" category in the amount of $38.76 million for 44 different projects. These funds represented less than 1 percent of the amounts loaned from these revolving funds that year. Activities eligible for revolving fund loans include constructing BMPs to control runoff, but support for ongoing operations and maintenance is not eligible. Revolving fund loans can also be used for eligible CSO control projects. In 2000, Clean Water State Revolving Fund Program loans were made in the "CSO Correction" category of a national EPA database in the amount of $411.3 million for 69 different projects and could have been used for CSO or sanitary sewer overflow projects. This amount represented about 9 percent of the funds loaned in 2000.

According to EPA, the agency also issues grants to universities and other research institutions to help implement the storm water program. Some of these grants provide training and guidance to Phase I permittees on watershed protection and the proper selection of BMPs.

Other sources of funding may be available to local governments beginning in 2002. In December 2000, the Congress authorized programs for fiscal years 2002 through 2004 to provide grants to local governments for (1) pilot projects for managing municipal CSOs, sanitary sewer overflows, and storm water discharges on a watershed basis and for testing BMPs and (2) controlling pollutants from MS4s to demonstrate and determine cost-effective, innovative technologies for reducing pollutants from storm water discharge. EPA's proposed budget does not request funds for these programs. In addition, the Congress authorized programs for fiscal years 2002 and 2003 to provide grants to local governments for planning, designing, and constructing treatment works to intercept, transport,

[37]Under the Clean Water State Revolving Fund Program, the federal government provides grants to capitalize states' funds. States provide loans to local governments for wastewater projects.

control, or treat municipal CSOs and sanitary sewer overflows. EPA's proposed budget requested $450 million for this program.

EPA, States, and Local Governments Believe the NPDES Storm Water Program Is Effective, but It Has Not Been Evaluated

EPA, state, and municipal officials generally believe that the NPDES Storm Water Program will improve water quality. These officials believe that the program will result in more bodies of water that meet water quality standards, improved aesthetic conditions, reduced risk from bacterial contamination, and improvements attributable to the discovery and management of pollutants in storm water that otherwise would have gone unnoticed. EPA attempted to put a dollar value on these benefits in its benefit/cost analysis prepared for the Phase II storm water regulations, estimating that such benefits could range from $672 million to $1.1 billion per year (in 1998 dollars).[38]

However, little information is currently available on the benefits of the storm water program or its general effectiveness. There is no doubt that it will take time for the results of the Phase I program to be demonstrated. As EPA notes in its February 2000 report to the Congress, pollution control efforts under water quality management programs produce long-term changes, and the agency expects water quality improvements attributable to the Phase I program to become evident in the future, as the program matures. In this report, EPA concluded that the program has improved storm water management at the local level, improved water quality, and decreased pollutant loads in storm water. However, EPA relied on a survey of only nine Phase I cities in making these conclusions and, therefore, also reported that the agency could not provide national estimates on water quality protection and improvements generated by Phase I of the program. To evaluate the entire program, EPA would have to establish goals for the program that are based on its mission; obtain information about the program's results; compare the results with the goals; and make changes to the program, if warranted, to get closer to achieving the agency's goals.

EPA and the states also have not taken advantage of information that is available to evaluate the program. Each city we visited was regularly monitoring its storm water to establish baseline information on pollutant levels and was reporting this information to EPA or the regulatory state agency each year. Although cities with Phase I permits are required to report on their storm water monitoring results and changes in water

[38] Using another method, EPA estimated the benefits at $1.6 billion per year.

quality, overall, EPA and the states have not successfully developed measurable goals for the program or demonstrated its effectiveness through the review of municipal reports. An EPA official said that some states had requested funding to analyze program data because they did not have the resources to do so, and that EPA had provided the funding in a few cases. EPA also has not established any guidelines for how these data should be reported. Therefore, the reports may be as variable as the cost information we obtained in our five site visits.

EPA has not yet taken any of these data-analysis steps because, according to EPA officials, other program challenges within the Office of Wastewater Management compete with storm water management efforts for priority. For example, EPA officials stressed that available resources within the office must address other significant wet-weather pollution problems, such as CSOs and sanitary sewer overflows, and nonpoint source pollution problems, such as agricultural practices, forestry, and mining. One agency official noted that the highest priority is addressing needs that the agency and local governments have identified for improving wastewater infrastructure, such as sewage treatment facilities. The program also has relatively few staff assigned—about five in the headquarters office and about 10 in the regional offices—for the municipal, industrial, and construction portions of the program. In a program plan recently prepared for the storm water program, EPA estimated that nine to 10 staff would be needed in EPA headquarters to evaluate the program and implement other program requirements.

EPA officials described two efforts that may be the first steps in developing better information about the program. First, EPA intends to issue a grant to the University of Alabama in June 2001 to evaluate monitoring data submitted by a sample of municipalities with Phase I permits. This effort will (1) determine the different types of monitoring being conducted by Phase I municipalities, (2) assess water quality in and around permitted municipalities and determine any correlation between program implementation and impacts on water quality, and (3) recommend approaches for improving the effectiveness of municipal storm water monitoring programs. EPA expects the results of this study in 2003. Second, an EPA official stated that the agency would like to establish a system for analyzing program findings, incorporating necessary changes that are based on these findings, and evaluating the program's effectiveness. The agency plans to implement a pilot project in 2001 in the agency's Atlanta Region IV office for analyzing data reported in annual reports and developing key indicators for the program. If this project is successful and resources are available, the project could be expanded.

Conclusions

EPA regards urban runoff as a significant threat to water quality across the nation and considers it to be one of the most significant reasons that water quality standards are not being met nationwide. Prompted by the Congress, EPA has responded with a variety of programs, including the NPDES Storm Water Program, which requires more than 1,000 local governments to implement storm water management programs. Those municipalities that are currently involved in Phase I of the program have been attempting to reduce pollutants in storm water runoff for several years. It is time to begin evaluating these efforts. However, EPA has not established measurable goals for this program. In addition, the agency has not attempted to evaluate the effectiveness of this program in reducing storm water pollution or to determine its cost. The agency attributes this problem to inconsistent data reporting from permitted municipalities, insufficient staff resources, and other competing priorities within the Office of Wastewater Management. Although Phase I municipalities report monitoring and cost data to EPA or state regulatory agencies annually, these agencies have not reviewed this information to determine whether it can be of use in determining the program's overall effectiveness or cost. Our analysis shows that the reported cost information will be difficult to analyze unless EPA and its state partners set guidelines designed to elicit more standardized reporting. Better data on costs and program effectiveness are needed—especially in light of the Phase II program that will involve thousands more municipalities in 2003. EPA's planned research grant to the University of Alabama and its pilot project in the agency's Region IV to analyze data from annual reports and develop baseline indicators is a step in the right direction and could point the way for a more comprehensive approach.

Recommendation

To determine the extent to which activities undertaken through the NPDES Storm Water Program are reducing pollutants in urban runoff and improving water quality, and the costs of this program to local governments, we recommend that the Administrator, EPA, direct the Assistant Administrator for the Office of Water to

- establish measurable goals for the program;

- establish guidelines for obtaining consistent and reliable data from local governments with Phase I permits, including data on the effects of the program and the costs to these governments;
- review the data submitted by these permittees to determine whether program goals are being met and to identify the costs of the program; and
- assess whether the agency has allocated sufficient resources to oversee and monitor the program.

Agency Comments and Our Evaluation

We provided a draft of this report to EPA and DOT for their review and comment. EPA generally agreed with the report and with the recommendation, although it did not explicitly comment on all parts of it. (EPA's comments appear in app. VI.) In response to our recommendation that EPA set measurable goals for the storm water program, EPA stated that under the second phase of the program, local governments will establish their own goals. Although this is an important activity, EPA will have difficulty evaluating the program's effectiveness at a national level without setting goals that reflect the program's mission of improving water quality. The agency (1) agreed that it should establish guidelines for obtaining consistent and reliable data from local governments about their programs and (2) plans to award grants to two universities for reviews of monitoring data reported by local governments. EPA did not comment on whether local governments should report on the costs of their programs. EPA also agreed that it and its state partners should review data reported by local governments to determine whether the program's goals are being met. In April 2001, EPA officials told us that the agency planned to undertake a project in the Region IV (Atlanta) office to evaluate the methods local governments are using to control storm water. EPA's letter indicates that the agency now plans to implement this project in three regional offices and 10 states. EPA did not comment on the part of our recommendation that the agency review the level of resources devoted to overseeing and monitoring the program. EPA also provided technical comments that we incorporated where appropriate.

DOT generally agreed with the draft report and provided technical comments that we incorporated where appropriate. In particular, DOT suggested that we revise several references in the draft report to paved surface area and its relationship to increases in urban runoff, to emphasize that impervious surfaces, of which paved surfaces are a significant subset, cause increases in runoff. We revised the language in these places.

As agreed with your offices, unless you publicly announce its contents earlier, we plan no further distribution of this report until 7 days after the date of this report. At that time, we will send copies of this report to the Administrator, Environmental Protection Agency, and the Secretary of Transportation. We will make copies available to others on request. If you or your staff have any questions about this report, please call me at (202) 512-2834. Key contributors to this report are listed in appendix VII.

Peter F. Guerrero
Director, Physical Infrastructure Issues

The Storm Water Program in Baltimore City, Maryland

Baltimore City's municipal separate storm sewer system (MS4) is regulated by the Maryland Department of Environment (MDE) and, according to a city official, services the entire city. The city is currently implementing its second, 5-year National Pollutant Discharge Elimination System (NPDES) permit, issued on February 8, 1999. Before obtaining the first NPDES storm water permit in 1993, Baltimore City addressed the adverse affects of storm water runoff by implementing Maryland's Storm Water Management Program and Erosion and Sediment Control Program. According to the 2000 census, Baltimore City's population is about 651,000.

Urban Runoff Problems in Baltimore City

Baltimore City's urban runoff discharges to four major areas—Gwynns Falls, Jones Falls, Herring Run, and the Patapsco River—and then ultimately to the Chesapeake Bay. In 1990, the Environmental Protection Agency's (EPA) 319(a) report[1] implicated urban runoff as the main source of pollution in these waters. Moreover, Baltimore City was one of the areas studied in EPA's Nationwide Urban Runoff Program in the 1980s. This study reported that urban runoff contributed over 60 percent of the total nitrogen, phosphorus, and organic carbon; over 70 percent of the chemical oxygen demand; and over 80 percent of the total suspended solids, lead, and zinc in local water bodies.

An MDE official told us that nutrients, zinc, and suspended solids are among the constituents most commonly found in urban runoff, but the quantitative contribution to water quality impairment in the state's waters was not known. Also, in 1996, the Chesapeake Executive Council designated the Baltimore Harbor as one of three toxic regions of concern in the Chesapeake Bay. The harbor suffers from sediment contaminated by banned substances (such as the termiticide chlordane) and contaminants currently being released (such as metals and organics). Furthermore, according to the Chesapeake Bay Program Office, data collected from Phase I permittees indicate that storm water runoff can be a significant source of metals and organics in the harbor.

A Baltimore City official told us that some portions of Maryland's waters are impaired because of unacceptable levels of nutrients, metals,

[1]Section 319(a) of the Clean Water Act requires, among other things, that states identify and report to EPA the navigable waters that cannot reasonably be expected to maintain water quality standards (e.g., established water body uses) without additional action to control nonpoint source pollution.

suspended sediments, and chlordane. Moreover, this official noted that the state does not consider data that municipalities collect under their NPDES storm water permits during the 303(d) listing process. Therefore, he believes that streams in Maryland are much more impaired than indicated by the listing process.

Baltimore City's Use of Best Management Practices

Like other NPDES storm water permit holders, Baltimore City uses a variety of best management practices (BMP) to reduce the amount of pollutants in runoff to the maximum extent practicable. These BMPs include detention ponds, shallow marshes (which use the biological and naturally occurring chemical processes in water and plants to remove pollutants), sand filter devices, public education programs, and the identification of illicit discharges to the MS4 system. Furthermore, Baltimore City participates in Maryland's effort to reduce nutrient levels in the Chesapeake Bay. Refer to the section of this report describing local government efforts to manage storm water for details concerning this nutrient-reduction goal. One other BMP includes the following:

- Baltimore City has incorporated the *2000 Maryland Storm Water Design Manual's* management policies, principles, methods, and practices into its current NPDES storm water discharge permit. The purpose of the design manual is to (1) protect the waters of the state from the adverse effects of urban storm water runoff; (2) provide design guidance on the most effective structural and nonstructural BMPs for development sites; and (3) improve the quality of BMPs that are constructed in the state, with particular attention to their performance, longevity, safety, ease of maintenance, community acceptance, and environmental benefit.

Costs Associated With Managing Storm Water

We were not able to obtain comprehensive information on the total cost to Baltimore City of managing storm water. Therefore, we do not present that information here.

Funding Sources

Baltimore City funds its storm water management control efforts with city water and sewer user fees and with state funds.

The Storm Water Program in Boston, Massachusetts

The Boston Water and Sewer Commission received a NPDES storm water permit in October 1999. The commission is a separate entity from the city of Boston and, therefore, does not manage some storm water controls that are common in Phase I permits, such as street sweeping, winter deicing, and many of the urban runoff controls required for new developments. Boston has combined sewer systems as well as separate sanitary sewers and storm drains. The commission maintains 206 storm water outfalls and serves approximately 33 percent of the city through its separate MS4 system. In addition to the resident population of about 589,000, this system also almost daily serves 340,000 commuting workers; 70,000 shoppers, tourists, and business people; and 75,000 commuting students. The commission's sanitary and combined flows are transported to the Massachusetts Water Resources Authority at Deer Island. The commission is also the permittee for EPA's Combined Sewer Overflow Program.

Urban Runoff Problems in Boston

The commission considers the identification and elimination of illegal sanitary sewer connections as the most effective means of improving water quality and protecting public health. It is also concerned with the washoff of animal wastes from residential and open land, which is another major contributor to the impairment of water quality because it can cause an increase in coliform levels in the storm water discharges to the receiving waters.

The commission has contracted for various studies to determine the impact of storm water runoff. The following two studies identified sources of bacterial contamination and characterized the quality of storm water discharged from different types of land uses. The studies included metering storm water flows, collecting and analyzing the storm water and receiving water quality samples, and identifying and remediating illegal sewer connections. Observations from the studies include the following:

- A 1996 study determined that pet waste, rather than sanitary sewage, was a key contributor of bacteria to the storm drain system that had possibly led to beach closings in the area.
- A 1998 study identified several illegal connections to the storm drain system. Furthermore, the study showed that deicing and sanding efforts resulted in levels of sodium, chloride, total dissolved solids, and cyanide that exceeded EPA's acute (high dose) toxicity levels.

Boston's Use of Best Management Practices

To meet the NPDES permit's requirements, the commission, like other permittees, continued BMPs, such as identifying illegal connections, and implemented new BMPs aimed at preventing the discharge of pollutants to storm drains and receiving waters. Refer to the section of this report describing local government efforts to manage storm water for details describing the commission's citywide catch-basin inspection cleaning and preventative maintenance program. Other efforts include the following:

- The commission has placed particle separators, which remove oil, grease, and sediments from storm water flows, throughout the city. The commission requires particle separators to be installed by developers on all newly constructed storm drains that serve outdoor parking areas. Fuel-dispensing areas not covered by a canopy or other type of roof enclosure must also have a particle separator.
- The commission requires developers to consider on-site retention of storm water for all new projects, wherever feasible. On-site retention aids in controlling the rate, volume, and quality of storm water discharged to the commission's storm drainage system.

Costs Associated With Managing Storm Water

We were not able to obtain comprehensive information on the total cost to the commission of managing storm water because the commission does not separate the cost of its storm water program from the cost of its sewer operations. Therefore, we do not present that information here.

Funding Sources

The commission funds its storm water management control efforts primarily with city water and sewer user fees and bond proceeds.

The Storm Water Program in Los Angeles County, California

Under the NPDES Storm Water Program, the Los Angeles Regional Water Quality Control Board issues 5-year permits to Los Angeles County for its municipal storm water program. The Los Angeles County permit, issued in July 1996, is the county's second storm water permit. This permit includes Los Angeles County as the principal permittee and 85 cities as permittees. According to the 2000 census, Los Angeles County's population is about 9.5 million.

Urban Runoff Problems in Los Angeles County

The effects of urban runoff on the ocean are of particular concern in southern California. Contaminated sediments, impaired natural resources, and potential human illness could threaten the county's tourism economy, estimated to be about $2 billion a year.

The following three studies have shown that urban runoff can pose health risks to swimmers near storm drains and contribute toxic metals to receiving water sediments:

- The Santa Monica Bay Restoration Project conducted a study to assess the possible adverse health effects of swimming in waters contaminated by urban runoff.[1] This study revealed that there is an increased risk of illness associated with swimming near flowing storm drain outlets and an increased risk of illness associated with swimming in areas with high concentrations of bacteria indicators. Furthermore, illnesses were reported more frequently on days when the samples were positive for enteric viruses. Refer to the section of this report describing the effects of runoff on aquatic life and human health for more details.
- The Southern California Coastal Water Research Project coordinated a study that assessed microbiological water quality and found that the majority of shoreline waters exceeded water quality standards during wet-weather conditions. Furthermore, the ocean waters near storm water outlets demonstrated the worst water quality regardless of the weather.[2]
- The Southern California Coastal Water Research Project also compared the runoff from an urban area and a nonurban area in the Santa Monica

[1]R.W. Haile and others, "The Health Effects of Swimming in Ocean Water Contaminated by Storm Drain Runoff," *Epidemiology,* July 1999, Vol. 10, No. 4.

[2]Southern California Coastal Water Research Project, *Southern California Bight 1998 Regional Monitoring Program, Volume 3: Storm Event Shoreline Microbiology,* 2000.

Bay Watershed.[3] The results of the study indicated that storm water plumes extended up to several miles offshore and persisted for a few days. Furthermore, the runoff from the urban area proved to be toxic to sea urchin fertilization, and dissolved zinc and copper were determined to be contributors to the toxicity. The study also found that in urban areas, sediments offshore generally had higher concentrations of contaminants such as lead and zinc.

Los Angeles County's Use of Best Management Practices

As in the other sites we visited, the county is managing its runoff through the use of conventional BMPs. These BMPs include the elimination of illicit connections and discharges to the storm sewer system, construction control measures, routine inspections, staff training, pollution prevention plans for public vehicle maintenance and material storage facilities, sweeping and cleaning public parking facilities, street sweeping, catch-basin cleaning, and public education.

The Los Angeles Regional Water Quality Control Board recently adopted a Total Maximum Daily Load (TMDL) Program to reduce trash loads to the Los Angeles River. As a result, the county is exploring a number of trash reduction BMPs, which are discussed in the section of this report describing local government efforts to manage storm water.

Costs Associated With Managing Storm Water

Table 3 indicates that the county and the other permittees have allocated significant funding for storm water management activities over the years. For example, for fiscal year 1999,[4] projected funding for storm water management activities for the county and the other permittees amounted to over $134 million.[5] The largest projections for both went toward public agency activities. For example, during fiscal year 1999, the principal permittee and the permittees together projected almost 67 percent of storm water management funds to public agency activities. The activities in this

[3]Southern California Coastal Water Research Project, *Study of the Impact of Stormwater Discharge on Santa Monica Bay–Executive Summary,* Nov. 1, 1999.

[4]The county's fiscal year begins July 1 and ends June 30.

[5]According to an official with the Los Angeles Regional Water Quality Control Board, this figure may also include activities that are outside the scope of the permit.

program include staff training, inspections of construction projects, street sweeping, and catch-basin cleaning.

Table 3: Summary of Fiscal Resources Projected for Los Angeles County and Its Co-permittees, Fiscal Years 1997-99

(Dollars in thousands)[a]

	Fiscal year 1997		Fiscal year 1998		Fiscal year 1999	
Activity	**County**	**Others[b]**	**County**	**Others[b]**	**County**	**Others**
Program Management	$2,225	$6,195	$1,856	$4,874	$1,466	$6,187
Illicit Connection, Illicit Discharge Program	1,620	3,515	1,017	3,075	764	2,901
Development planning and construction	784	6,208	1,300	3,769	1,452	5,743
Public agency activities	38,544	40,915	40,256	31,992	43,316	46,657
Public information and participation	2,840	5,538	4,360	3,856	4,629	6,177
Monitoring	2,018	619	1,768	729	1,598	737
Other	187	13,991	490	8,656	1,318	11,834
Total	**$48,218**	**$76,981**	**$51,048**	**$56,950**	**$54,543**	**$80,237**

[a]Totals may not add up because of rounding.

[b]Does not include 17 permittees for fiscal year 1998 and 13 permittees for fiscal year 1997 for the following reasons: The permittee operated on a different budget cycle, the final document was not available at the time of the annual report, or the information submitted by the permittee was not complete.

Source: GAO's analysis of cost data provided by the Los Angeles County Department of Public Works.

As shown in table 3, the county maintains primary responsibility for monitoring activities, having projected over $2 million for storm water monitoring activities in fiscal year 1997, almost $2 million in fiscal year 1998, and over $1.5 million in fiscal year 1999. Conversely, the permittees' projected funding levels for monitoring activities amounted to only $619,000 in fiscal year 1997, $729,000 in fiscal year 1998, and $737,000 in fiscal year 1999. According to an official with the Los Angeles Regional Water Quality Control Board, the County has consistently maintained primary responsibility for monitoring activities required under the permit.

Funding Sources

The primary source of funds for the county's storm water program is flood control assessments collected throughout the district. Although the county has not applied for any state revolving funds, it has applied for and received approval for federal funds through the Transportation Equity Act for the 21st Century (TEA-21) for a pilot study of an engineering device that would remove trash from storm water. Additionally, the county has received partial funding through Proposition A of the Safe Neighborhood Parks of 1992 and 1996[6] for two Vortex Separation Systems—a Continuous Deflective Separation unit and a Stormceptor unit. Additionally, the county received grant money from the Metropolitan Transit Authority, which partially funded catch-basin screens, a Continuous Deflective Separation unit, and 120 catch-basin inserts.[7]

[6]The Los Angeles County Regional Park and Open Spaces District (a district within the Parks Department) received this funding from Proposition A and, in turn, made grants to the Los Angeles County Department of Public Works for the BMP devices.

[7]The Metropolitan Transit Authority receives TEA-21 funds from the California Department of Transportation.

The Storm Water Program in Milwaukee, Wisconsin

The Wisconsin Department of Natural Resources (WDNR) has the authority to regulate the discharge of storm water from municipalities, construction sites, and industries under Natural Resources Code 216. This rule identifies Wisconsin municipalities that are required to obtain a storm water discharge permit under the Wisconsin Pollutant Discharge Elimination System (WPDES). Milwaukee completed its application process in 1994, and WDNR issued a WPDES permit to the city in October 1994. This was the first municipal storm water permit issued to a municipality in EPA's Region 5 covering the midwest. In July 2000, WDNR reissued Milwaukee's storm water permit. According to the 2000 census, Milwaukee's population is about 597,000.

Urban Runoff Problems in Milwaukee

Milwaukee has a combined sewer system as well as a separate sanitary sewer system. The Milwaukee Metropolitan Sewerage District implemented a rehabilitation program that cost over $2 billion to reduce the number of combined sewer overflow (CSO) events each year. The rehabilitation program involved the construction of deep tunnels to store untreated wastewater and rainwater for later treatment at a wastewater treatment plant. Since 1996, the deep tunnels have significantly reduced the number of overflow events from an average of 50 to 60 per year before the construction to an average of two per year afterwards.

Urban runoff has been identified as a leading source of pollution to the Milwaukee River basin's streams, lakes, and wetlands and the Milwaukee River estuary. To address pollution from urban runoff, WDNR issues storm water permits to municipalities with MS4s serving areas with populations of 100,000 or more, municipalities in Great Lakes "areas of concern" where water quality has been identified as a serious problem, municipalities with populations of 50,000 or more that are located in priority watershed planning areas, and designated municipalities that contribute to the violation of a water-quality standard or are significant contributors of pollutants to state waters.

Milwaukee's Use of Best Management Practices

In addition to BMPs such as the elimination of illicit connections and discharges to the storm sewer system, the reduction of pollutants in storm water runoff from construction sites, public education, catch-basin cleaning, street sweeping, and the use of detention basins, Milwaukee has explored the use of innovative BMPs. Refer to the section of this report describing local government efforts to manage storm water for more details about an educational campaign directed at a specific watershed. Additional BMPs include the following:

- An innovative storm water control device was installed in a parking lot at a heavily used municipal public works yard that was found to discharge significant amounts of storm water pollutants. Termed the Multi-Chambered Treatment Tank (MCTT), this device is suitable for areas with limited space, cleans up polluted runoff close to its source, removes pollutants that are not susceptible to other treatment methods, and is hidden from view. The MCTT consists of a catch basin, a settling chamber, and a filter. Although the results of the monitoring studies have revealed that the device has a positive effect on water quality, officials with the Department of Public Works explained that it is cost-prohibitive and suitable only for sites with limited space.
- The permittee has also been working with WDNR, the Department of Transportation, the U.S. Geological Survey, and a neighborhood association in a joint effort to develop a storm water monitoring assessment program consisting of two innovative storm water treatment devices. One device removes grit, contaminated sediments, heavy metals, and oily floating pollutants from surface runoff. The other device removes a broad range of pollutants from runoff, such as bacteria, heavy metals, nutrients, petroleum hydrocarbons, and suspended solids. The devices are to be installed along a new reach of the Milwaukee Riverwalk through the third ward of Milwaukee.

Costs Associated With Managing Storm Water

Reliable data on the total cost to manage storm water in Milwaukee were not available and cannot be presented here because certain activities are not reported as program costs in the city's annual report. These activities include street sweeping; leaf collection; catch-basin and inlet cleaning; maintenance of public boulevards, parks, and public green spaces; and the recycling of waste oil and antifreeze. Therefore, the program costs reflected in the annual report do not take into account many of the nonstructural BMPs employed by the city nor do the totals include activities funded through grants. The storm water management activities that were included in the city's 2000 budget request were estimated to cost $460,000.

Funding Sources

Milwaukee's storm water program is primarily funded through the city's sewer maintenance fund. Unlike the general revenue account, which is based on property taxes, the sewer maintenance fund is based on water consumption. The city has also received supplemental funding from the Wisconsin Nonpoint Source Water Pollution Abatement Program in the form of WDNR grants. The city has received over $1 million since 1991 for a wide variety of storm water management activities.

The Storm Water Program in Worcester, Massachusetts

Worcester's Department of Public Works (DPW) received a NPDES permit on November 1, 1998. The Sewer Operations Division, within the DPW, is directly responsible for operating and maintaining the city's separate storm sewer system, along with the sanitary and combined sewer system. Since 1993, the Sewer Operations Division has had a full-time storm water coordinator, reflecting Worcester's increased emphasis on meeting NPDES program requirements. Worcester has a population of about 173,000. Its water system covers an extensive area, including 371 miles of sanitary sewers, 340 miles of storm sewers, 56 miles of combined sewers, 27,000 manholes, over 14,000 catch basins, and 263 outfalls. Worcester's separate storm drain systems consist of 93 main drainage areas covering approximately 6,680 acres.

Urban Runoff Problems in Worcester

The constituents that are typically found in urban runoff in Worcester are the same as those normally found in urban runoff in older cities. Because virtually all of the paved surfaces in the Worcester area are devoted to the city's transportation infrastructure, the constituents generated include automobile-related petroleum products, such as total petroleum hydrocarbons, oil and grease, along with total suspended solids. Also, coliform, silt, and sediment have been identified in the city's runoff.

Worcester's Use of Best Management Practices

Like other permittees, the DPW has implemented BMPs under the major areas of education outreach, pollution prevention and source controls, storm-drainage system maintenance, regulatory efforts, and storm-drainage system infrastructure. Additionally, to reduce storm water pollution, the DPW has retrofitted a number of twin manholes in the city as discussed below. BMPs that are specific to Worcester include the following:

- The DPW implemented a demonstration project to determine the effectiveness of an oil and grit separator installed on a street drain. The drain is a major surface sewer main that services approximately 226 acres of heavily urbanized area with a typical mix of residential, commercial, and industrial use. The drain discharges into Lake Quinsigamond, which is a large lake used for recreational purposes such as swimming and boating. In its April 2000 annual plan submitted to EPA, the DPW noted that because of drought conditions, it currently did not have sufficient sampling data to determine the effectiveness of the project.

- The DPW has embarked on a comprehensive program to minimize the possibility that sewage and storm water will be mixed in its twin invert manholes. Since the program began, the DPW has installed hold-down devices on over 1,680 of the approximately 2,580 twin invert manholes in the city. The DPW expects to continue the program until all of the manholes have been retrofitted.
- The DPW is also working closely with the Massachusetts Department of Environmental Protection in its ongoing tracking efforts to ensure that industries in Worcester are doing their part to reduce storm water pollution.
- To improve its storm-drainage infrastructure, the city has established a voluntary plan to reduce the number of unpaved private roads. The dirt from these roads, especially after rain storms, causes sediment to build up in the drainage system. The DPW has developed a plan to pave the streets at a lower grade than would be necessary to meet the legal requirements for a public street. Under this plan, residents would not have to pay the additional betterment taxes that are now required to cover the costs of sediment removal and less sediment would be transported in runoff.

Costs Associated With Managing Storm Water

Since 1993, the DPW has allocated significant funding from the water and sewer utility fees it collects for controlling the effects of runoff, especially through catch-basin cleaning, street sweeping, and correcting illegal connections. For example, its fiscal year 1993 budget for storm water programs included about $1.6 million for specific programs and another $1 million for capital improvement programs, such as inflow/infiltration and flood control. The DPW also spent $500,000 to develop and submit its permit application. Furthermore, as shown in table 4, Worcester made extensive capital expenditures during fiscal years 1994 through 1999 on pertinent storm water projects to improve the quality of storm water runoff emanating from the city's storm water sewer system.

Table 4: City of Worcester's Capital Expenditures for Storm Water Management

(Dollars in thousands)

	Fiscal year					
Activity	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Sewer construction	$0	$500	$500	$300	$300	$300
Infiltration control	0	400	400	100	100	100
Pump station rehabilitation	200	200	200	200	200	200
Sewer rehabilitation	300	750	300	750	750	1,500
Landfill closeout	150	1,200	200	500	0	0
Belmont Drainage project	0	100	600	100	0	0
Beaver Brook Culvert project	0	500	100	100	300	100
Surface drain control	40	150	200	200	200	200
Geographic Information System	0	0	0	125	125	125
Other	0	70	10	0	0	0
Total	**$690**	**$3,870**	**$2,510**	**$2,375**	**$1,975**	**$2,525**

Note: The Belmont Drainage project involved enlarging the drain to eliminate surcharging and siltation and moving the outfall to eliminate stagnation. The Beaver Brook Culvert project involved repairing the culvert and conducting a study that included a detailed hydraulic analysis of the drainage basin.

Source: Worcester Department of Public Works.

Furthermore, during fiscal year 1999, the DPW spent approximately another $2.1 million to operate and maintain storm water activities. Key expenditures included about $1.2 million for street sweeping, about $617,000 for catch-basin maintenance, $52,000 for root control, and another $48,000 for street paving. Also included was $40,000 per year for sampling five outfalls around the city three times per year as required by the permit. According to a DPW official, in previous fiscal years, the DPW funded the same or similar operation and maintenance activities to help control storm water runoff. As a result, the costs since 1994 were similar to those for 1999, except for annual adjustments for inflation. Therefore, the annual operation and maintenance expenditures ranged from about $1.7 million for 1994 to about $2.1 million for 1999.

According to a DPW official, the department expects to spend from $3 million to $4.5 million annually over the next several years on storm water-related activities. The amount of the cost increase will depend on whether EPA asks the city to increase its spending.

Funding Sources

The DPW funds its storm water management controls effort from the water and sewer user fees it assesses to homes and businesses.

Comments From the Environmental Protection Agency

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 14 2001

OFFICE OF WATER

Mr. Peter F. Guerrero
Director, Physical Infrastructure Issues
United States General Accounting Office
Washington, DC 20548

Dear Mr. Guerrero:

Thank you for the opportunity to review your draft report entitled "Better Data and Evaluation of Urban Runoff Needed to Assess Effectiveness." We appreciate the difficulty that assimilating and interpreting such information on an extremely complex subject must have presented. Your report provides a fair and balanced depiction of the Agency's efforts, with the assistance of our State and local partners, to implement a national urban storm water runoff control program.

As the report correctly acknowledges, the Environmental Protection Agency (EPA) believes that urban runoff is a significant threat to water quality and is actively working to control the discharge of pollutants in storm water runoff. EPA's urban storm water control program has been a very successful undertaking to date and we are taking steps to address several of the recommendations identified in the report.

One of the challenges of controlling urban storm water runoff is to be able to address a wide array of complex environmental issues, even within the boundaries of one municipality. EPA's urban storm water program is developed with the understanding that a "one size fits all" approach will not work. For example, existing municipal separate storm sewer system (MS4) permits are tailored to suit the needs of each individual municipality. In fact, the municipalities select the majority of the measures that will be implemented to control storm water runoff. Similarly, EPA's Phase II regulatory framework for small MS4s requires the municipality to identify appropriate BMPs to control runoff and establish measurable goals against which program effectiveness will be measured. These BMPs and measurable goals then become the enforceable permit conditions for that municipality. EPA expects that approximately 5,000 small MS4s will each have a unique set of measurable goals that will define expectations of a successful storm water control program.

While EPA has developed a sound regulatory basis for urban storm water control, competing initiatives have limited our ability to invest sufficient resources to fully evaluate the effectiveness of the program and the associated implementation costs. We believe that the flexibility afforded MS4 permittees provides some assurance that permit requirements do not become onerous or unjustified. Additionally, with the MS4 permits reissued every five years,

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EPA expects that dialogue between MS4s and permitting authorities will better focus on those activities found to be most beneficial.

Over the next year, we will address challenges relating to evaluating the effectiveness of municipal storm water programs. Consistent with the first recommendation, EPA will evaluate storm water monitoring data that has been collected since program inception. Two grantees (UCLA and the University of Alabama) will review monitoring data that has been submitted as part of routine discharge monitoring reports and annual reports. EPA expects these efforts will evaluate the correlation between storm water discharges and trends in water quality impairment. Another anticipated finding from these grants is a compilation of the range of monitoring activities required of municipalities in storm water permits and the identification of the monitoring that appears to be most effective in demonstrating program results.

To meet another challenge, we are evaluating MS4 permit requirements and annual reports to identify the types of storm water control activities in place and the environmental and programmatic results of these activities. Initially, this effort will evaluate MS4s in at least three EPA Regions and 10 states to gather information on the range of methods employed by permitted MS4s to control storm water discharges. Through this effort, EPA expects to determine whether program goals are being met and establish meaningful indicators of program performance. Should this effort prove useful, EPA will expand the evaluation to a national effort that will evaluate MS4 permits and annual reports in all affected EPA Regions and states. In either case, results of this effort will be disseminated nationally to ensure that findings are incorporated into other MS4 programs, as appropriate.

Enclosed are additional comments on terminology and regulatory citations provided in the report. Again, we appreciate the opportunity to review and comment on the draft report. If you have any questions about these comments or would like to discuss urban storm water runoff issues, please contact me or call Jeff Lape, Acting Director of the Water Permits Division, at (202) 564-9545.

Sincerely,

Michael Cook

Michael B. Cook
Director
Office of Wastewater Management

Enclosure

Enclosure

Below are several additional comments for your consideration that address terminology and regulatory citations provided in the report:

- The term "nonpoint source" throughout the report, when referring to storm water runoff, is somewhat misleading in that the federal definition of "point source" includes many of the types of storm water discharges discussed in the draft report as "nonpoint source pollution." We recommend clarifying that EPA's NPDES storm water permits regulate point source discharges that includes storm water runoff from small, medium, and large municipal separate storm sewer systems. In fact, to avoid confusion between point sources and nonpoint sources in an NPDES context, we recommend that you consider using the term "wet weather discharges" when referring to storm water runoff.

- The third sentence in the first full paragraph on page 3 states that "EPA requires cities to use 'best management practices' to reduce contamination in storm water runoff." We recommend that you change the word "requires" to "recommends." While best management practices are common for reducing storm water contamination, EPA regulations allow MS4s to reduce the discharge of pollutants to the maximum extent practicable using management practices, control techniques, and system, design, and engineering methods, and such other provisions which are appropriate.

- The last sentence in the second full paragraph on page 3 states that "managing storm water runoff will reduce runoff and improve water quality." We recommend changing this sentence to indicate that "managing storm water runoff will reduce the volume and concentration of pollutants in runoff and improve water quality.

- The last sentence of the same paragraph indicates that "Neither EPA nor states have developed measurable program goals or reviewed municipal reports on the results of storm water programs to determined whether the reports provide information that could demonstrate the program's effectiveness." A similar statement is made in the first full paragraph on page 31. We recommend that these two sentences be revised to indicate that "EPA and states have generally been unsuccessful in developing measurable program goals and in demonstrating program effectiveness through the review of municipal reports." EPA and some states have attempted to determine program effectiveness through the review of municipal reports but, to date, these efforts have been unsuccessful in making this determination.

GAO Contacts and Staff Acknowledgments

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Staff Acknowledgments

In addition to those named above, Jennifer Clayborne, Richard LaMore, Sally Coburn, Elizabeth McNally, Charles Bausell, and Timothy Guinane made key contributions to this report.

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Effects of Lawn Fertilizer on Nutrient Concentration in Runoff from Lakeshore Lawns, Lauderdale Lakes, Wisconsin

Introduction

Transport of nutrients (primarily forms of nitrogen and phosphorus) to lakes and resulting accelerated eutrophication are serious concerns for planners and managers of lakes in urban and developing suburban areas of the country. Runoff from urban land surfaces such as streets, lawns, and rooftops has been noted to contain high concentrations of nutrients; lawns and streets were the largest sources of phosphorus in residential areas (Waschbusch, Selbig and Bannerman, 1999). The cumulative contribution from many lawns to the amount of nutrients in lakes is not well understood and potentially could be a large part of the total nutrient contribution.

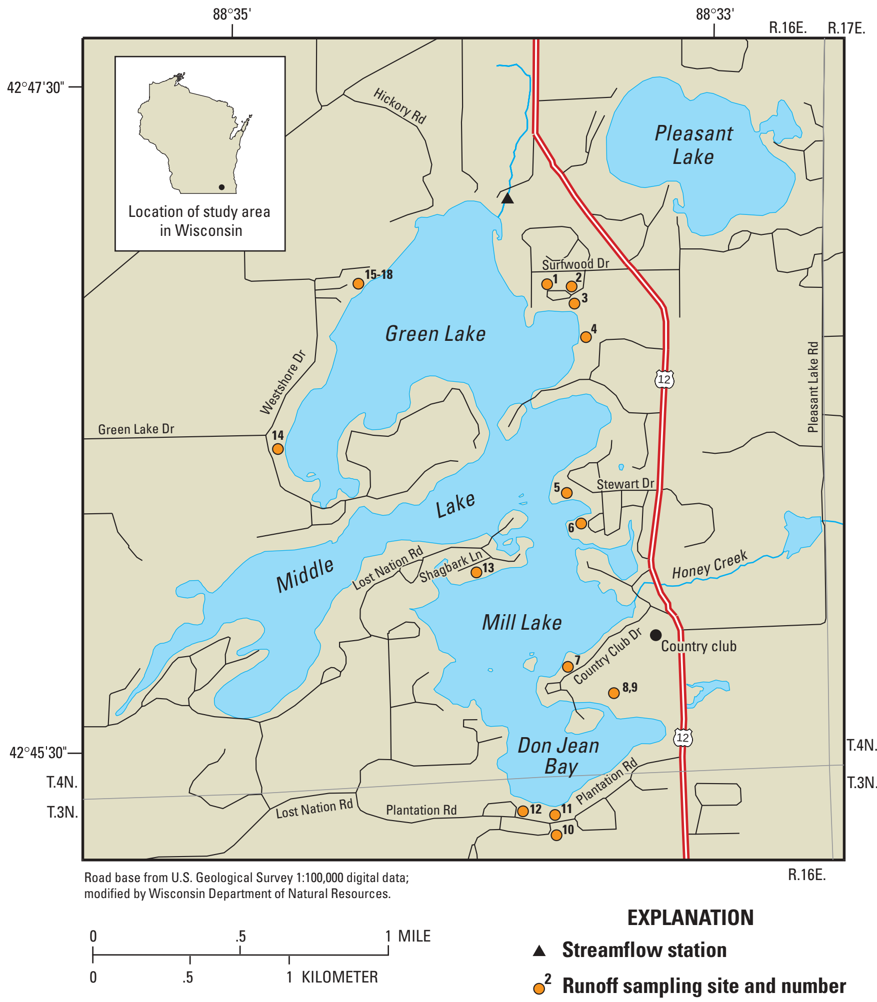

Figure 1. Site locations surrounding Lauderdale Lakes, Wis.

Why study runoff from lawns?

The shorelines of many lakes are already highly developed, and the potential water-quality effects of this development are increasing. Many lawn-care professionals and homeowners hold a common belief that runoff from lawn surfaces is minimal and that phosphorus movement from lawns is not a problem (Barth, 1995). The homeowners' goal to maintain lush green lawns may conflict with the lake manager's goal to minimize nutrient inputs. In cooperation with the Lauderdale Lakes Lake Management District and the Wisconsin Department of Natural Resources, the U.S. Geological Survey (USGS) conducted a study during 1999–2000 to determine the magnitude of nutrient runoff from nearshore residential lawns surrounding a lake and to determine whether fertilizer application and the type of fertilizer (regular or nonphosphorus types) affect the amount of nutrients in runoff from lawns. Such information is important for developing stormwater best-management practices and for developing or improving shoreland zoning ordinances and other local regulations to protect or improve the water quality of lakes (Wisconsin Department of Natural Resources, Wisconsin Shoreland Management Program, http://www.dnr.state.wi.us/org/water/wm/dsfm/shore/title.htm, accessed February 8, 2002).

The study area was located at Lauderdale Lakes in Walworth County, a chain of lakes in the more populated southeastern part of Wisconsin (fig. 1). The 15-mile shoreline of the lakes is about 70 percent developed, primarily as single-family housing, and is the focus for additional residential development. Most of the lakefront homes have sloping lawns that are maintained to the water's edge (fig. 2). Information about the specific sources and amounts of phosphorus entering the lakes was needed to develop a plan for reducing the input of phosphorus. The lakes are phosphorus limited, meaning that phosphorus is the nutrient limiting plant growth and affecting lake productivity. A previous study (Garn and others, 1996) found that surface-water inflow from the small nearshore contributing drainage area accounted for only 4 percent of the water inflow to the lake but represented 51 percent of the total annual phosphorus input from all sources. The Lake Management District is in the process of installing

Figure 2. Lakeshore development and lawns at Lauderdale Lakes, Wis.

Figure 3. Tube-type lawn sampler (site 2).

and implementing various measures to reduce the phosphorus input to the lakes, among which is a “lake-friendly” fertilizer program that encourages residents to apply nonphosphorus turf fertilizer. The Lake Management District has been supplying residents with phosphorus-free fertilizer for purchase for about 3 years, and data were needed to evaluate the effectiveness of the program.

Equipment and Methods

In 1999 and spring 2000, lawn samplers designed to collect surface runoff were installed using methods described in Waschbusch, Selbig, and Bannerman (1999, p. 7). The samplers collect runoff through two 5-foot pieces of 1/2-inch-diameter PVC tubing placed flush with the surface of the ground, on a sloping lawn, with an angle of about 150 degrees between the two tubes (fig. 3). Runoff entered the tubing through a 1/8-inch slot cut at intervals along the length of the tube; each tube was then wrapped with fiberglass screen to prevent insects and large debris from entering. The tube was held in place on the lawn surface with wire staples. At the end of each tube, a connecting piece of 1/2-inch silicone tubing directed the collected runoff into a covered 1-quart glass jar placed in the ground in a 4-inch-diameter protective PVC sleeve with a cover.

During the summer of 2000, the original sampler design was modified to increase sample volumes at sites that did not generate sufficient runoff samples and to minimize contamination problems caused by insects and earthworms entering the samples despite the fiberglass screen. One variation to increase runoff-collection efficiency was to enlarge the slots cut in the pipes to 1/4-inch. Another technique used at sites with the least runoff production was to replace the tubing with two lengths of 4-foot-long plastic lawn edging that directed runoff toward the collecting jar (fig. 4); this solution was more effective at increasing captured runoff and minimizing contamination than increasing the slot size.

Clean sample bottles were placed in the lawn samplers before each expected storm or at about 2-week intervals when sites were inspected if there was no rain. Samplers were cleaned and rinsed with deionized water during each visit to remove any accumulated dirt or debris. Notes were kept on volume of runoff in the collection bottle; color and noticeable sediment, debris, or insects in the bottle; and site condition. Sample bottles were collected as soon as possible after each storm (usually within 1 to 5 days) and brought to Madison, where the contents were filtered with a 0.45-micrometer filter, preserved with sulfuric acid, and then delivered to the Wisconsin State Laboratory of Hygiene for nutrient analyses. Samples were analyzed according to standard laboratory methods (Wisconsin State Laboratory of Hygiene, written commun., 2001) for concentrations of total phosphorus (TP), total dissolved phosphorus, total Kjeldahl nitrogen (TKN), dissolved ammonia nitrogen, and dissolved nitrate plus nitrite nitrogen. When insufficient sample volume was collected from a storm to analyze for all nutrients, analyses were done first for total phosphorus.

Figure 4. Edging-type lawn sampler (site 5).

Description of Sampling Sites

The Lauderdale Lakes are a chain of three interconnected lakes with a surface area of 807 acres. The lakes are ground-water drainage lakes in which more than 90 percent of the water inflows are from ground water and direct precipitation. Some surface water enters the lakes by way of a few ephemeral drainageways or as overland flow from the nearshore area. Lake and drainage-basin characteristics are described in detail by Garn and others (1996). Lakeshore developments include about 1,010 single-family homes, of which about 30 percent are year-round residences. Other developments include a golf course, a boat marina, and two recreational camps.

In the lakeshore area within 300 feet of the shoreline, soils consist primarily of the Casco-Rodman Complex (60 percent of the area), Rodman-Casco Complex (12 percent of the area), and Casco-Fox Silt Loam (6 percent of the area). The Casco-Rodman Complex is found on 20–30 percent slopes; surface textures range from loam to silt loam, and subsoils are clay loam to sandy loam. The Rodman-Casco Complex is found on slopes of 30 to 45 percent formed in loamy deposits over sand and gravel. The Casco-Fox soils are found on slopes of 6 to 12 percent and have a silt loam texture (Haszel, 1971). Soil disturbance can be severe during building construction in suburban areas, commonly resulting in subsoil compaction by heavy equipment followed by layering with topsoil. Such disturbance has the potential for greatly increasing runoff and nutrient losses.

Samplers were installed at 18 locations along the lakeshore (fig.1), representing different types of lawn-fertilizer use, undeveloped areas, and one area of mixed land use (part agricultural, ditched paved roads, and lawns). Sites were grouped into three categories: regular-fertilizer sites, nonphosphorus-fertilizer sites, and unfertilized sites. Samplers were installed at 12 sites and operated during the growing season in 1999. In 2000, six additional sites were installed, including two samplers in a swale. Samplers were installed at seven lawn sites where traditional fertilizer was applied, three sites where nonphosphorus fertilizer was applied, and six control sites where no fertilizer was applied (three steep, wooded sites; two lawns; and an undeveloped grass field). Much of the area is wooded, and many of the lawns have an overhead canopy of hardwood trees. Two samplers were installed in a swale area on the south side of Mill Lake (Don Jean Bay) that collected mixed runoff from an agricultural field, lawns, and streets. The drainage area of the upgradient sampler was 8 acres and of the downgradient sampler was 38 acres, of which about 25 percent was cropland.

Property owners were asked to participate in the runoff study. It was assumed that most lawn fertilizer users followed usual manufacturer recommendations of four applications per season made in about April–May, June–July, August–September, and October at 3 to 3.5 pounds per 1,000 square feet. Homeowners applying regular fertilizer fertilized their lawns two or more times per year. Each participant’s property was inspected to ensure that lawn slope was at least 20 feet long, grade was at

Table 1. Physical characteristics of sampling sites at Lauderdale Lakes, Wis. [P, phosphorus; ppm, parts per million; %, percent, turf-quality values are defined in text; ft^2, square feet; --, no data]

Site ID	Station number	Site type	Soil type/texture[a]	Soil P concentration[b] (ppm)	Slope (%)	Vegetative cover density (%)	Turf quality	Runoff area (ft^2)	Number of samples	Percentage of storm events
Regular fertilizer application sites										
2	424652088333901	Wooded lawn	Hebron loam, gravelly	68	21	65	6	150	10	67
3	424650088333501	Lawn	Hebron loam	32	9	90	8.5	180	8	80
5	424616088334201	Wooded lawn	Casco-Rodman loam-silt loam	66	20	100	9	114	8	33
8	424541088334602	Golf course lawn	Casco-Rodman loam-silt loam	35	20	100	9.5	250	15	63
9	424541088334601	Golf course lawn	Casco-Rodman loam-silt loam	78	24	100	9.5	186	9	54
10	424514088334001	Swale	Casco-Fox silt loam	--	5	--	--	8 acres	9	69
11	424518088334301	Swale	Casco-Fox silt loam	--	4	--	--	38 acres	10	77
12	424519088334101	Lawn	Casco-Fox silt loam	28	16	100	10	104	1	8
15	424654088343103	Lawn	Fox silt loam	11	11	60	6	152	5	24
Nonphosphorus-fertilizer application sites										
6	424611088334001	Wooded lawn	Casco-Rodman loam-silt loam	20	14	80	7.5	250	18	67
13	424603088340201	Wooded lawn	Casco-Rodman loam-silt loam	21	34	60	5	140	15	54
14	424623088345101	Wooded lawn	Casco-Rodman loam-silt loam	70	14	85	8	225	8	30
Unfertilized sites										
1	424652088334401	Grass field	Fox sandy loam	65	9	100	7	128	2	13
4	424643088333601	Wooded lawn	Casco-Rodman loam-silt loam	38	12	85	8	188	6	47
7	424543088334001	Wooded lawn	Casco-Rodman loam-silt loam	14	22	70	6	209	12	46
16	424654088343101	Wooded	Rodman-Casco loam/sand,gravel	28	41	95	1	200	9	33
17	424654088343102	Wooded	Rodman-Casco loam/sand,gravel	24	33	95	1	300	13	48
18	424654088343104	Wooded	Rodman-Casco sandy, gravelly	16	30	65	2	140	7	28

[a]From Haszel, 1971.

[b]50–75 ppm P optimum recommendation for turfgrass. Analysis by Soil and Plant Laboratory, University of Wisconsin, Madison.

least 5 percent, and sample catchment area was not affected by runoff from rain gutters, driveways, or other lawns or sources. A soil sample collected at the time of sampler installation was analyzed for soil texture, pH, and phosphorus content by the University of Wisconsin Soil and Plant Analysis Laboratory. A visual vegetative soil-cover density, in percent, and a turf-quality rating were assigned to each lawn during visits. Turf quality was based on a 1 to 10 scale: for example, a score of 10 represented 100 percent best-quality green grass cover, 5 represented 50 percent grass cover with bare spots, weeds, and dead grass providing additional cover, and 1 indicated no turfgrass cover, with dead grass, weeds, and other vegetation providing primary soil cover. The more heavily fertilized sites (5, 8, 9, 12) had the best turf-quality ratings. Various physical characteristics of the sampling sites are summarized in table 1.

Nutrient Concentration in Runoff

Rainfall and Runoff

Long-term precipitation records from the National Weather Service stations at Whitewater (about 9 miles northwest of Lauderdale Lakes) and Lake Geneva (about 13 miles southeast) were used to estimate rainfall at Lauderdale Lakes (National Oceanic and Atmospheric Administration, 1999–2000). Data from a recording rain gage at a USGS streamflow-gaging station at Jackson Creek near Elkhorn (9 miles south) was used after the rain gage was installed on May 25, 1999. Rainfall was above the 1961-90 average for April, May, and June 1999 and near or below average the remainder of the season. In 2000, rainfall amounts for May, June, and September were substantially above average (fig. 5). Ten runoff events occurred from 12 storms in the 1999 sampling season and 13 runoff events occurred from 15 storms in 2000; generally, the storms in 2000 were larger than those in 1999. A storm event was defined as more than 0.3 inches of rain, and a runoff event as one that resulted in at least two runoff samples with sufficient volume for analysis (about 100 ml). A summary of the storm dates and precipitation amounts is given in table 2.

Although measurement of quantity of runoff was not part of this study, a qualitative evaluation of runoff may be obtained by comparing the

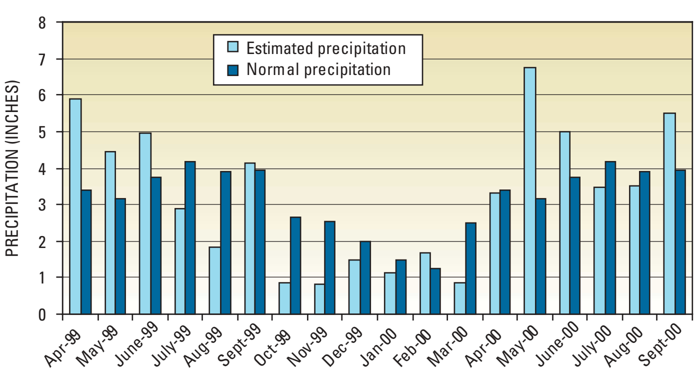

Figure 5. Estimated monthly precipitation at Lauderdale Lakes, Wis., during 1999–2000 compared to normal monthly precipitation.

Table 2. Storm information and number of sites with runoff samples at Lauderdale Lakes, Wis., 1999–2000 [est, estimated]

Storm number	Storm start date	Total precip amount (inches)	Number of sites with runoff samples
99S1	4/9/1999	0.86 [a]	4
99S2	4/22/1999	3.73 [a]	9
99S3	5/12/1999	0.63 [a]	3
99S4	5/16/1999	0.80 [a] est	4
99S5	5/17/1999	0.66 [a] est	3
99S6	6/1/1999	0.70	8
99S7	6/10/1999	3.35	6
99S8	7/17/1999	1.11	4
99S9	8/13/1999	0.37	5
99S10	9/27/1999	3.66	11
00S1	2/21/2000	2.0 [b]	11
00S2	4/19/2000	2.59	2
00S3	5/9/2000	1.36	9
00S4	5/18/2000	1.95	5
00S5	5/27/2000	3.85	14
00S6	6/11/2000	1.95	9
00S7	7/2/2000	1.40	12
00S8	7/10/2000	1.33	5
00S9	7/31/2000	1.62	3
00S10	8/5/2000	1.17	16
00S11	8/17/2000	0.70	5
00S12	9/11/2000	1.94	17
00S13	9/22/2000	1.89	9

[a] Measured at Whitewater.

[b] From 6 inches snowmelt and light rain.

Figure 6. Site 12 at Lauderdale Lakes, Wis.—an example of high-quality turfgrass.

number of sites where runoff was sampled for each storm (table 2) and the number of storms sampled at each site (table 1). The magnitude of runoff is dependent on a combination of factors including rainfall amount and intensity, soil-surface storage and detention, and infiltration rate. Infiltration is affected by soil type, vegetative cover, slope, and other factors (Haan, Barfield, and Hayes, 1994, p. 52–54). In general, sites with dense vegetative cover and coarse soils with high infiltration rates produced less runoff. Specifically, site 12 of the fertilized sites (fig. 6), which had the best-quality turf and fertilizer applications of 4 times per year, produced the least runoff (only 8 percent of all storms). Other sites (5, 8, 9) with high turf quality and density produced more frequent runoff samples, possibly because of steeper slopes or other factors. At six of the lawn sites, more than 50 percent of the storm events produced runoff.

The phenomenon of soil-water repellency, or hydrophobicity, was observed at many of the lawn sites, especially after dry periods. Water repellency of soils reduces affinity to water so that the soil resists wetting, thus reducing infiltration capacity, decreasing plant growth, and increasing surface runoff. The phenomenon has been widely accepted as a problem for many soils in seasonally dry climates. Soils with grass cover in temperate climates have recently been found to develop resistance to wetting—a common problem known as “localized dry spot” on golf courses (Doerr, Shakesby and Walsh, 2000; Kostka, 2000). Therefore, water repellency could be an additional factor influencing runoff from residential lawn soils (L.F. DeBano, University of Arizona, oral commun., 2001). At Lauderdale Lakes, there was also some indication that lawn shading by trees and less frequent use of fertilizer (sites 6, 7, and 13) resulted in less dense and patchy turf cover, increasing runoff. In ongoing turf studies at the University of Wisconsin (W.R. Kussow, Department of Soil Science, written commun., 2000), researchers found that not fertilizing turfgrass caused thinning of the turf, increased the amount of runoff, and increased nitrogen and phosphorus loss. Generally, the percentage of storms resulting in surface runoff from many of the lawns was higher than expected. Runoff from lawns may occur more frequently than previously thought because of the complex interaction of many factors.

Nutrient Concentrations in Runoff and Effects of Fertilizer Use

Summary statistics of nutrient concentrations measured in runoff from different site categories are given in table 3 and compared in figure 7. Detailed data for each of the sites were published annually in the U.S. Geological Survey Water-Data Reports (Holmstrom and others, 2000; Garn and others, 2001). There was a wide range in concentration of most nutrients among storms during the study period. Given this variability, geometric means or medians are more meaningful for comparison because they are better estimates of central tendency than arithmetic means. The nonparametric Kruskal-Wallis test was used to test for overall differences in concentration distributions, and the Wilcoxon rank sum test was used to test for differences in medians between pairs of lawn categories (P.W. Rasmussen, Wisconsin Department of Natural Resources, written commun., 2001). A confidence level of 10 percent (p = 0.10) was chosen to evaluate the results of the statistical tests. The difference in medians for samples from two different lawn categories was considered statistically significant if p values were less than 0.10.

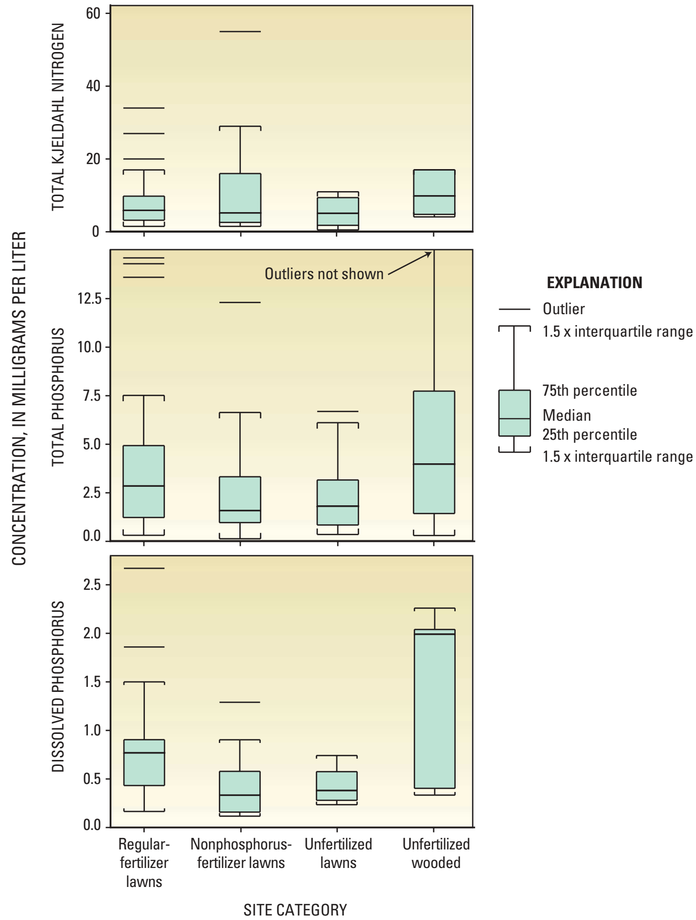

Figure 7. Nutrient concentrations in runoff from different categories of sampling sites at Lauderdale Lakes, Wis.

A quality-control study was done to determine nutrient-concentration effects of grass clippings, earthworms, and insects that managed to get into water samples. All of these contamination sources had a large effect by increasing nitrogen and phosphorus concentrations. Samples that were affected by these contamination sources, identified from field notes, were excluded from data analysis, but the exclusions did not significantly change the overall results.

No significant differences in concentration among lawn categories were found for any of the nitrogen species. Fertilizer use did not affect total nitrogen concentrations in runoff. In addition, nitrite plus nitrate concentrations in runoff were generally low.

Dissolved phosphorus concentrations were significantly different (p = 0.02) among the lawn categories. Moreover, the median concentration of dissolved phosphorus from regular-fertilizer sites (0.77 milligram per liter (mg/L)) was significantly greater than that from nonphosphorus-fertilizer sites (0.33 mg/L) and unfertilized lawn sites (0.38 mg/L). Total phosphorus in runoff from regular-fertilizer sites compared to nonphosphorus-fertilizer and to unfertilized-lawn sites had p-values of 0.11 and 0.14, respectively. Thus, median total phosphorus concentrations were not significantly different at $p < 0.1$. Dissolved phosphorus was a fraction of total phosphorus, and its concentrations ranged from 22 to 45 percent of total phosphorus for all lawn categories.

Figure 8. Dense understory vegetation on wooded slope of sites 16 and 17 at Lauderdale Lakes, Wis.

The median dissolved phosphorus concentration in lawn runoff from regular-fertilizer sites was twice that for unfertilized and nonphosphorus-fertilizer sites. Runoff from lawn sites with nonphosphorus-fertilizer applications had a median dissolved phosphorus and total phosphorus concentration that was similar to unfertilized sites. Dissolved phosphorus in runoff is important because it is readily available for plant growth. Although not significant at $p < 0.1$, lawn sites with regular fertilizer applications had a median total phosphorus concentration in runoff that was 1.6 times that for unfertilized sites and 1.8 times that for nonphosphorus-fertilizer sites.

In comparison with other studies, phosphorus concentrations in lawn runoff at Lauderdale Lakes were slightly higher than concentrations found in runoff from urban lawns in Madison, Wis. (Waschbusch, Selbig and Bannerman, 1999), but were similar to those in lawn runoff from suburban lawns in Minneapolis/St. Paul, Minn. (Barten and Jahnke, 1997). Surprisingly, nutrient concentrations in runoff from the unfertilized, steep, wooded hillsides (sites 16, 17, and 18) were higher than those from the lawn sites and thus were separated from the unfertilized lawn sites in the data comparisons. These wooded sites (fig. 8) may be different from other wooded sites because of their steep slopes, thick surface organic and litter layer, and dense understory vegetation (crown vetch) planted for erosion control. Waschbusch, Selbig, and Bannerman (1999) found a direct relation between phosphorus concentration and percentage of overhead tree canopy that could affect source-area concentrations. In the Lauderdale Lakes study, however, all lawn categories contained sites with overhead tree canopy, and the lawn sites treated with regular fertilizer had the fewest trees; therefore, differences between regular-fertilizer sites and the other lawn sites could be even greater if there was an effect from tree cover.

Total phosphorus concentration in lawn runoff had a significant ($p = 0.08$) relation to soil-phosphorus concentration (table 1); total dissolved phosphorus had no significant relation. The low category of soil-phosphorus concentration (0 to 24 parts per million (ppm)) had a significantly lower median concentration of total phosphorus in lawn runoff (about half) than the medians from medium (25-65 ppm) or high (66 ppm or more) soil-phosphorus concentration lawns. There was no significant difference between runoff concentrations from medium and high soil-phosphorus concentration lawns. Barten and Jahnke (1997) also found a significant difference in concentration of phosphorus in runoff from different categories of lawn soil fertility. In their study, total and soluble reactive phosphorus concentrations in runoff from high soil-phosphorus concentration lawns were twice as large as the concentrations in runoff from low soil-phosphorus concentration lawns.

Median nutrient concentrations from the Don Jean Bay swale area with mixed land use were more similar to those from the unfertilized wooded sites and fertilized lawn sites than to those from other lawn sites (table 3). The range in concentrations for ammonia nitrogen and total Kjeldahl nitrogen in runoff from the swale, however, was greater than those for the other sites.

Although it was not within the scope of this study to measure runoff volumes from each of the sites and quantify the mass of nutrients transported offsite, the concentration data will be useful for future computations of unit-area loads (that is, mass of a particular nutrient species per unit contributing area). Concentrations of nutrients from lawns observed in this

Table 3. Statistical summary of nutrient concentrations in runoff from different site categories, Lauderdale Lakes, Wis. [n, number of samples; TKN, total Kjeldahl nitrogen; NO_2, nitrite nitrogen; NO_3, nitrate nitrogen; TP, total phosphorus; Diss P, dissolved phosphorus; all concentrations in milligrams per liter]

	Ammonia N	TKN	$NO_2 + NO_3$	TP	Diss P
Regular-fertilizer lawn sites					
Geometric mean	1.11	5.9	0.09	2.57	0.7
Median	1.07	5.9	0.12	2.85	0.77
Mean	2.18	8.6	0.17	4.02	0.93
Max	14.5	34	0.56	23.2	3.32
Min	0.05	1.5	0.01	0.31	0.17
n	23	23	23	58	23
Nonphosphorus-fertilizer lawn sites					
Geometric mean	1	6.5	0.14	1.89	0.34
Median	0.93	5.2	0.14	1.58	0.33
Mean	3.95	12.2	0.57	3.3	0.45
Max	36.2	55	5.22	23.5	1.29
Min	0.04	1.5	0.14	0.14	0.12
n	14	14	14	38	15
Unfertilized lawn sites					
Geometric mean	0.76	4.08	0.12	1.73	0.4
Median	0.63	5.1	0.14	1.81	0.38
Mean	1.12	5.85	0.17	2.33	0.43
Max	2.98	11	0.4	6.69	0.74
Min	0.22	0.53	0.01	0.36	0.23
n	9	9	9	19	8
Unfertilized wooded sites					
Geometric mean	2.95	12.7	0.16	3.52	1.04
Median	4.38	9.8	0.24	3.98	1.99
Mean	5.33	29.3	0.9	6.78	1.4
Max	11.6	130	2.24	30.6	2.26
Min	0.41	4.1	0.01	0.3	0.33
n	5	6	5	28	5
Don Jean Bay swale sites					
Geometric mean	3.48	14.5	0.06	2.46	0.49
Median	3.96	19	0.04	2.66	0.41
Mean	11.91	31.3	0.15	3.55	0.91
Max	88.1	160	0.6	9.07	3.33
Min	0.56	2	0.01	0.37	0.18
n	11	11	10	19	9

study are much greater (by 3 to 5 times) than the estimated concentrations used to calculate total phosphorus load from surface runoff to Lauderdale Lakes in a previous study by Garn and others (1996, p. 16). All of the nutrient load from lawn runoff may not actually reach or be deposited in the lake because of varying flowpaths, soil permeability, breaks in slope, vegetative buffers, and other obstructions; however, in many cases, lawns extend and slope continuously to the water's edge to provide a direct source of loading.

The annual phosphorus load from the nearshore area of Lauderdale Lakes may be greater than the 430 pounds previously estimated. Using a revised median concentration of 2.3 mg/L for surface runoff from an estimated 220 acres of developed shoreline (67 percent of shoreline) within 200 feet from the edge of water, annual total phosphorus load from residential lawns could be as much as 370 pounds (assuming all of the phosphorus reaches the lake). If a delivery of 50 percent of the load is assumed, and the total surface-water load is recomputed using the surface runoff values from the previous study, the total annual surface-water load from the nearshore drainage area would be 620 pounds, which represents 60 precent of the total annual phosphorus input from all sources. Studies at Lauderdale Lakes and several other ongoing studies by the USGS in Wisconsin will provide additional information on the effects of lawns and shoreline development on nutrient loads to lakes.

Limitations of Results

- Many runoff samples (about 30 percent) overflowed the collecting bottle and may not be truly representative of the mean concentration from each storm. According to T.D. Stuntebeck (U.S. Geological Survey, unpub. data, 2002), overflow samples for suspended solids and total phosphorus had higher concentrations than those from samples that did not overflow the container, but the opposite was true for dissolved phosphorus. Barten and Jahnke (1997) also found that overflow samples had lower concentrations for some constituents. Overflow occurred, however, for all categories of sites, and differences noted could potentially be even greater.
- The number of samples for some categories was relatively small for rigorous statistical analysis, and the small numbers could lead to inconsistencies among comparisons for different pairs of categories.
- Nutrient-concentration data are for onsite runoff and should be used with caution when making offsite interpretations. Not all of the nutrient load from lawn runoff may actually enter the lake.
- Some changes in nutrient species composition affecting dissolved constituents may have occurred in those samples that were not collected within 2 days after a storm.

Conclusions

- A high percentage of storms resulted in surface runoff from many of the lawns. Runoff from lawns may occur relatively frequently, more than 50 percent of the storms for many lawns.
- Fertilizer use did not affect nitrogen concentrations in runoff. Nitrite plus nitrate concentrations in runoff were generally low.
- Total phosphorus concentration in lawn runoff was directly related to the phosphorus concentration of lawn soils.
- Dissolved phosphorus concentrations were significantly different among the lawn categories; the median from regular-fertilizer sites was twice that from unfertilized or nonphosphorus-fertilizer sites.
- Runoff from lawn sites with nonphosphorus fertilizer applications had a median total phosphorus concentration that was similar to that of unfertilized sites, an indication that nonphosphorus fertilizer use may be an effective, low-cost practice for reducing phosphorus in runoff.

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